US 20180356770A1

(19) United States

(12) Patent Application Publication (10) Pub. No.: US 2018/0356770 A1

ElBsat et al. (43) Pub. Date: Dec. 13, 2018

(54) **BUILDING ENERGY OPTIMIZATION SYSTEM WITH AUTOMATED AND DYNAMIC ECONOMIC LOAD DEMAND RESPONSE (ELDR) OPTIMIZATION**

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(21) Appl. No.: **15/974,411**

(22) Filed: **May 8, 2018**

Related U.S. Application Data

(63) Continuation-in-part of application No. 15/616,616, filed on Jun. 7, 2017.

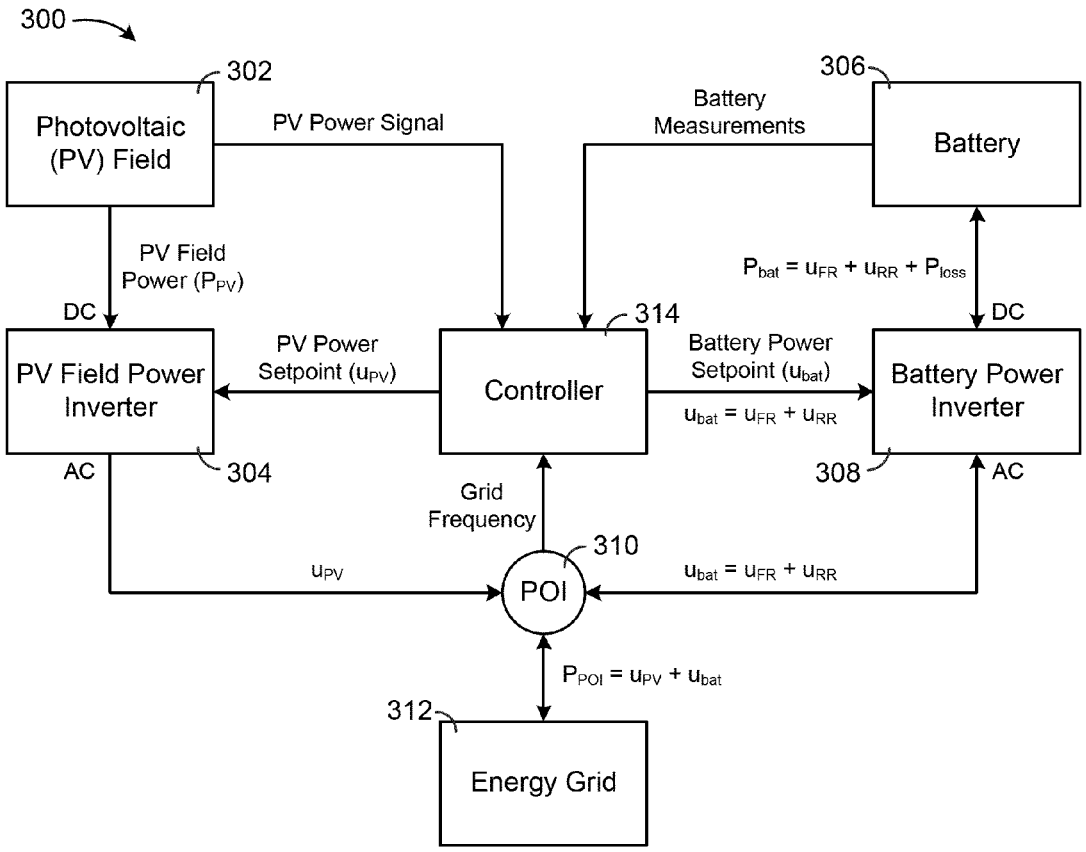
Publication Classification

(51) **Int. Cl.**
G05B 13/02 (2006.01)

(52) **U.S. Cl.**
CPC ***G05B 13/021*** (2013.01); *H02J 3/00* (2013.01); ***G05B 13/026*** (2013.01)

(57) **ABSTRACT**

An energy optimization system for a building includes a processing circuit configured to provide a first bid including one or more first participation hours and a first load reduction amount for each of the one or more first participation hours to a computing system. The processing circuit is configured to operate one or more pieces of building equipment based on one or more first equipment loads and receive one or more awarded or rejected participation hours from the computing system responsive to the first bid. The processing circuit is configured to generate one or more second participation hours, a second load reduction amount for each of the one or more second participation hours, and one or more second equipment loads based on the one or more awarded or rejected participation hours and operate the one or more pieces of building equipment based on the one or more second equipment loads.



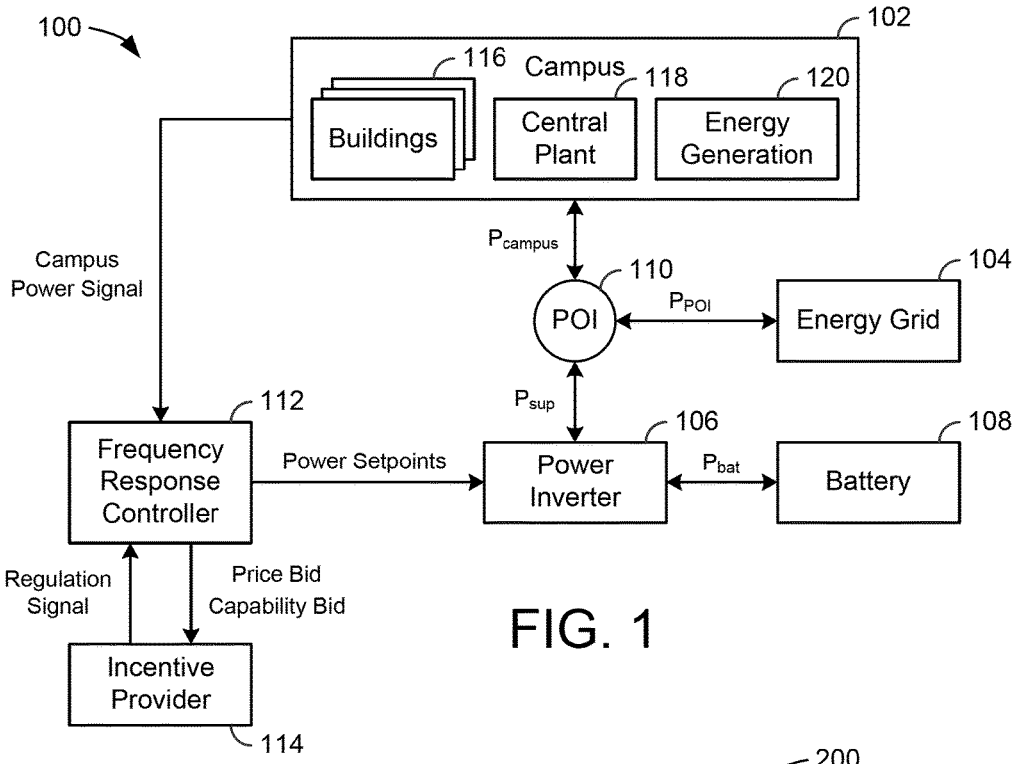

100
102
116
Campus
118
120
Buildings
Central Plant
Energy Generation
P_{campus}
Campus Power Signal
110
104
POI
P_{POI}
Energy Grid
P_{sup}
112
106
108
Frequency Response Controller
Power Setpoints
Power Inverter
P_{bat}
Battery
Regulation Signal
Price Bid
Capability Bid
Incentive Provider
114

FIG. 1

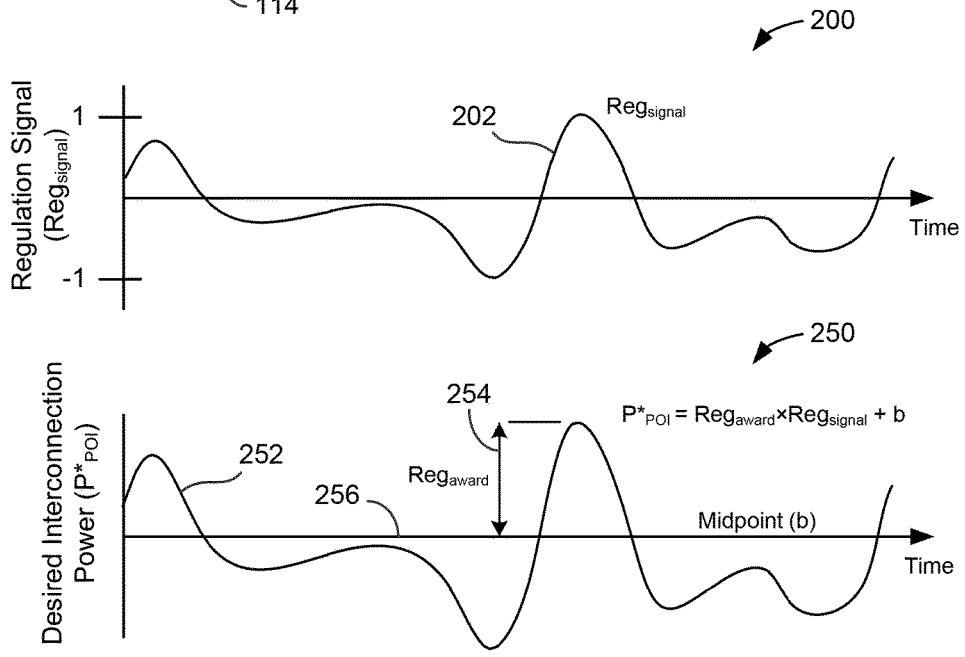

200
Regulation Signal (Reg_{signal})
1
-1
202
Reg_{signal}
Time
250
Desired Interconnection Power (P^*_{POI})
254
$P^*_{POI} = Reg_{award} \times Reg_{signal} + b$
252
Reg_{award}
256
Midpoint (b)
Time

FIG. 2

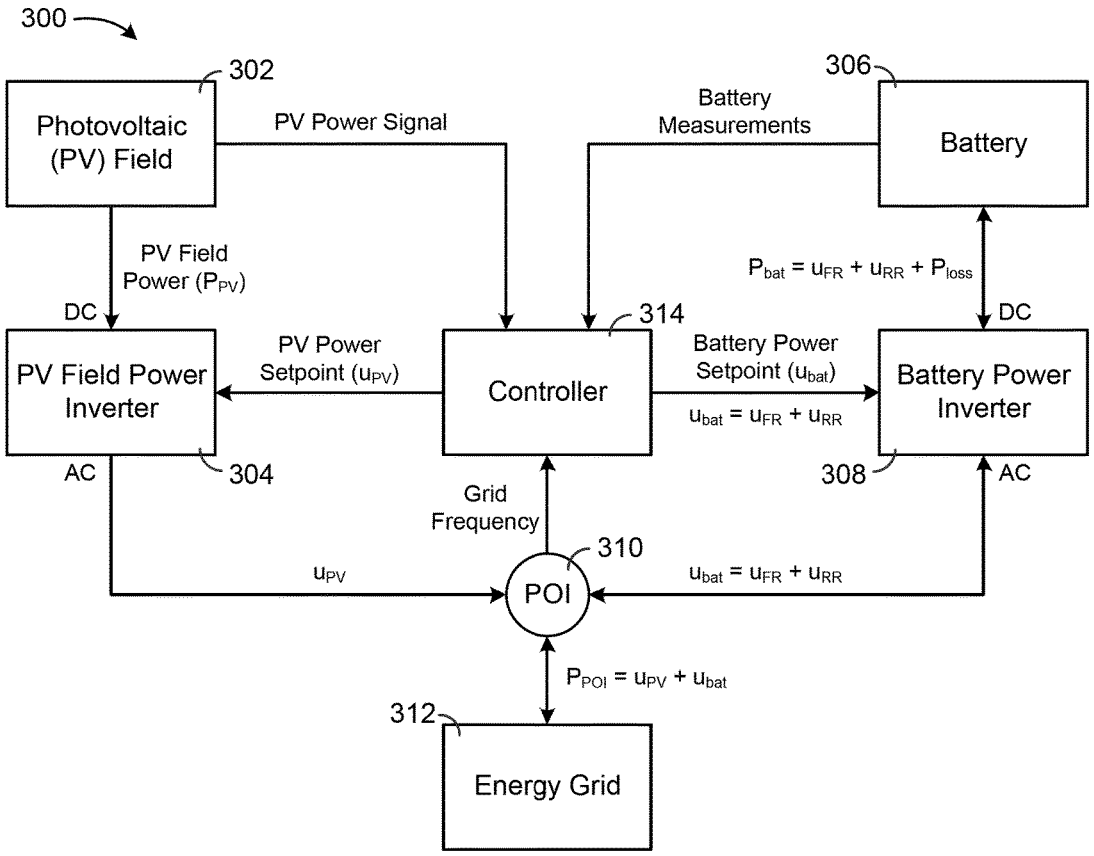

300
302
Photovoltaic (PV) Field
PV Power Signal
306
Battery Measurements
Battery
PV Field Power (P_{PV})
DC
$P_{bat} = u_{FR} + u_{RR} + P_{loss}$
DC
314
PV Field Power Inverter
PV Power Setpoint (u_{PV})
Controller
Battery Power Setpoint (u_{bat})
$u_{bat} = u_{FR} + u_{RR}$
Battery Power Inverter
AC
304
308
AC
Grid Frequency
310
u_{PV}
POI
$u_{bat} = u_{FR} + u_{RR}$
$P_{POI} = u_{PV} + u_{bat}$
312
Energy Grid

FIG. 3

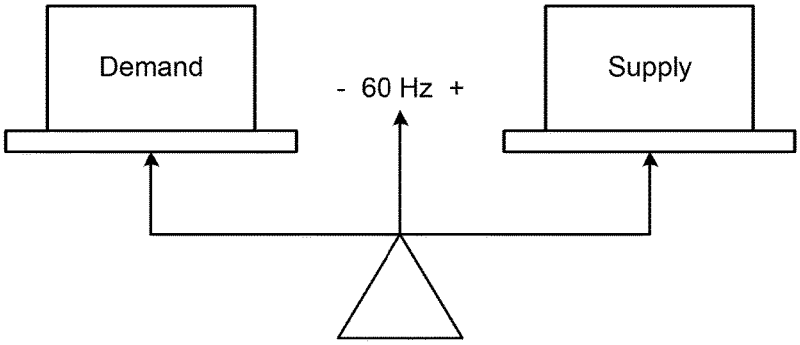

Demand
- 60 Hz +
Supply

FIG. 4

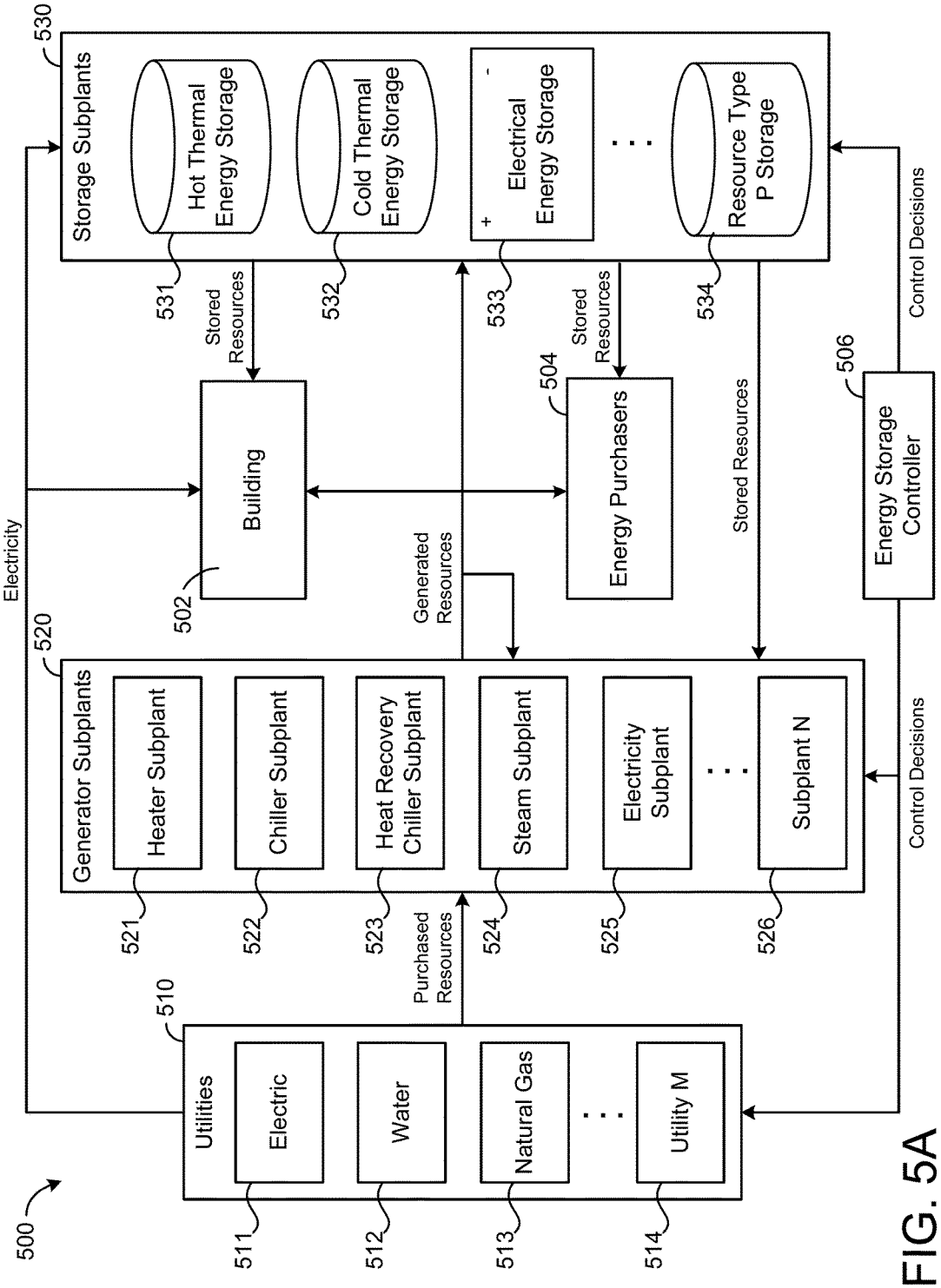

500
Utilities
Electric
Water
Natural Gas
Utility M
510
511
512
513
514
Purchased Resources
Generator Subplants
Heater Subplant
Chiller Subplant
Heat Recovery Chiller Subplant
Steam Subplant
Electricity Subplant
Subplant N
520
521
522
523
524
525
526
Electricity
Building
502
Generated Resources
Energy Purchasers
504
Stored Resources
Stored Resources
Storage Subplants
Hot Thermal Energy Storage
Cold Thermal Energy Storage
Electrical Energy Storage
Resource Type P Storage
530
531
532
533
534
Stored Resources
Energy Storage Controller
506
Control Decisions
Control Decisions

FIG. 5A

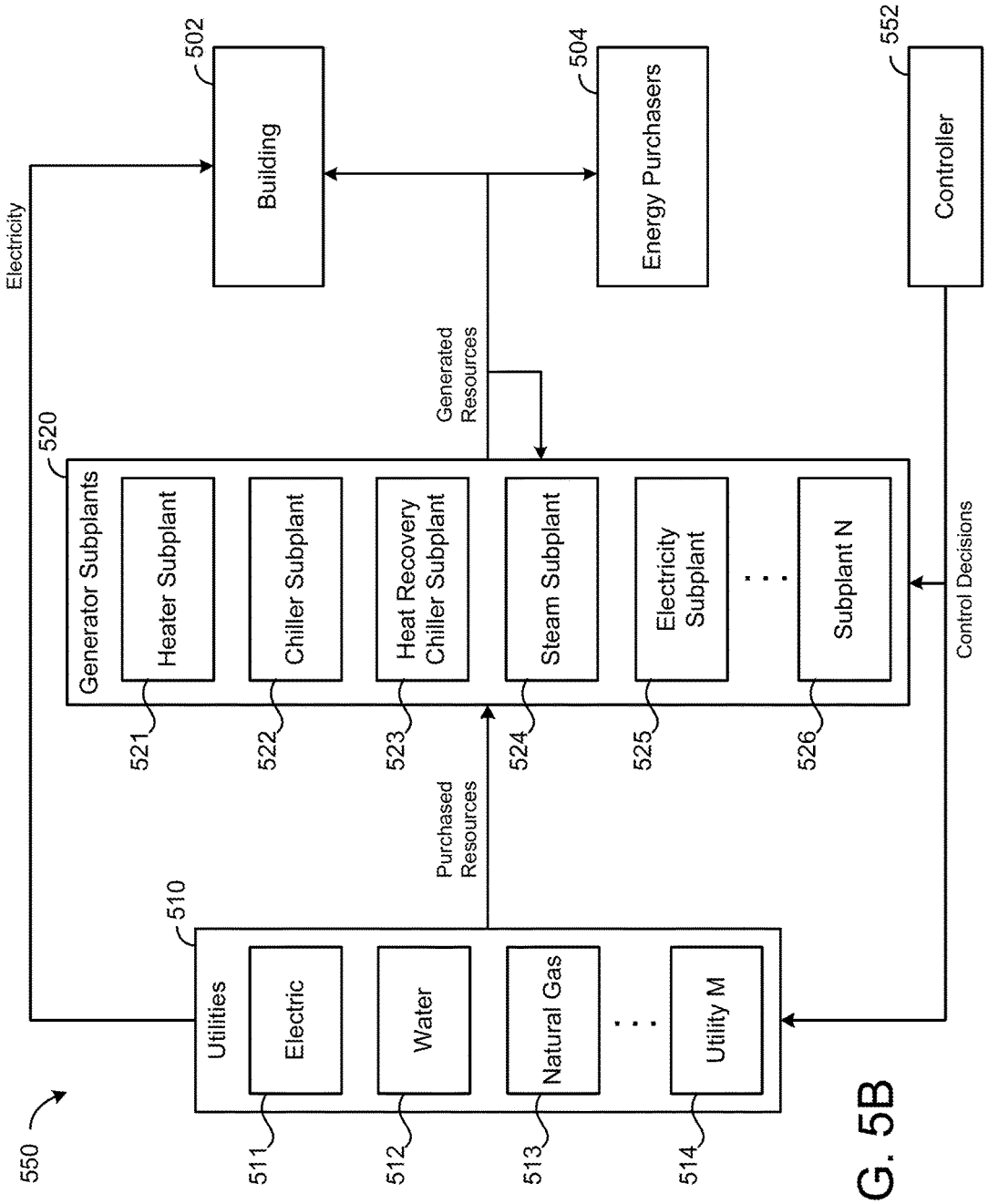

502
Building
504
Energy Purchasers
552
Controller
Electricity
Generated Resources
520
Generator Subplants
Heater Subplant
Chiller Subplant
Heat Recovery Chiller Subplant
Steam Subplant
Electricity Subplant
Subplant N
Control Decisions
521
522
523
524
525
526
Purchased Resources
510
Utilities
Electric
Water
Natural Gas
Utility M
511
512
513
514
550

FIG. 5B

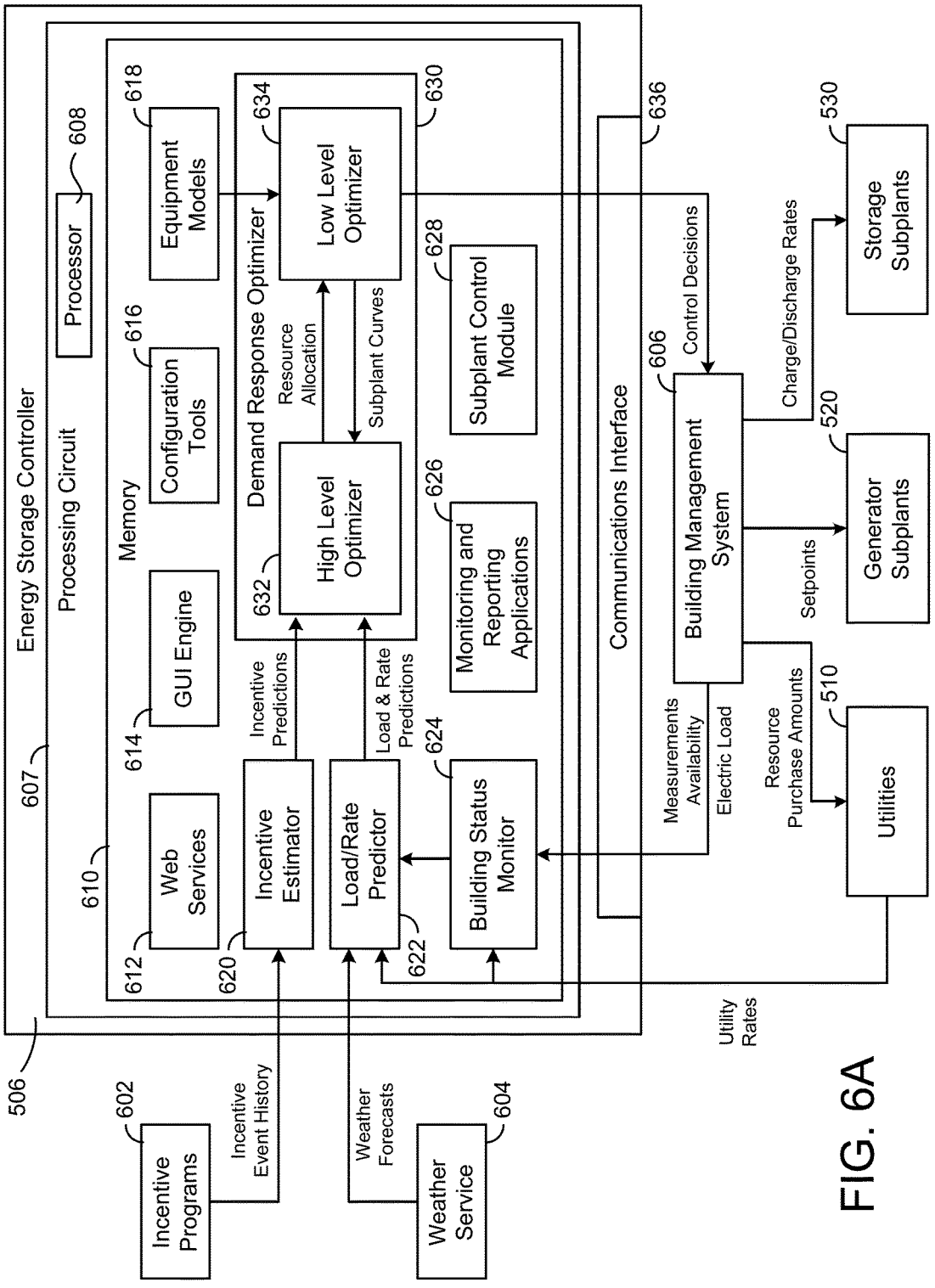

Energy Storage Controller
506
Processing Circuit
607
Processor
608
Memory
610
Web Services
612
GUI Engine
614
Configuration Tools
616
Equipment Models
618
Incentive Estimator
620
Load/Rate Predictor
622
Building Status Monitor
624
Monitoring and Reporting Applications
626
Demand Response Optimizer
630
High Level Optimizer
632
Low Level Optimizer
634
Subplant Control Module
628
Communications Interface
636
Building Management System
606
Generator Subplants
520
Storage Subplants
530
Utilities
510
Incentive Programs
602
Weather Service
604
Incentive Event History
Weather Forecasts
Incentive Predictions
Load & Rate Predictions
Resource Allocation
Subplant Curves
Control Decisions
Charge/Discharge Rates
Setpoints
Measurements Availability
Electric Load
Resource Purchase Amounts
Utility Rates

FIG. 6A

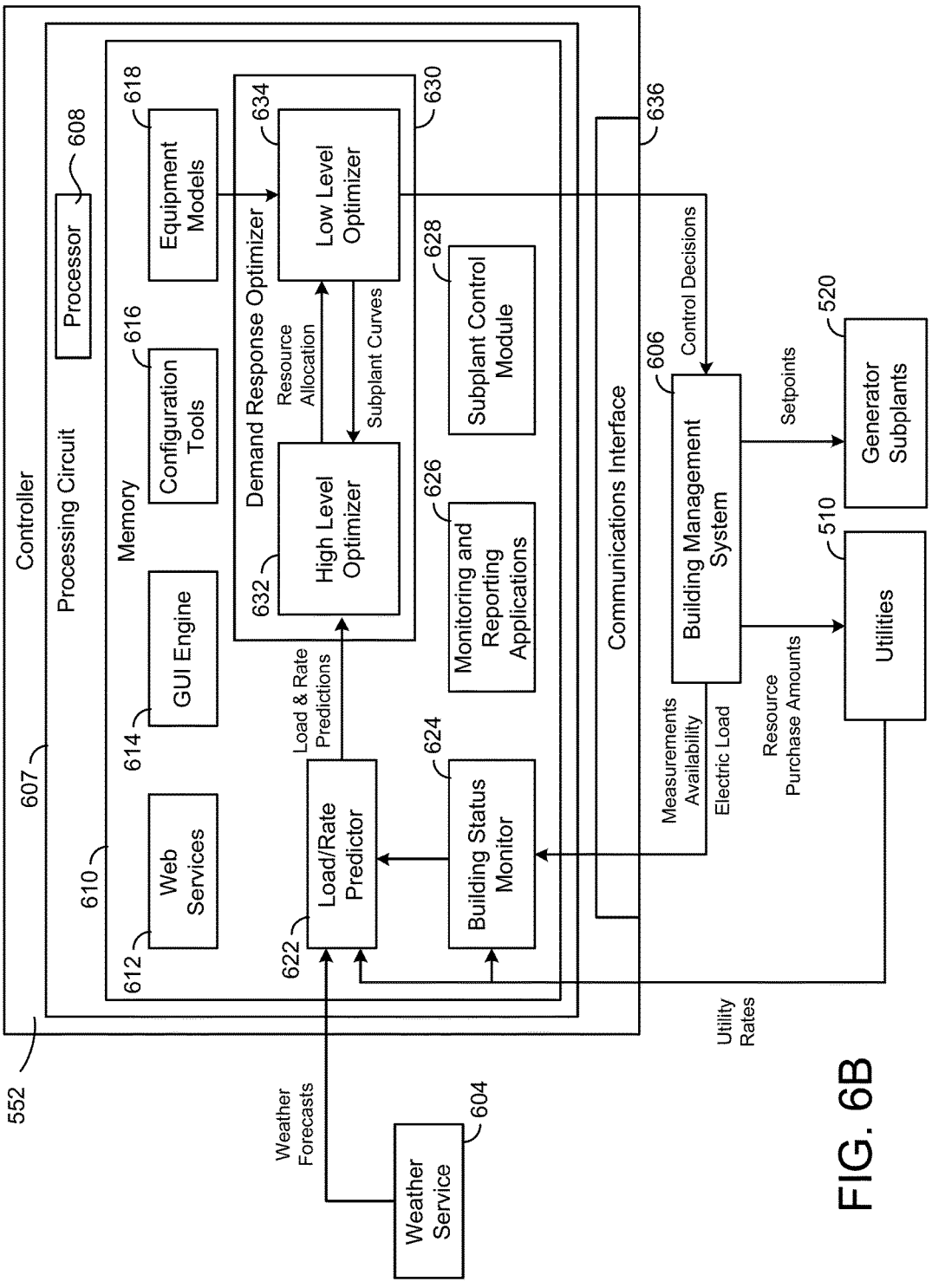

552
Controller
Processing Circuit
Processor
608
Memory
607
610
Web Services
612
614
GUI Engine
616
Configuration Tools
618
Equipment Models
Demand Response Optimizer
630
632
High Level Optimizer
634
Low Level Optimizer
Resource Allocation
Subplant Curves
626
Monitoring and Reporting Applications
628
Subplant Control Module
622
Load/Rate Predictor
624
Building Status Monitor
Load & Rate Predictions
Communications Interface
636
606
Building Management System
Control Decisions
Setpoints
520
Generator Subplants
510
Utilities
Measurements Availability
Electric Load
Resource Purchase Amounts
Utility Rates
Weather Forecasts
604
Weather Service

FIG. 6B

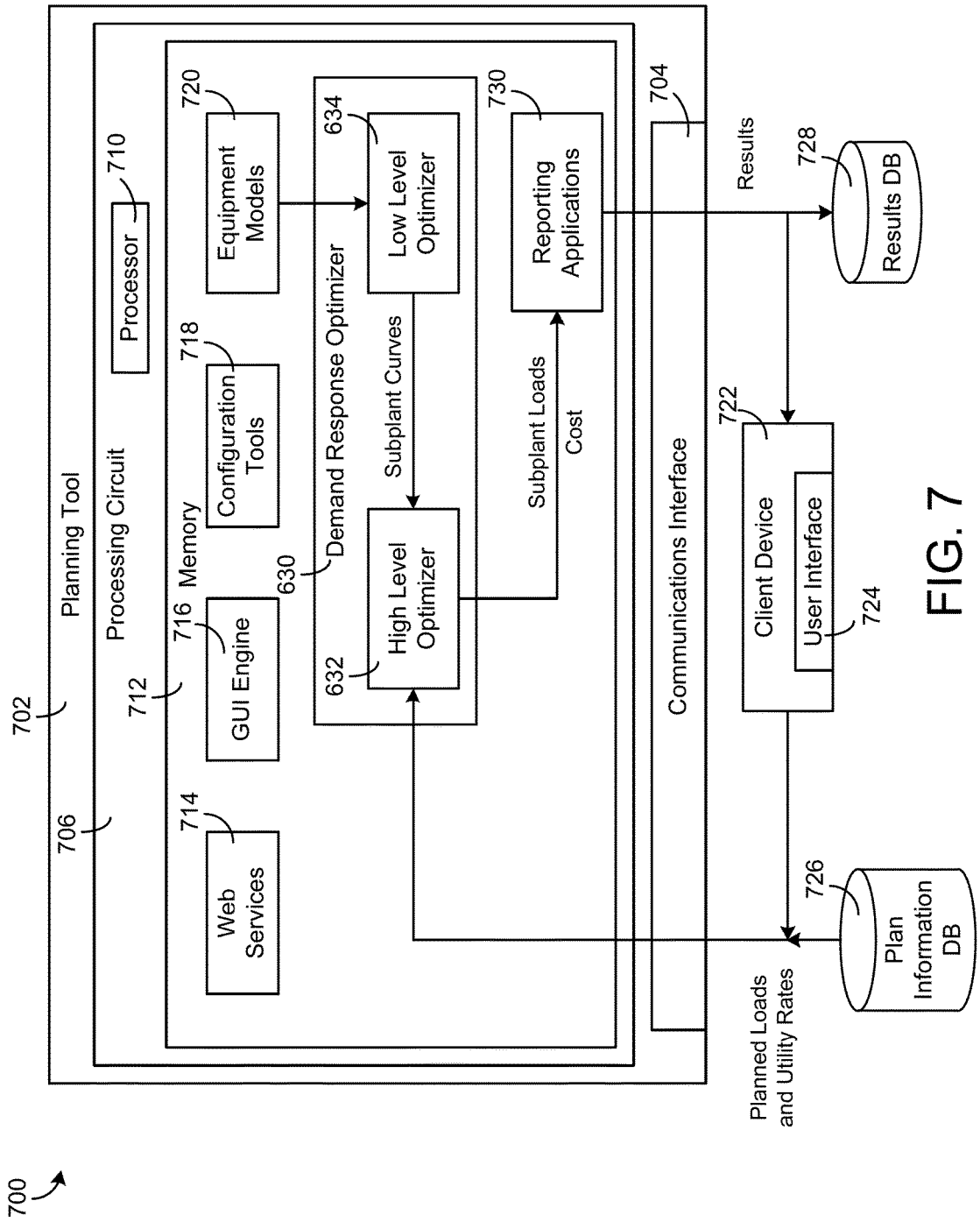

700
702
Planning Tool
706
Processing Circuit
710
Processor
712
Memory
714
Web Services
716
GUI Engine
718
Configuration Tools
720
Equipment Models
630
Demand Response Optimizer
632
High Level Optimizer
634
Low Level Optimizer
Subplant Curves
730
Reporting Applications
Subplant Loads
Cost
704
Communications Interface
Results
728
Results DB
722
Client Device
724
User Interface
726
Plan Information DB
Planned Loads and Utility Rates

FIG. 7

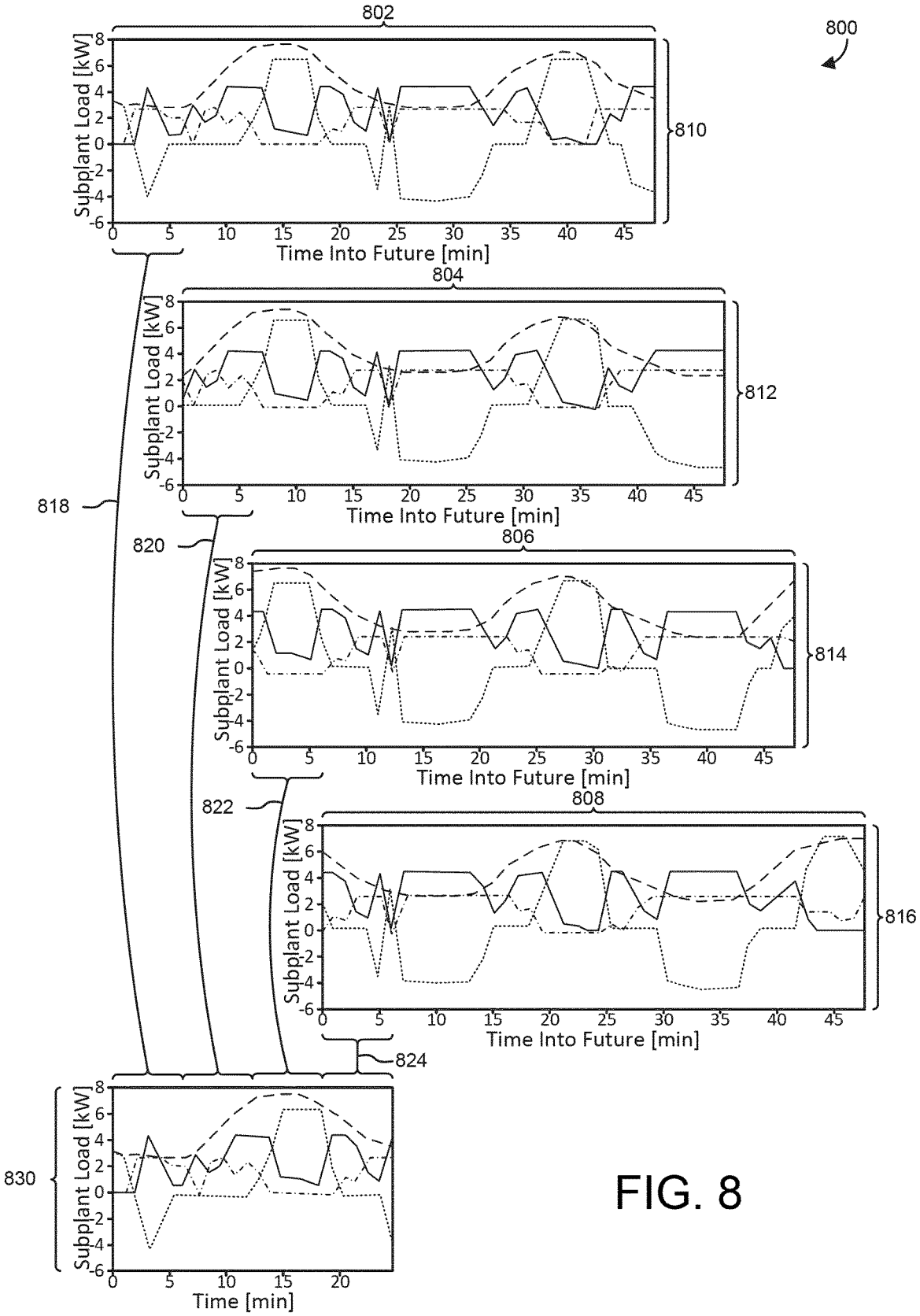

800
802
804
806
808
810
812
814
816
818
820
822
824
830
Subplant Load [kW]
Time Into Future [min]
Time [min]

FIG. 8

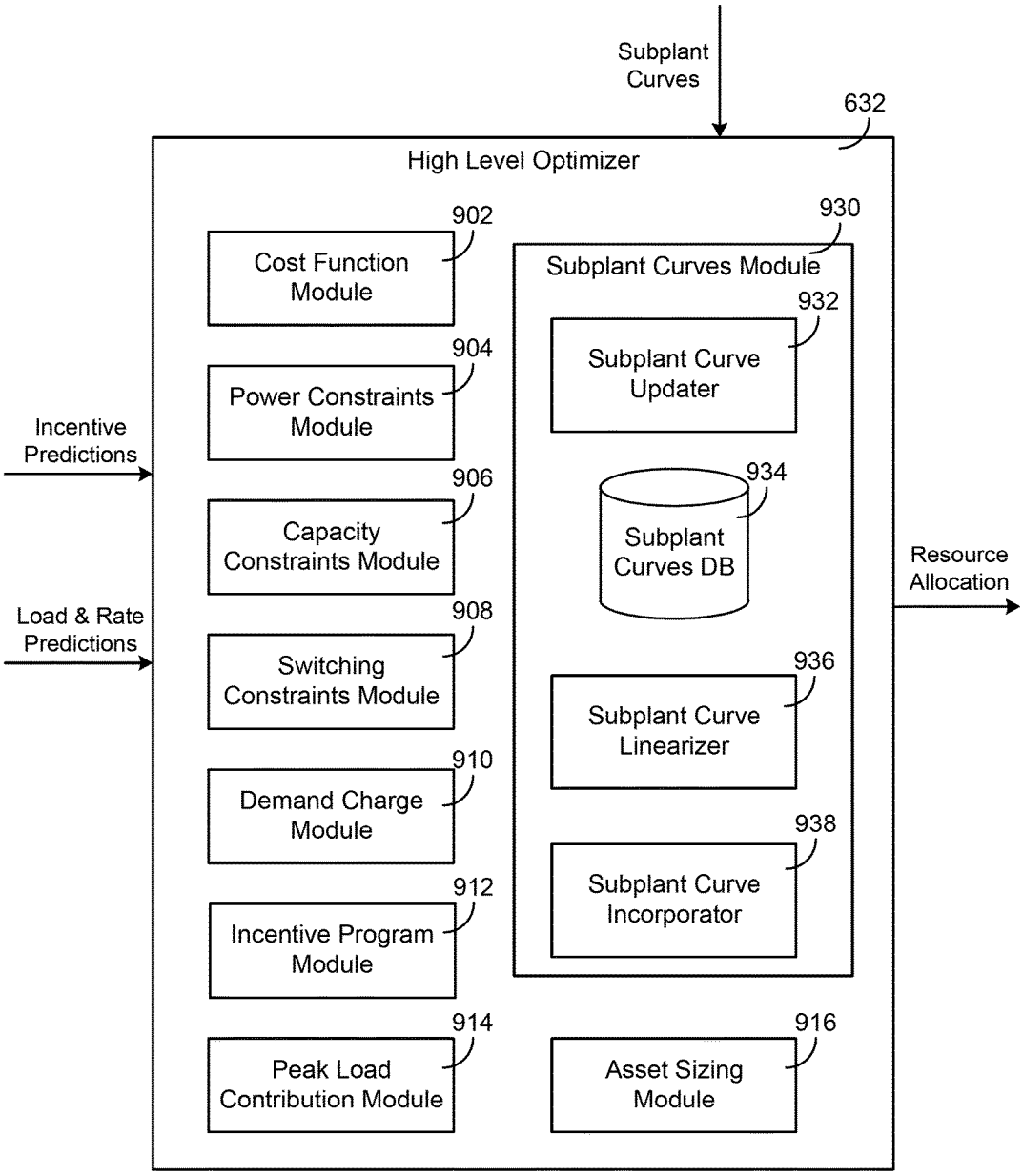

Subplant Curves
632
High Level Optimizer
902
Cost Function Module
904
Power Constraints Module
906
Capacity Constraints Module
908
Switching Constraints Module
910
Demand Charge Module
912
Incentive Program Module
914
Peak Load Contribution Module
930
Subplant Curves Module
932
Subplant Curve Updater
934
Subplant Curves DB
936
Subplant Curve Linearizer
938
Subplant Curve Incorporator
916
Asset Sizing Module
Incentive Predictions
Load & Rate Predictions
Resource Allocation

FIG. 9

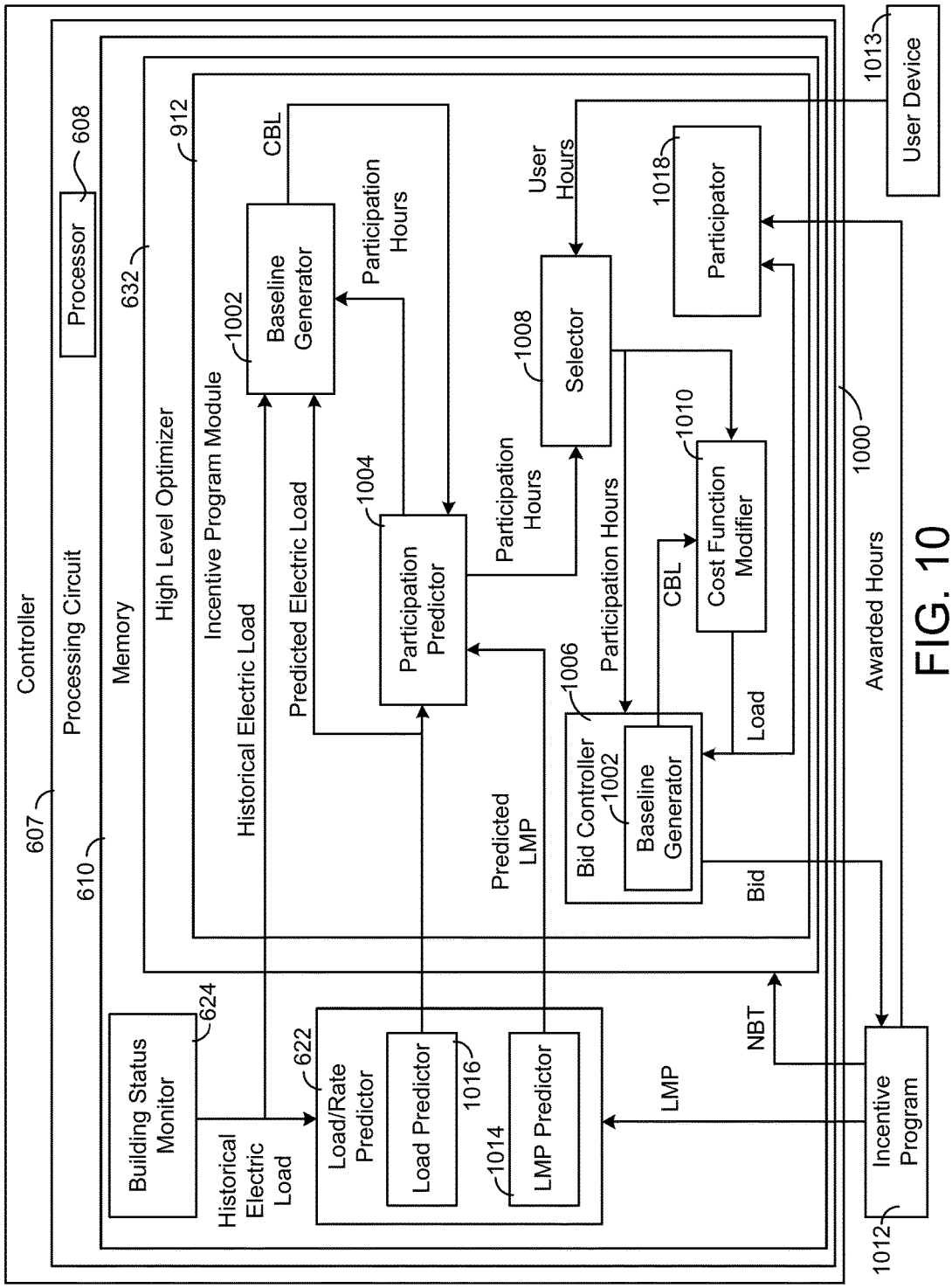

Controller
607
Processing Circuit
610
Processor
608
Memory
632
High Level Optimizer
912
Incentive Program Module
1000
Building Status Monitor
624
Historical Electric Load
Load/Rate Predictor
622
Load Predictor
1016
LMP Predictor
1014
Historical Electric Load
Predicted Electric Load
Baseline Generator
1002
CBL
Participation Hours
Participation Predictor
1004
Predicted LMP
Participation Hours
Selector
1008
User Hours
Participation Hours
Bid Controller
1006
Baseline Generator
1002
Bid
CBL
Cost Function Modifier
1010
Load
Participator
1018
Awarded Hours
User Device
1013
NBT
LMP
Incentive Program
1012

FIG. 10

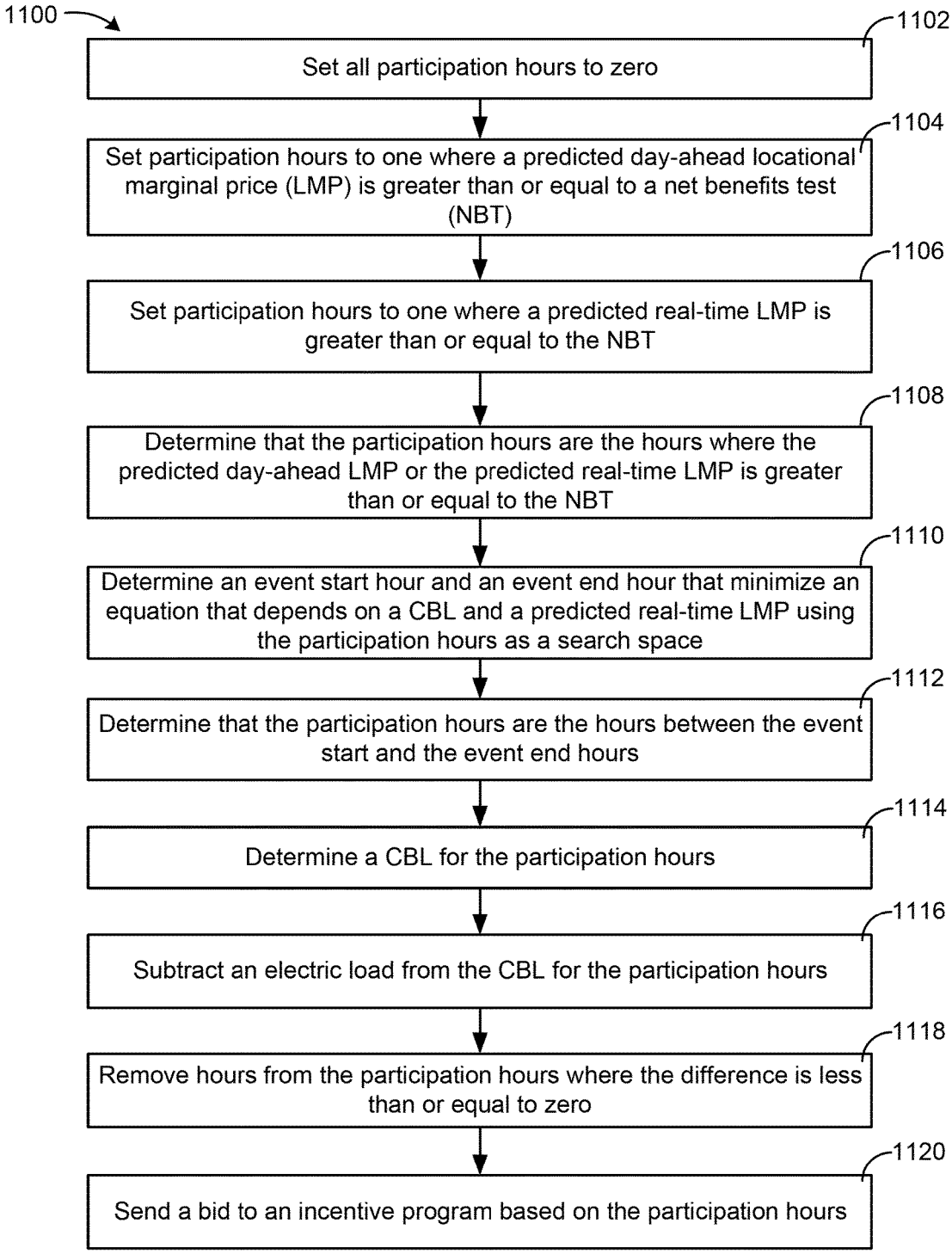

1100
1102
Set all participation hours to zero
1104
Set participation hours to one where a predicted day-ahead locational marginal price (LMP) is greater than or equal to a net benefits test (NBT)
1106
Set participation hours to one where a predicted real-time LMP is greater than or equal to the NBT
1108
Determine that the participation hours are the hours where the predicted day-ahead LMP or the predicted real-time LMP is greater than or equal to the NBT
1110
Determine an event start hour and an event end hour that minimize an equation that depends on a CBL and a predicted real-time LMP using the participation hours as a search space
1112
Determine that the participation hours are the hours between the event start and the event end hours
1114
Determine a CBL for the participation hours
1116
Subtract an electric load from the CBL for the participation hours
1118
Remove hours from the participation hours where the difference is less than or equal to zero
1120
Send a bid to an incentive program based on the participation hours

FIG. 11A

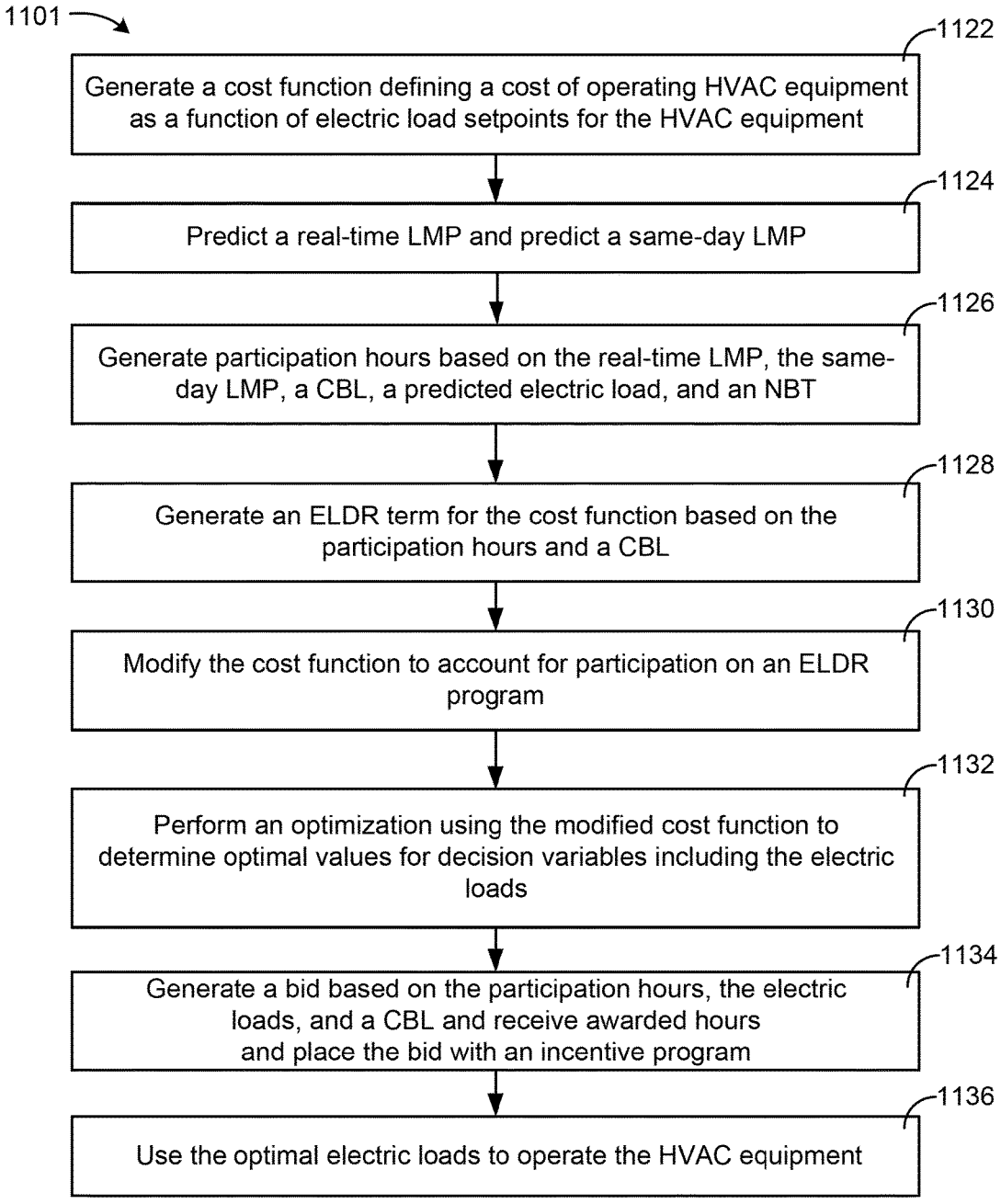

1101
1122
Generate a cost function defining a cost of operating HVAC equipment as a function of electric load setpoints for the HVAC equipment
1124
Predict a real-time LMP and predict a same-day LMP
1126
Generate participation hours based on the real-time LMP, the same-day LMP, a CBL, a predicted electric load, and an NBT
1128
Generate an ELDR term for the cost function based on the participation hours and a CBL
1130
Modify the cost function to account for participation on an ELDR program
1132
Perform an optimization using the modified cost function to determine optimal values for decision variables including the electric loads
1134
Generate a bid based on the participation hours, the electric loads, and a CBL and receive awarded hours and place the bid with an incentive program
1136
Use the optimal electric loads to operate the HVAC equipment

FIG. 11B

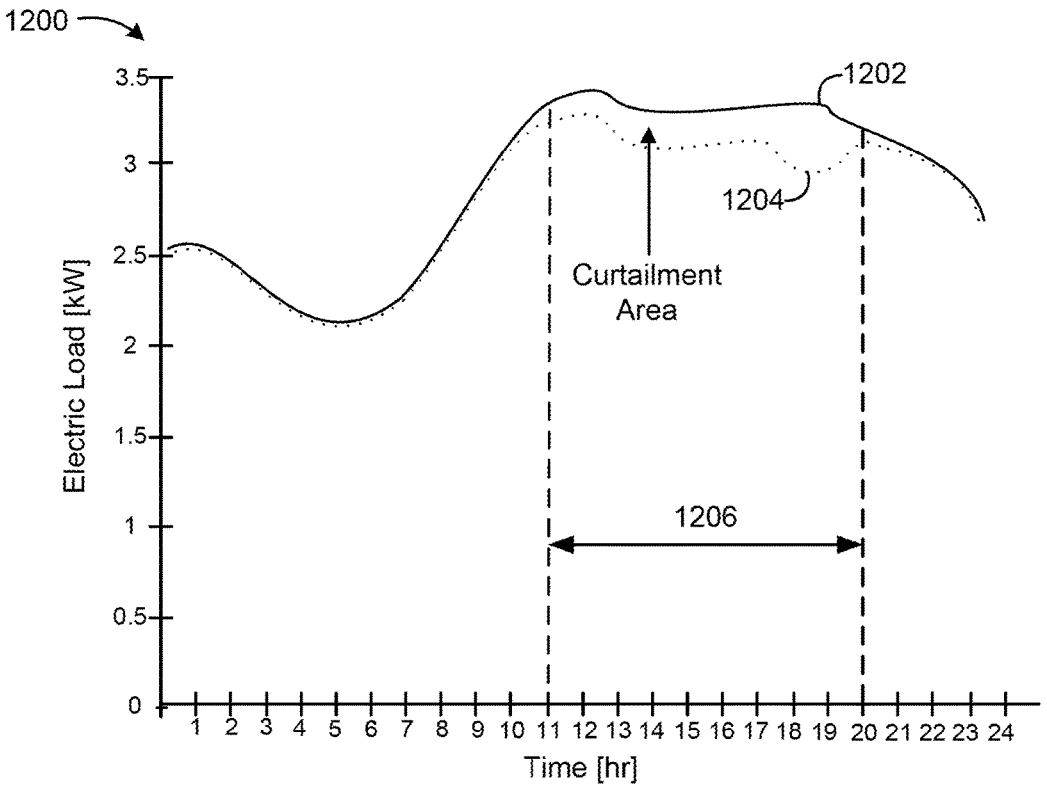

1200
1202
1204
Curtailment Area
1206
Electric Load [kW]
Time [hr]
3.5
3
2.5
2
1.5
1
0.5
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24

FIG. 12

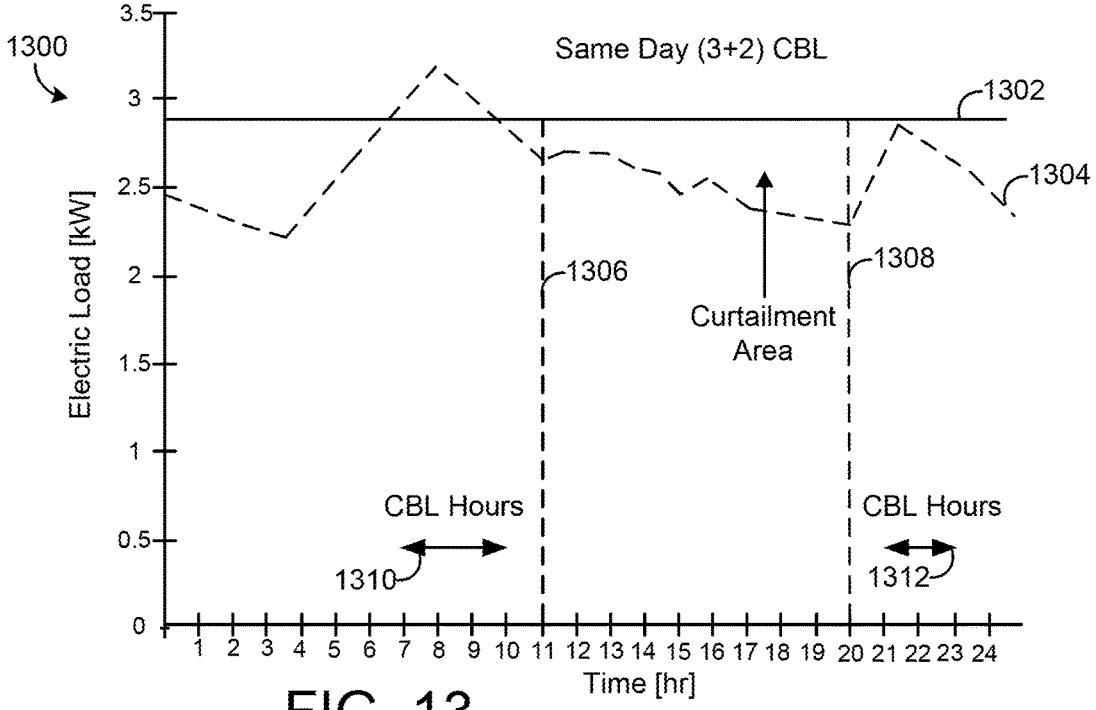

1300
Same Day (3+2) CBL
1302
1304
1306
1308
Curtailment Area
CBL Hours
1310
CBL Hours
1312
Electric Load [kW]
Time [hr]
0
0.5
1
1.5
2
2.5
3
3.5
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24

FIG. 13

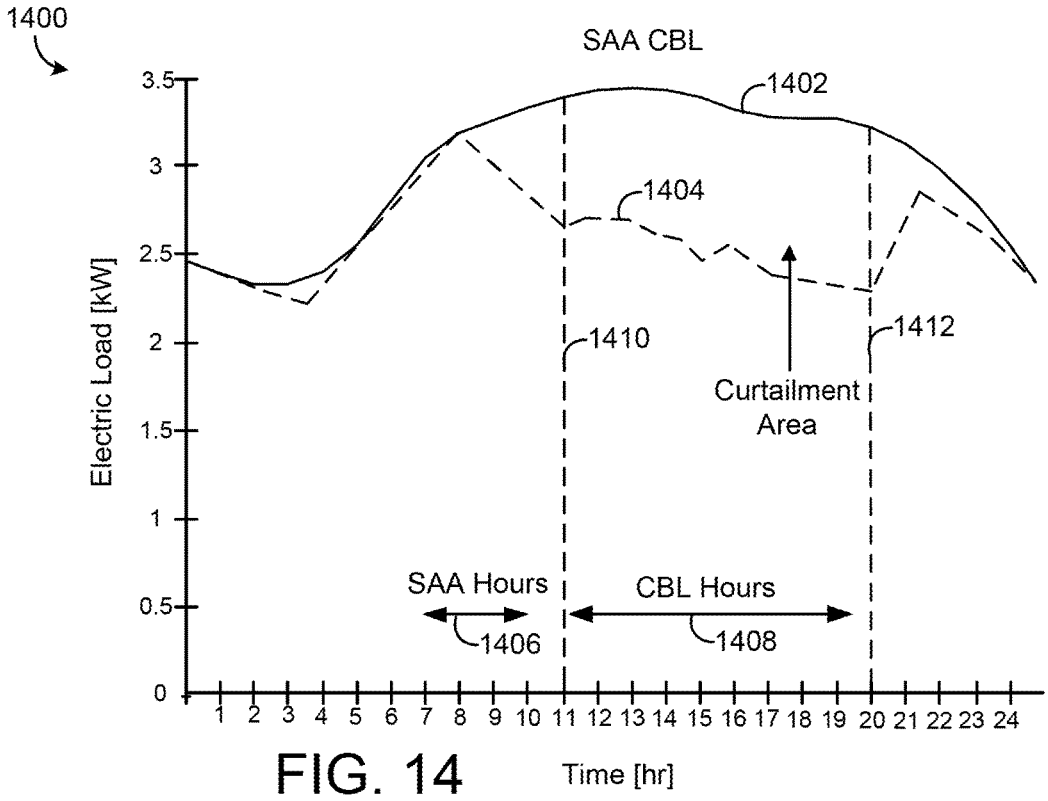

1400
SAA CBL
1402
1404
1410
1412
Curtailment Area
SAA Hours
1406
CBL Hours
1408
Electric Load [kW]
Time [hr]
0
0.5
1
1.5
2
2.5
3
3.5
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24

FIG. 14

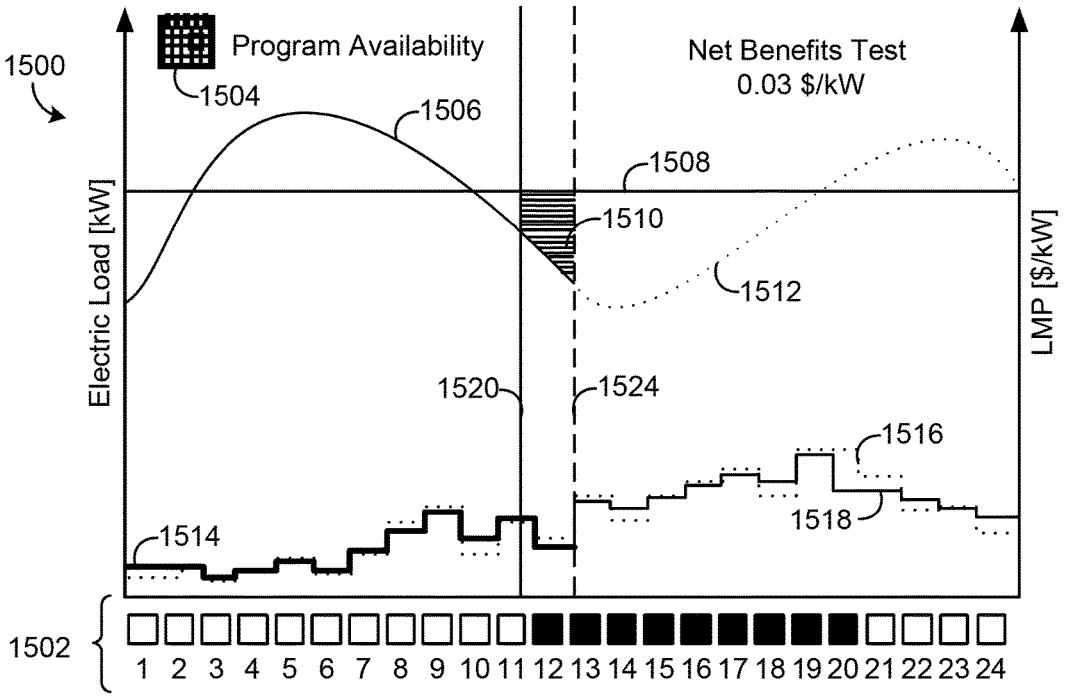

1500
Program Availability
1504
1506
Net Benefits Test
0.03 $/kW
1508
1510
1512
Electric Load [kW]
LMP [$/kW]
1520
1524
1516
1518
1514
1502
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24

FIG. 15

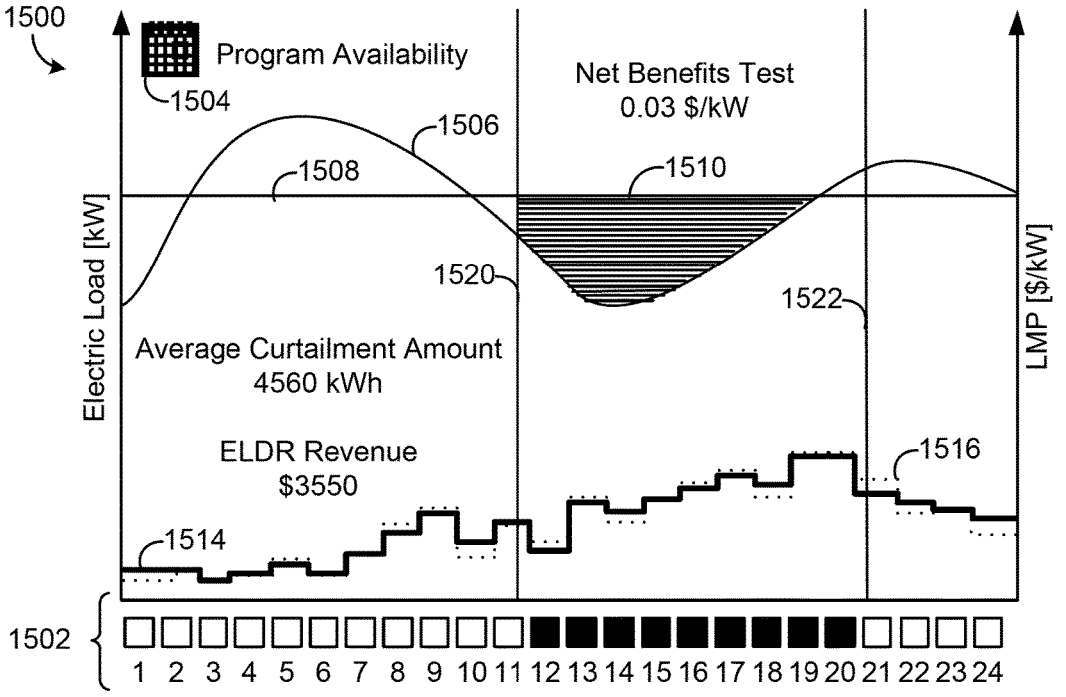

1500
Program Availability
1504
1506
Net Benefits Test
0.03 $/kW
1508
1510
Electric Load [kW]
LMP [$/kW]
1520
1522
Average Curtailment Amount
4560 kWh
ELDR Revenue
$3550
1516
1514
1502
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24

FIG. 16

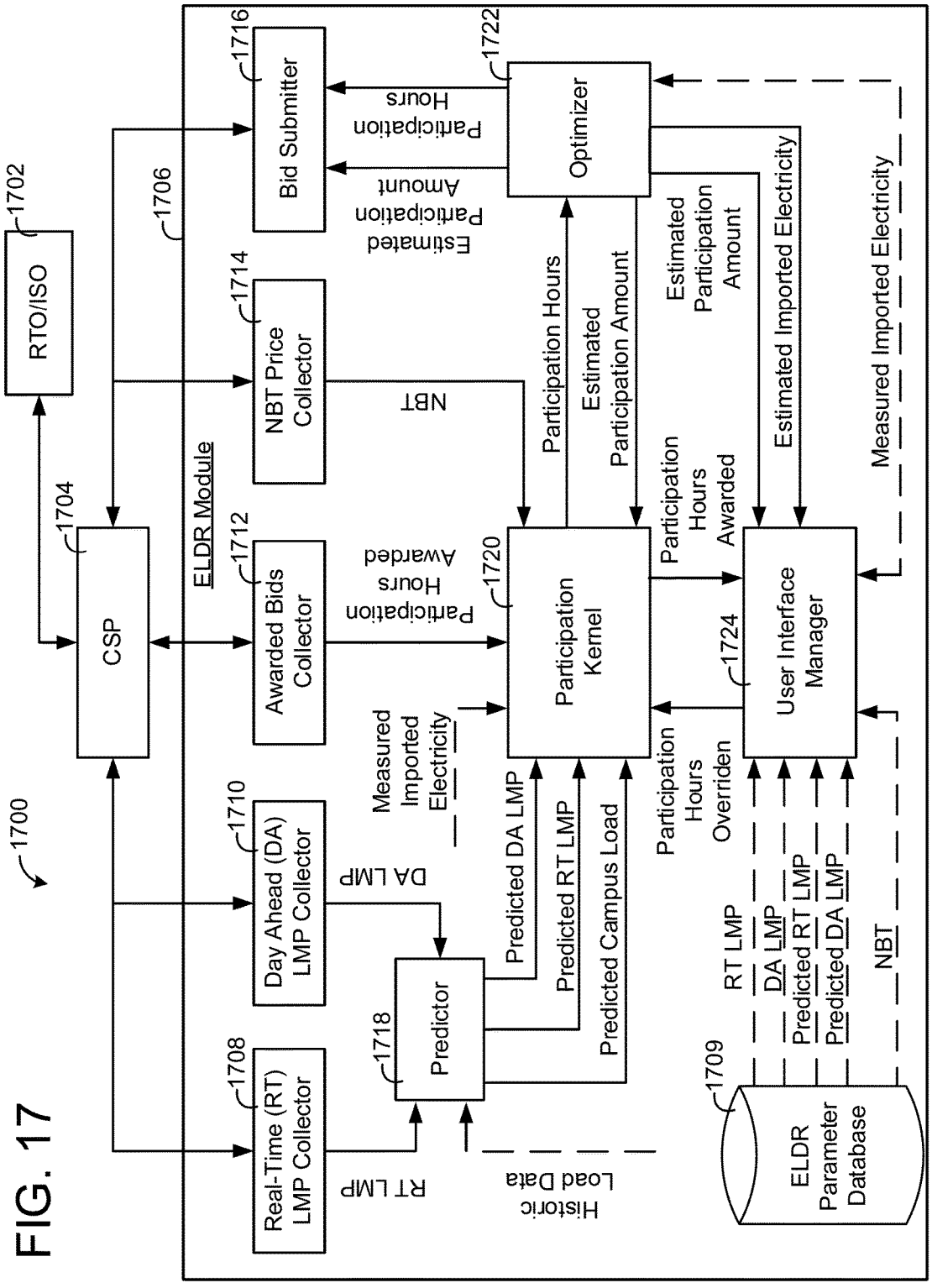

1700
1702
RTO/ISO
1704
CSP
1706
ELDR Module
1708
Real-Time (RT) LMP Collector
1710
Day Ahead (DA) LMP Collector
1712
Awarded Bids Collector
1714
NBT Price Collector
1716
Bid Submitter
1718
Predictor
1720
Participation Kernel
1722
Optimizer
1724
User Interface Manager
1709
ELDR Parameter Database
RT LMP
DA LMP
NBT
Historic Load Data
Predicted DA LMP
Predicted RT LMP
Predicted Campus Load
Measured Imported Electricity
Participation Hours Awarded
Estimated Participation Amount
Participation Hours Overriden
Estimated Imported Electricity
Measured Imported Electricity
Estimated Participation Amount
Participation Hours

FIG. 17

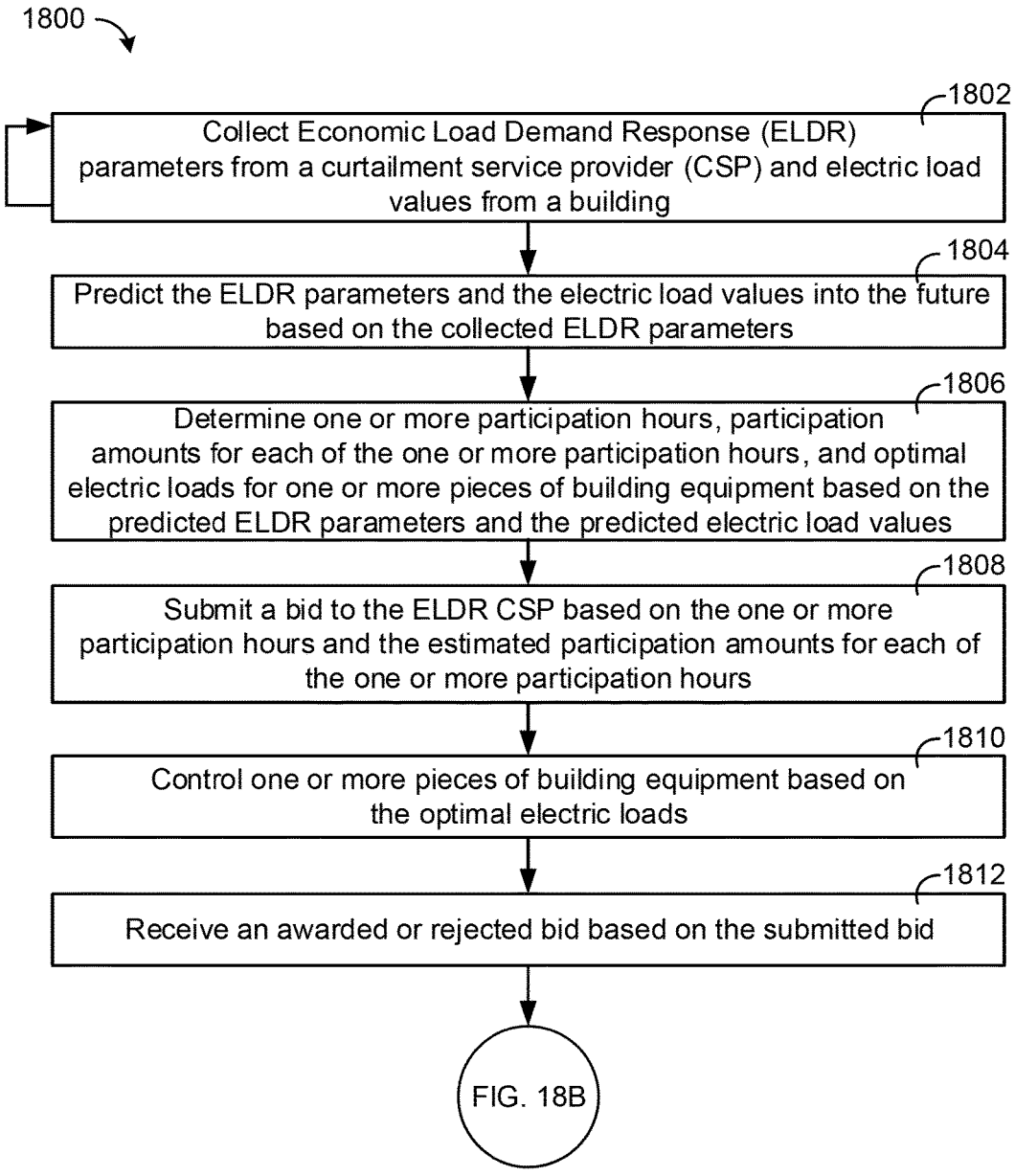

1800
1802
Collect Economic Load Demand Response (ELDR) parameters from a curtailment service provider (CSP) and electric load values from a building
1804
Predict the ELDR parameters and the electric load values into the future based on the collected ELDR parameters
1806
Determine one or more participation hours, participation amounts for each of the one or more participation hours, and optimal electric loads for one or more pieces of building equipment based on the predicted ELDR parameters and the predicted electric load values
1808
Submit a bid to the ELDR CSP based on the one or more participation hours and the estimated participation amounts for each of the one or more participation hours
1810
Control one or more pieces of building equipment based on the optimal electric loads
1812
Receive an awarded or rejected bid based on the submitted bid
FIG. 18B

FIG. 18A

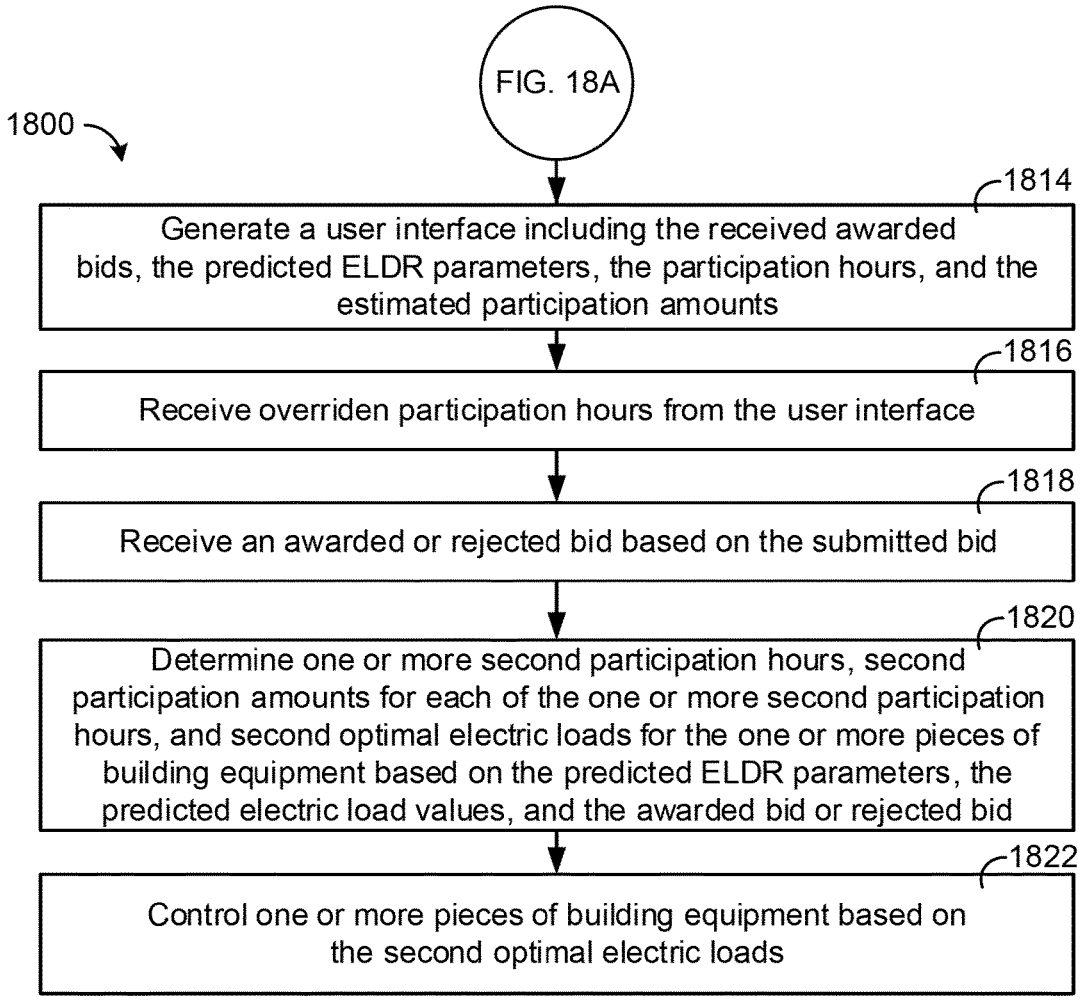

FIG. 18A
1800
1814
Generate a user interface including the received awarded bids, the predicted ELDR parameters, the participation hours, and the estimated participation amounts
1816
Receive overriden participation hours from the user interface
1818
Receive an awarded or rejected bid based on the submitted bid
1820
Determine one or more second participation hours, second participation amounts for each of the one or more second participation hours, and second optimal electric loads for the one or more pieces of building equipment based on the predicted ELDR parameters, the predicted electric load values, and the awarded bid or rejected bid
1822
Control one or more pieces of building equipment based on the second optimal electric loads

FIG. 18B

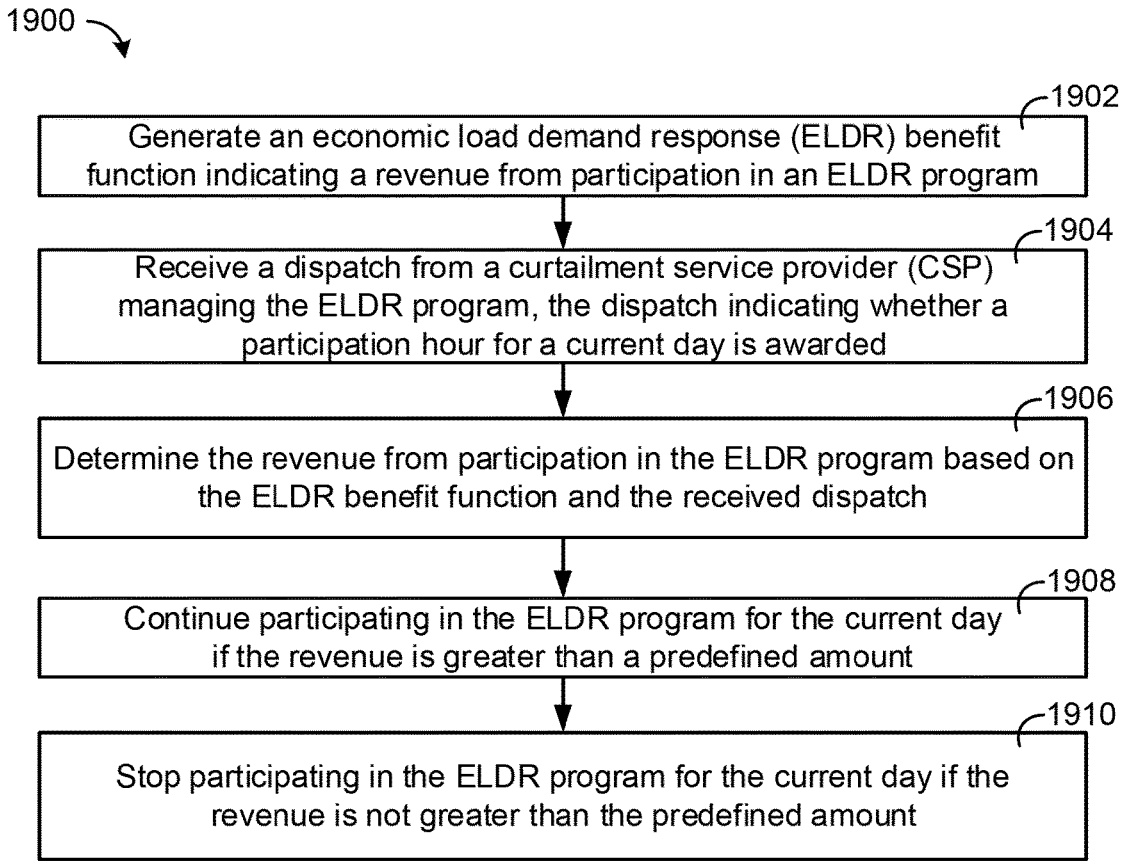

1900
1902
Generate an economic load demand response (ELDR) benefit function indicating a revenue from participation in an ELDR program
1904
Receive a dispatch from a curtailment service provider (CSP) managing the ELDR program, the dispatch indicating whether a participation hour for a current day is awarded
1906
Determine the revenue from participation in the ELDR program based on the ELDR benefit function and the received dispatch
1908
Continue participating in the ELDR program for the current day if the revenue is greater than a predefined amount
1910
Stop participating in the ELDR program for the current day if the revenue is not greater than the predefined amount

FIG. 19

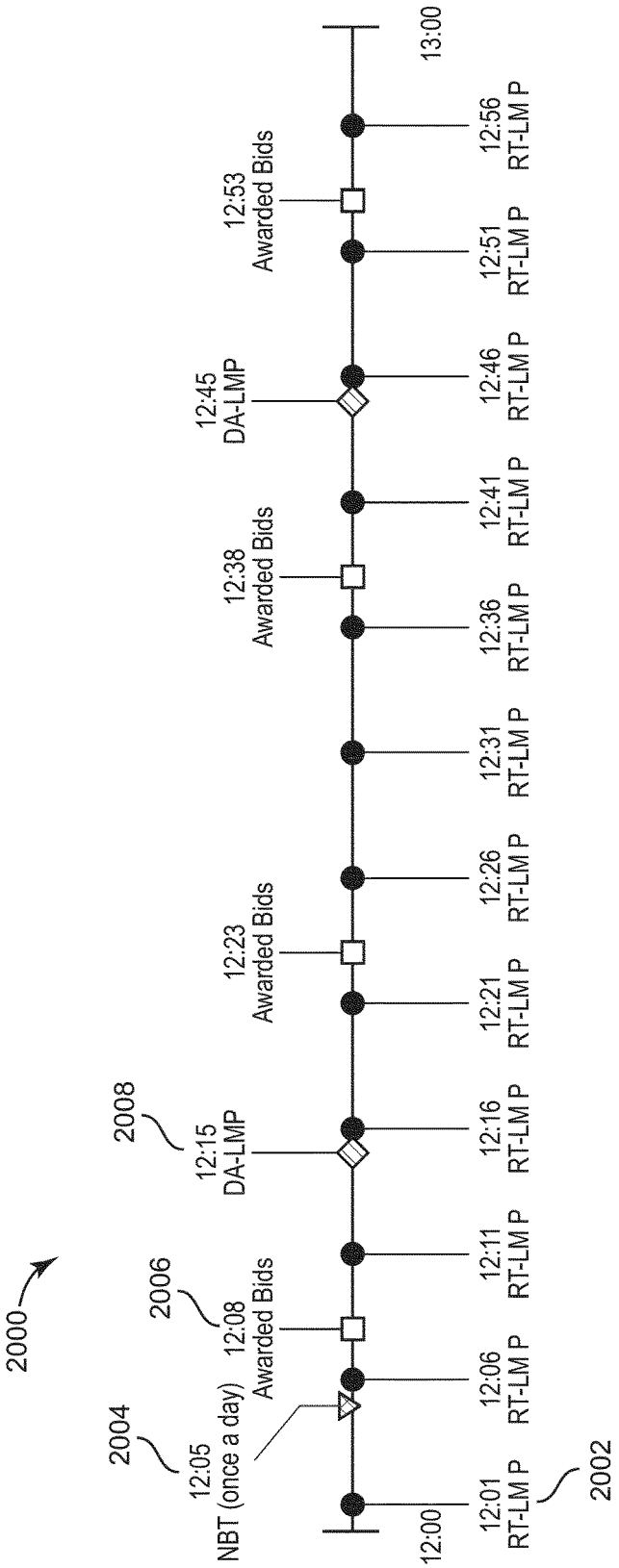

2000
2002
2004
2006
2008
12:00
12:01 RT-LM P
12:05 NBT (once a day)
12:06 RT-LM P
12:08 Awarded Bids
12:11 RT-LM P
12:15 DA-LMP
12:16 RT-LM P
12:21 RT-LM P
12:23 Awarded Bids
12:26 RT-LM P
12:31 RT-LM P
12:36 RT-LM P
12:38 Awarded Bids
12:41 RT-LM P
12:45 DA-LMP
12:46 RT-LM P
12:51 RT-LM P
12:53 Awarded Bids
12:56 RT-LM P
13:00

FIG. 20

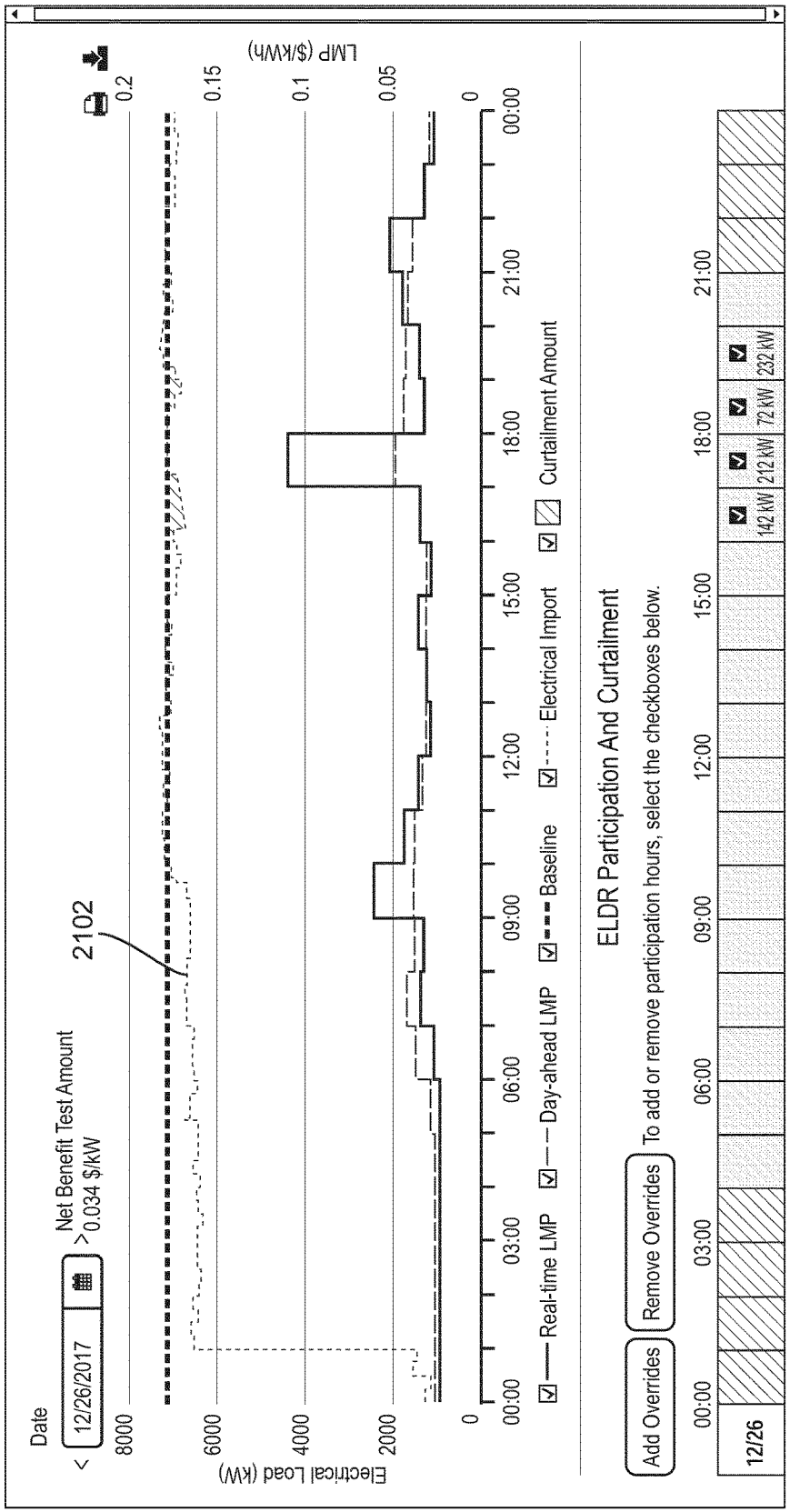

2200
2102
Date
12/26/2017
Net Benefit Test Amount
>0.034 $/kW
Electrical Load (kW)
LMP ($/kWh)
Real-time LMP
Day-ahead LMP
Baseline
Electrical Import
Curtailment Amount
ELDR Participation And Curtailment
Add Overrides
Remove Overrides
To add or remove participation hours, select the checkboxes below.
12/26
142 kW
212 kW
72 kW
232 kW

FIG. 21

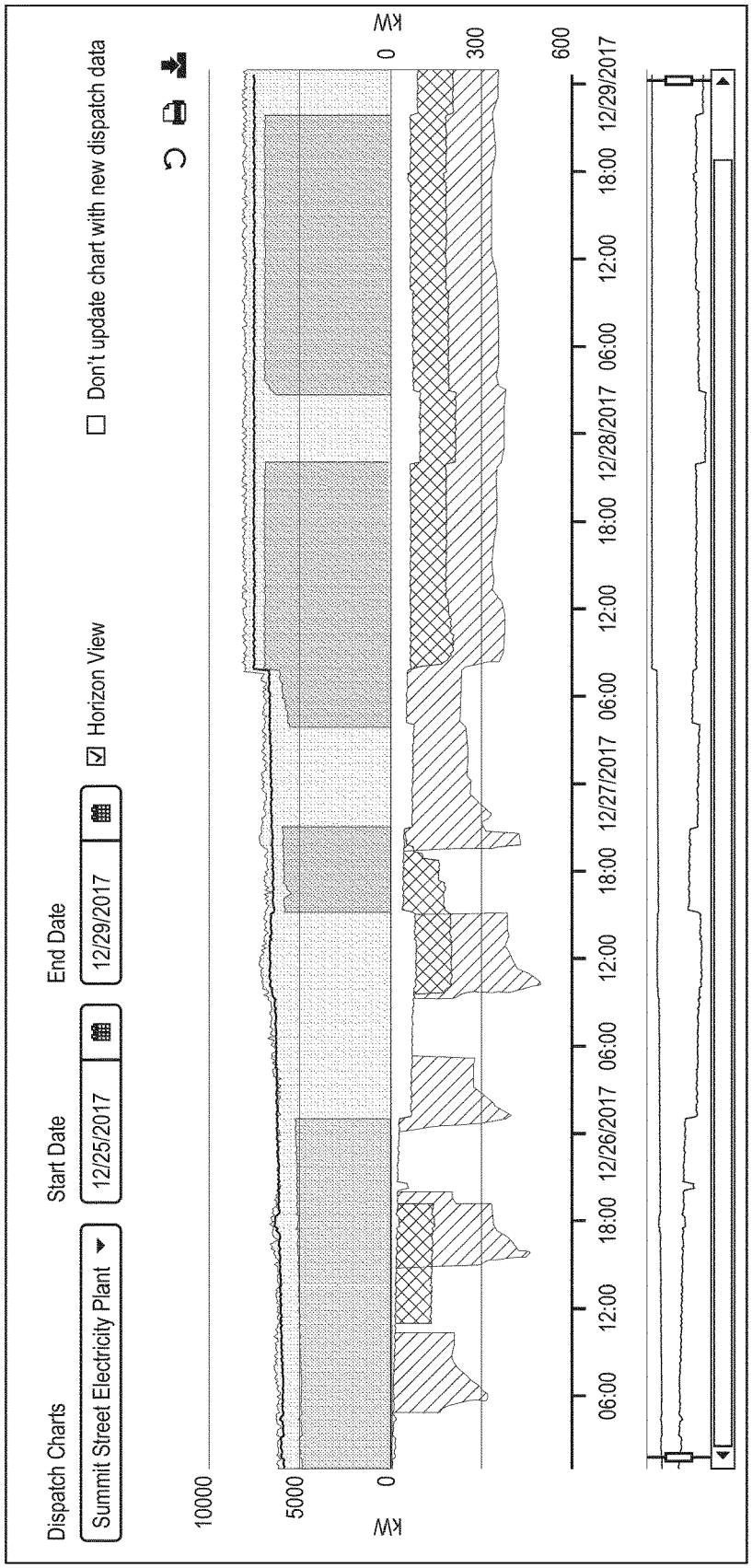

2300
Dispatch Charts
Summit Street Electricity Plant
Start Date
12/25/2017
End Date
12/29/2017
Horizon View
Don't update chart with new dispatch data
10000
5000
0
kW
0
300
600
kW
06:00
12:00
18:00
12/26/2017
06:00
12:00
18:00
12/27/2017
06:00
12:00
18:00
12/28/2017
06:00
12:00
18:00
12/29/2017

FIG. 22

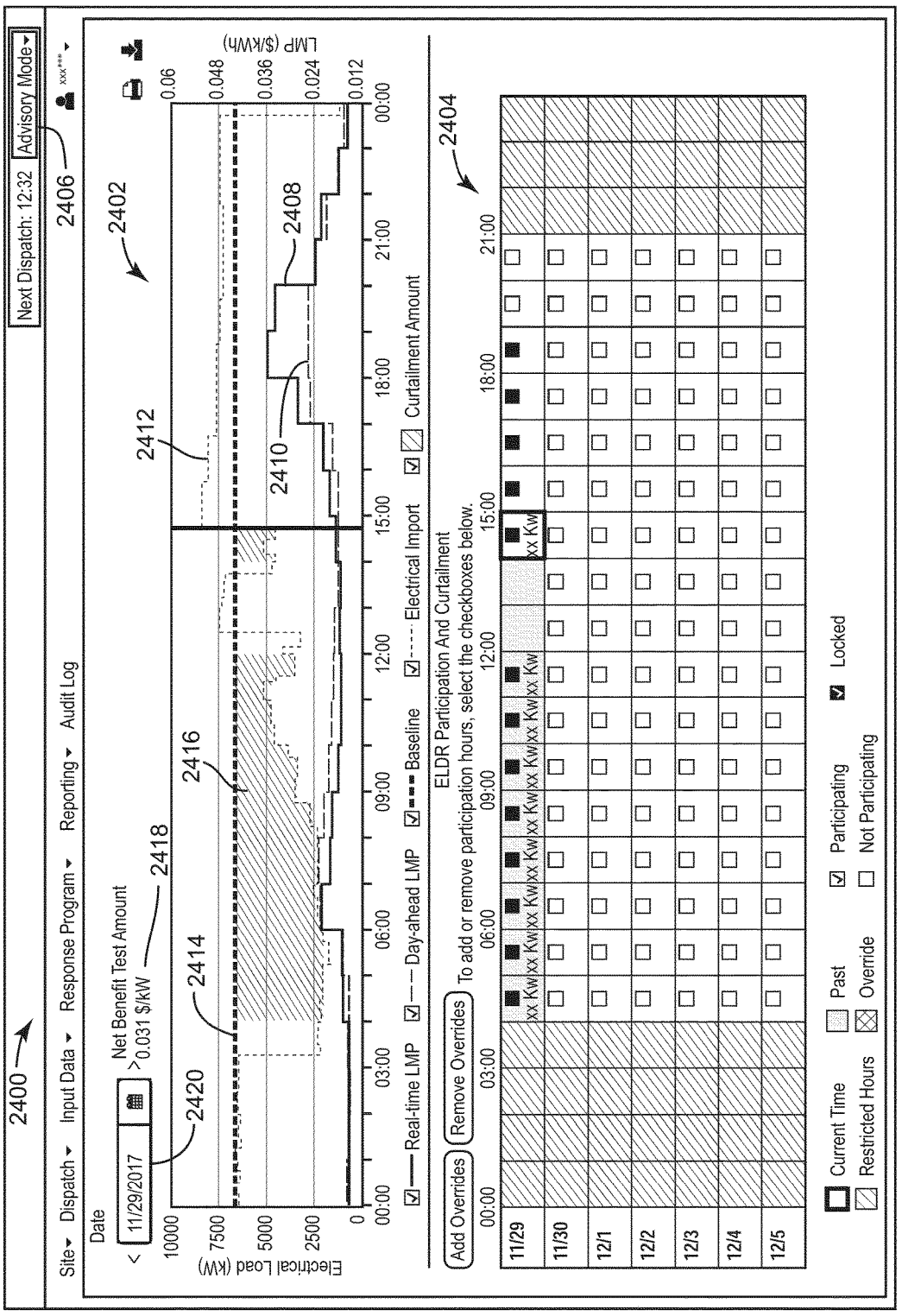

2400
Next Dispatch: 12:32
Advisory Mode
2406
Site
Dispatch
Input Data
Response Program
Reporting
Audit Log
Date
11/29/2017
Net Benefit Test Amount
>0.031 $/kW
2418
2420
2414
2416
2402
2412
2410
2408
Electrical Load (kW)
LMP ($/kWh)
Real-time LMP
Day-ahead LMP
Baseline
Electrical Import
Curtailment Amount
2404
ELDR Participation And Curtailment
Add Overrides
Remove Overrides
To add or remove participation hours, select the checkboxes below.
xx Kw
11/29
11/30
12/1
12/2
12/3
12/4
12/5
Current Time
Restricted Hours
Past
Override
Participating
Not Participating
Locked

FIG. 23

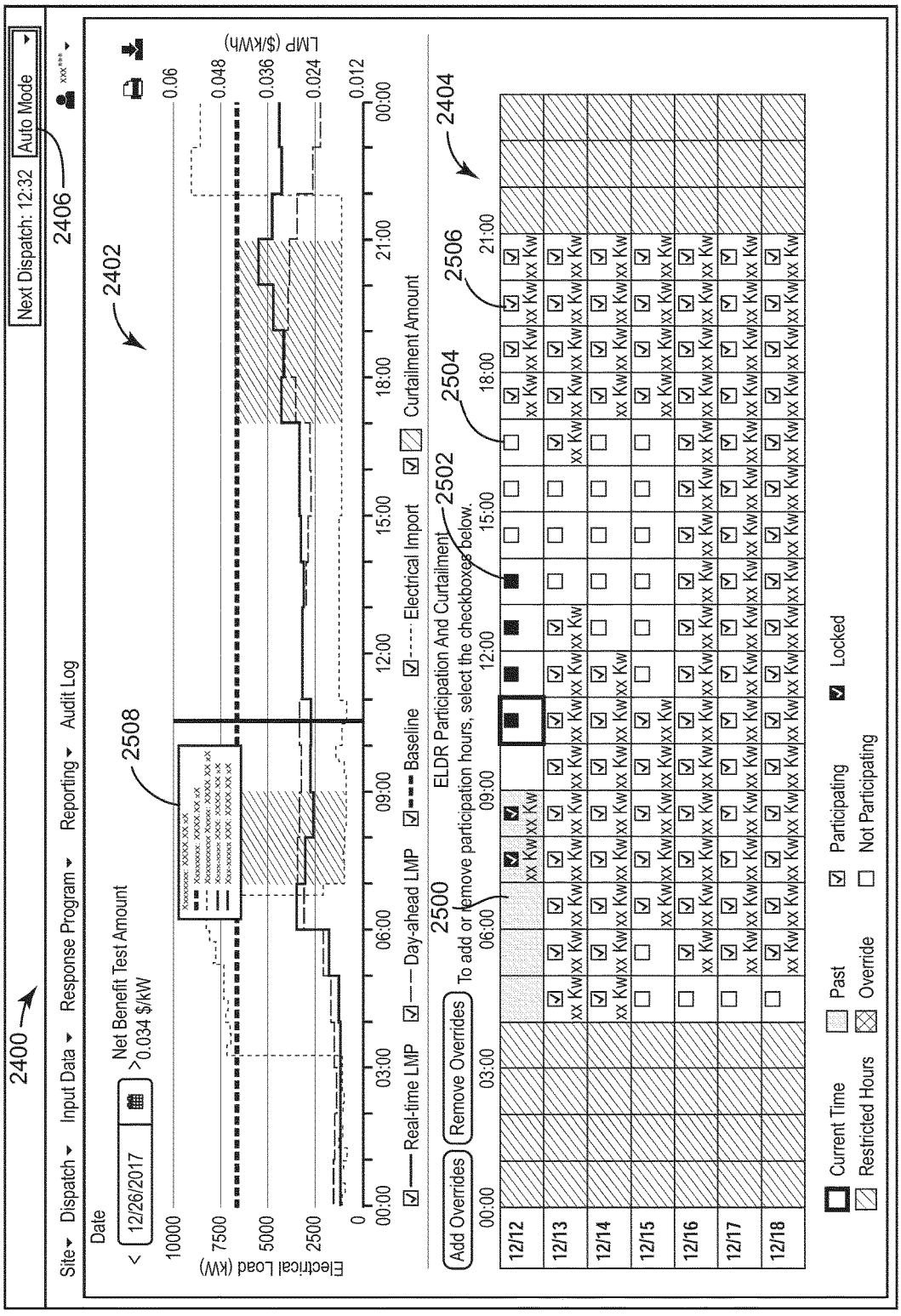

2400
Site
Dispatch
Input Data
Response Program
Reporting
Audit Log
Next Dispatch: 12:32
Auto Mode
2406
2402
2508
Date
12/26/2017
Net Benefit Test Amount
>0.034 $/kW
Electrical Load (kW)
LMP ($/kWh)
Real-time LMP
Day-ahead LMP
Baseline
Electrical Import
Curtailment Amount
2500
ELDR Participation And Curtailment
To add or remove participation hours, select the checkboxes below.
Add Overrides
Remove Overrides
2502
2504
2506
2404
12/12
12/13
12/14
12/15
12/16
12/17
12/18
Current Time
Past
Participating
Locked
Restricted Hours
Override
Not Participating

FIG. 24

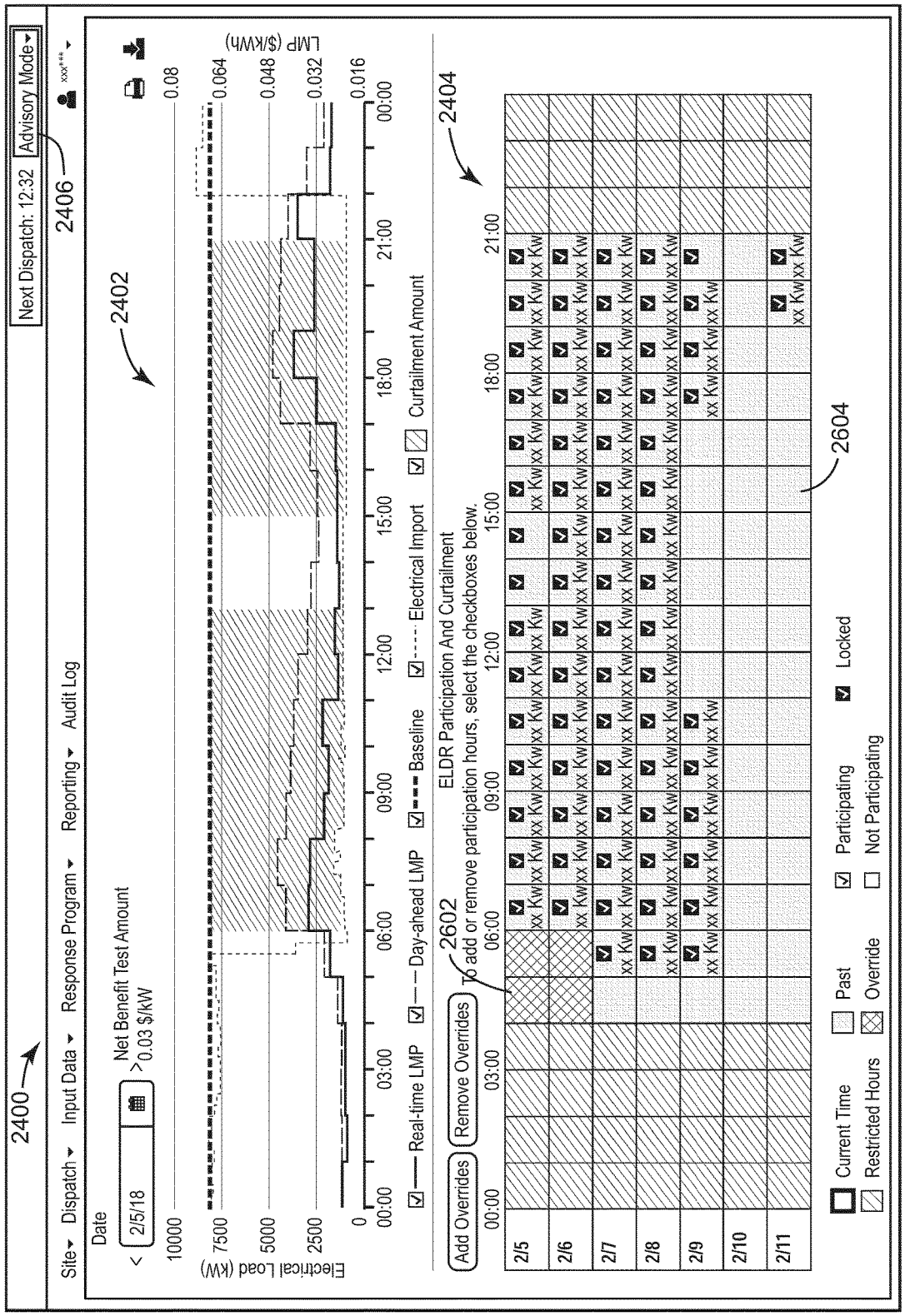

2400
Next Dispatch: 12:32
Advisory Mode
2406
Site
Dispatch
Input Data
Response Program
Reporting
Audit Log
2402
Date
2/5/18
Net Benefit Test Amount
>0.03 $/kW
Electrical Load (kW)
LMP ($/kWh)
Real-time LMP
Day-ahead LMP
Baseline
Electrical Import
Curtailment Amount
ELDR Participation And Curtailment
2404
Add Overrides
Remove Overrides
2602
To add or remove participation hours, select the checkboxes below.
2604
Current Time
Past
Participating
Locked
Restricted Hours
Override
Not Participating

FIG. 25

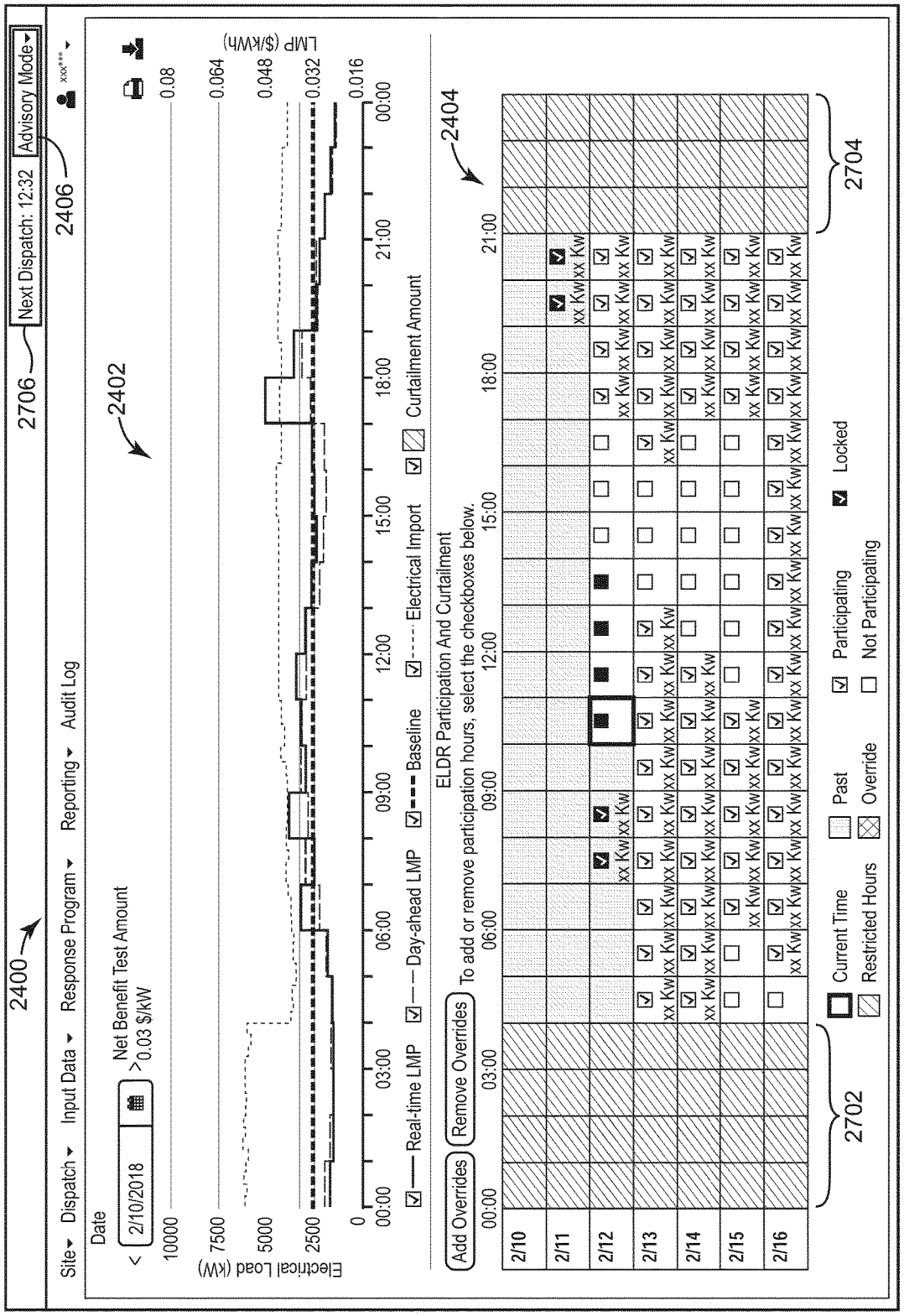

2400
2706
Next Dispatch: 12:32
Advisory Mode
Site
Dispatch
Input Data
Response Program
Reporting
Audit Log
2406
2402
Date
2/10/2018
Net Benefit Test Amount
>0.03 $/kW
Electrical Load (kW)
LMP ($/kWh)
Real-time LMP
Day-ahead LMP
Baseline
Electrical Import
Curtailment Amount
ELDR Participation And Curtailment
2404
Add Overrides
Remove Overrides
To add or remove participation hours, select the checkboxes below.
2/10
2/11
2/12
2/13
2/14
2/15
2/16
2702
2704
Current Time
Past
Participating
Locked
Restricted Hours
Override
Not Participating

FIG. 26

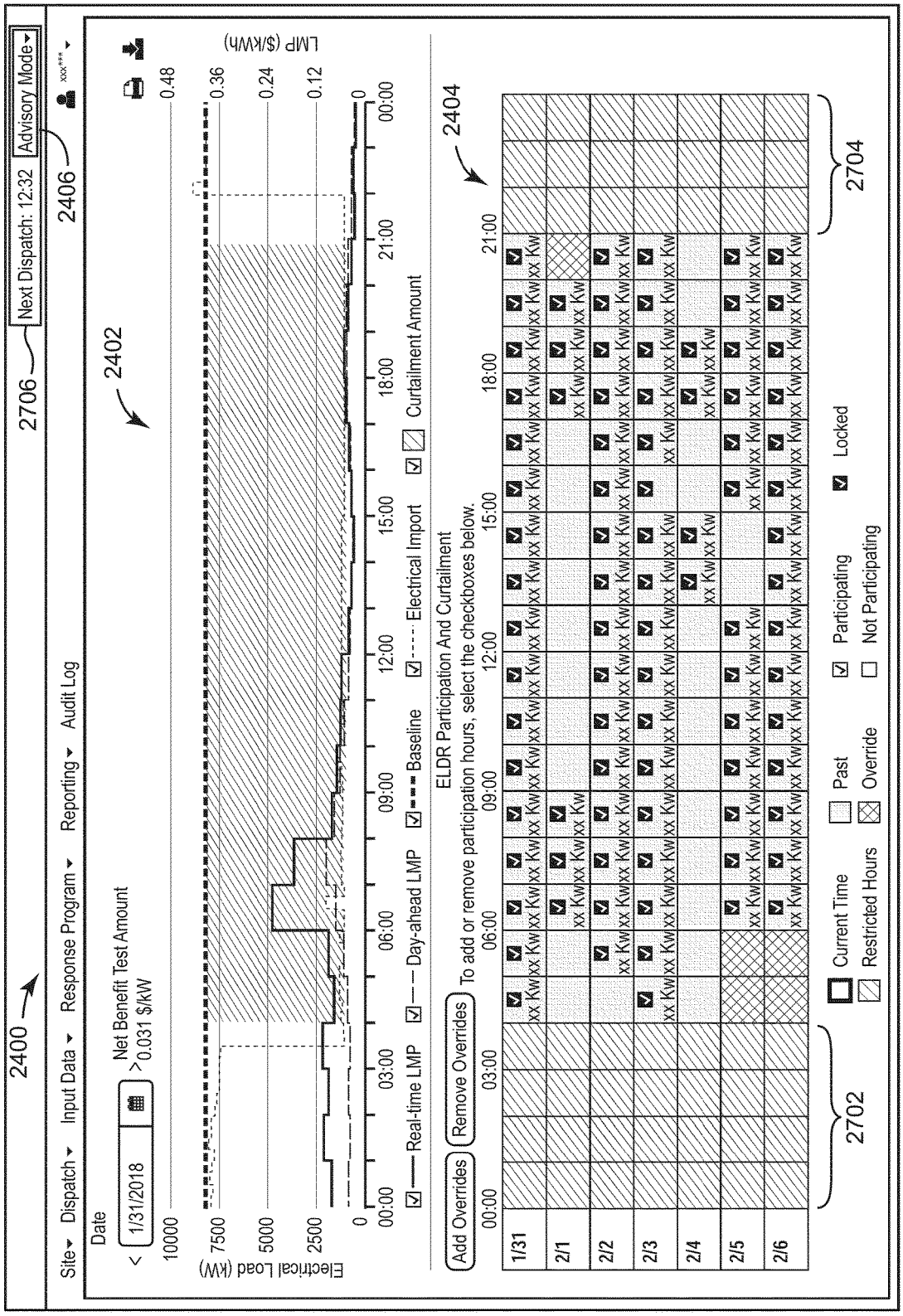

2400
2706
Next Dispatch: 12:32
Advisory Mode
Site
Dispatch
Input Data
Response Program
Reporting
Audit Log
2406
2402
Date
1/31/2018
Net Benefit Test Amount
> 0.031 $/kW
Electrical Load (kW)
LMP ($/kWh)
Real-time LMP
Day-ahead LMP
Baseline
Electrical Import
Curtailment Amount
ELDR Participation And Curtailment
2404
Add Overrides
Remove Overrides
To add or remove participation hours, select the checkboxes below.
2702
2704
Current Time
Past
Participating
Locked
Restricted Hours
Override
Not Participating

FIG. 27

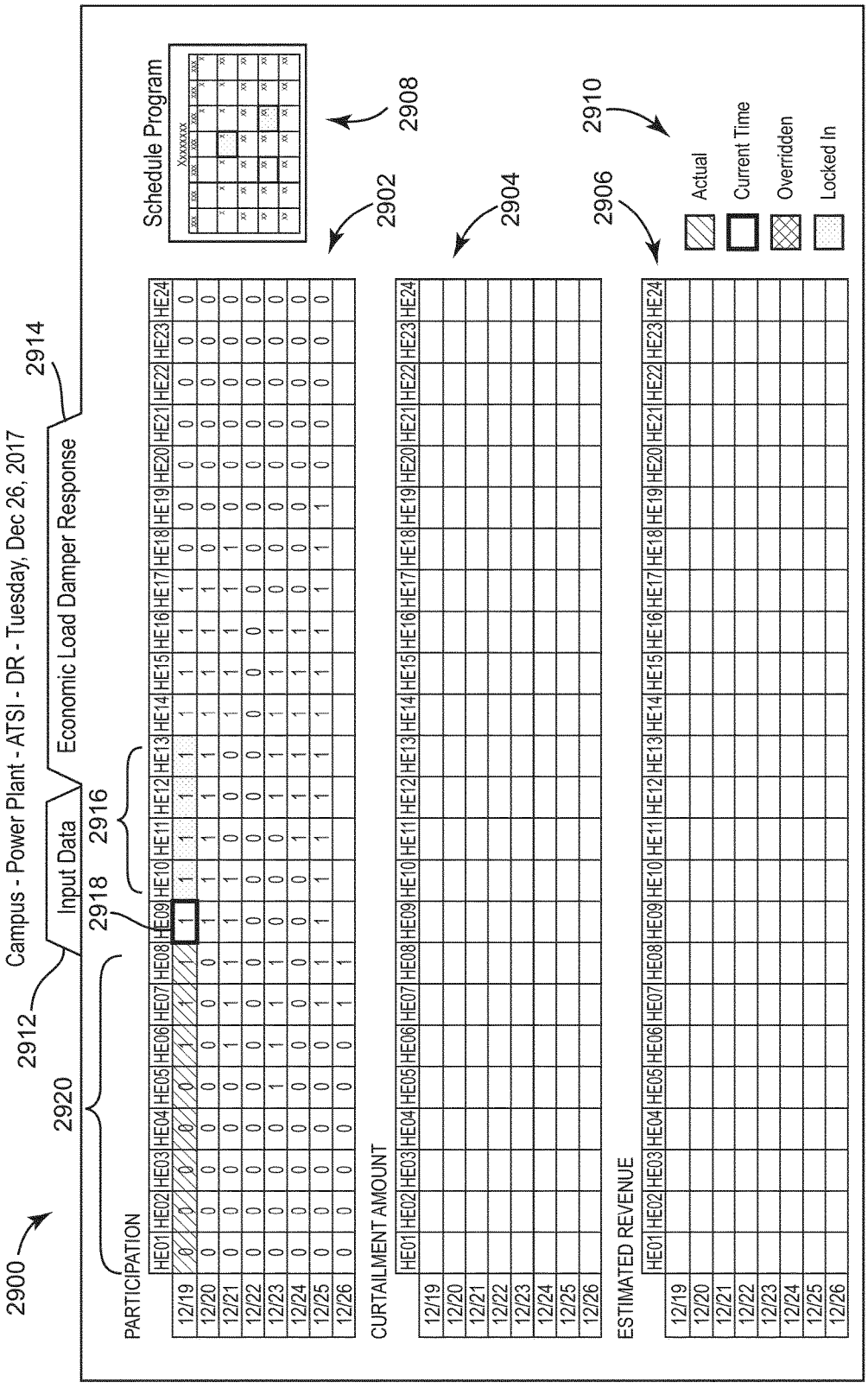

2900
Campus - Power Plant - ATSI - DR - Tuesday, Dec 26, 2017
2912
Input Data
Economic Load Damper Response
2914
2916
2918
2920
Schedule Program
2908
2902
2904
2906
2910
Actual
Current Time
Overridden
Locked In
PARTICIPATION
CURTAILMENT AMOUNT
ESTIMATED REVENUE
HE01 HE02 HE03 HE04 HE05 HE06 HE07 HE08 HE09 HE10 HE11 HE12 HE13 HE14 HE15 HE16 HE17 HE18 HE19 HE20 HE21 HE22 HE23 HE24
12/19
12/20
12/21
12/22
12/23
12/24
12/25
12/26

FIG. 28

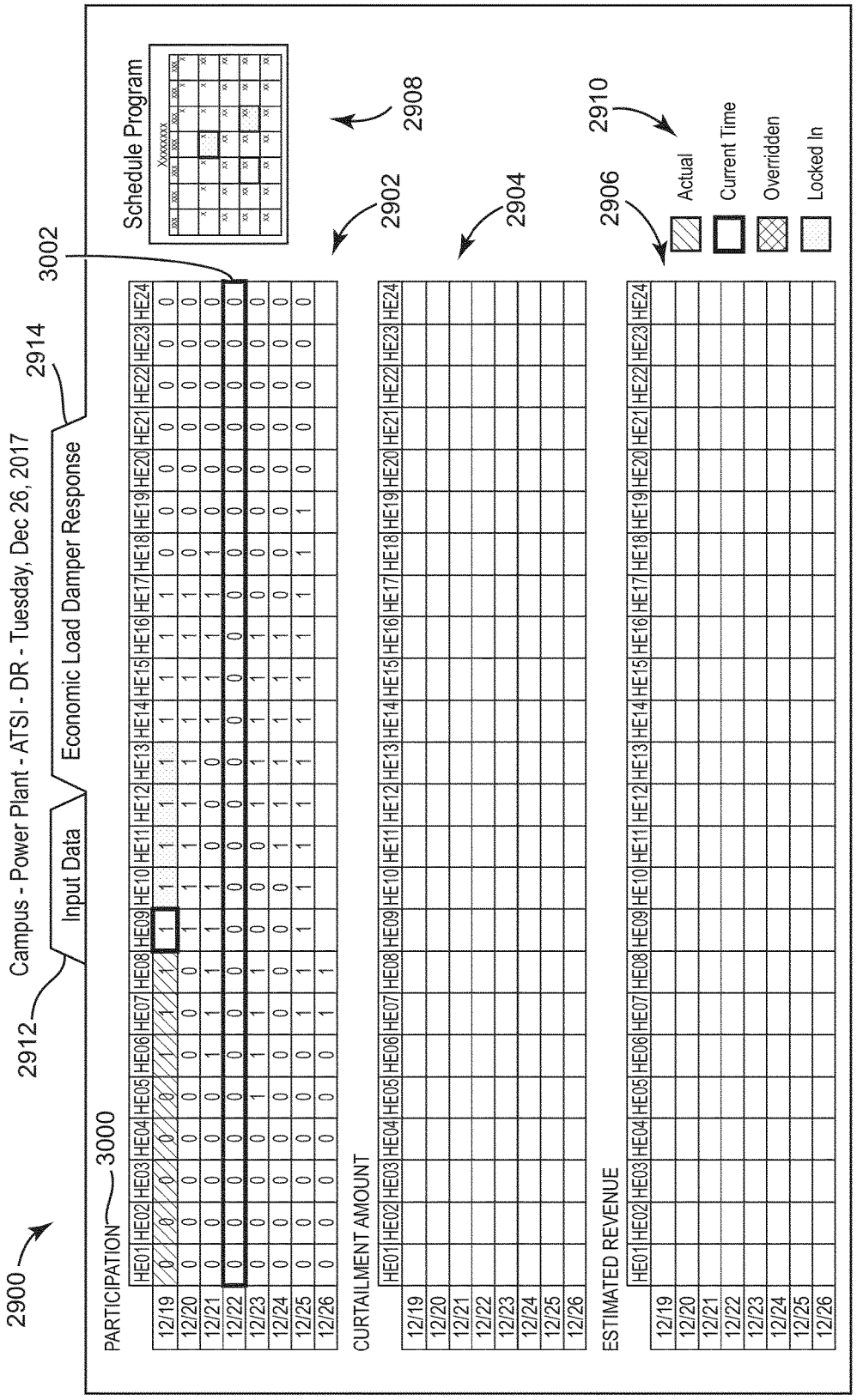

2900
2912
Campus - Power Plant - ATSI - DR - Tuesday, Dec 26, 2017
Input Data
Economic Load Damper Response
2914
3002
Schedule Program
2908
2902
2904
2910
2906
Actual
Current Time
Overridden
Locked In
PARTICIPATION
3000
CURTAILMENT AMOUNT
ESTIMATED REVENUE
HE01 HE02 HE03 HE04 HE05 HE06 HE07 HE08 HE09 HE10 HE11 HE12 HE13 HE14 HE15 HE16 HE17 HE18 HE19 HE20 HE21 HE22 HE23 HE24
12/19
12/20
12/21
12/22
12/23
12/24
12/25
12/26

FIG. 29

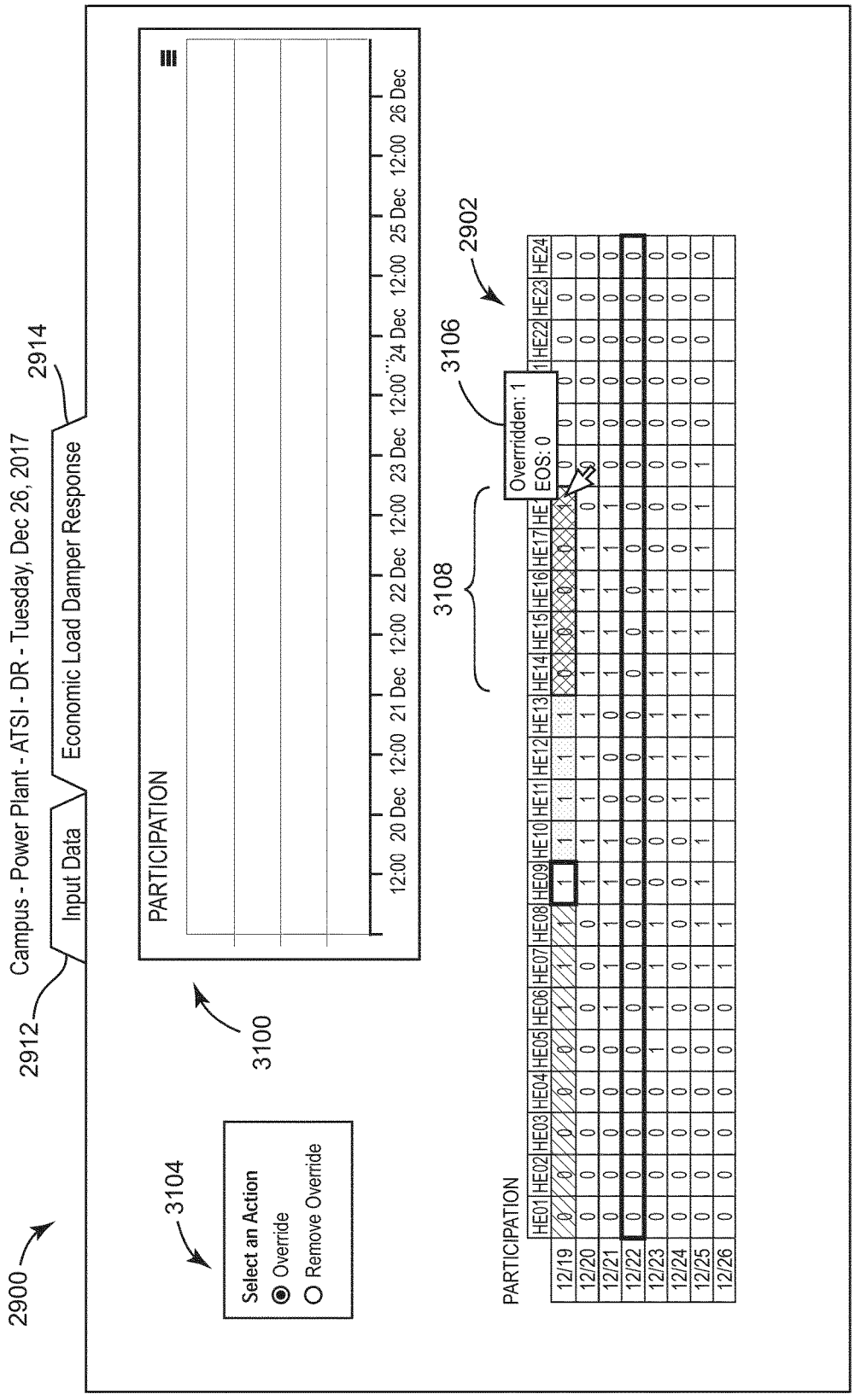

2900
Campus - Power Plant - ATSI - DR - Tuesday, Dec 26, 2017
2912
Input Data
Economic Load Damper Response
2914
3100
PARTICIPATION
12:00 20 Dec 12:00 21 Dec 12:00 22 Dec 12:00 23 Dec 12:00 24 Dec 12:00 25 Dec 12:00 26 Dec
3104
Select an Action
Override
Remove Override
3106
Overridden: 1
EOS: 0
3108
2902
PARTICIPATION
HE01 HE02 HE03 HE04 HE05 HE06 HE07 HE08 HE09 HE10 HE11 HE12 HE13 HE14 HE15 HE16 HE17 HE1 HE22 HE23 HE24
12/19 0 0 0 0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 0 0 0
12/20 0 0 0 0 0 0 0 1 1 1 1 1 1 1 1 1 1 0 0 0 0
12/21 0 0 0 0 0 1 1 1 1 1 0 0 0 1 1 1 1 0 0 0 0
12/22 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
12/23 0 0 0 0 1 1 1 1 0 0 0 1 1 1 1 1 0 0 0 0 0
12/24 0 0 0 0 0 0 0 0 0 0 1 1 1 1 1 1 0 0 0 0 0
12/25 0 0 0 0 0 0 1 1 1 1 1 1 1 1 1 1 0 0 0 0 0
12/26 0 0 0 0 0 0 1 1

FIG. 30

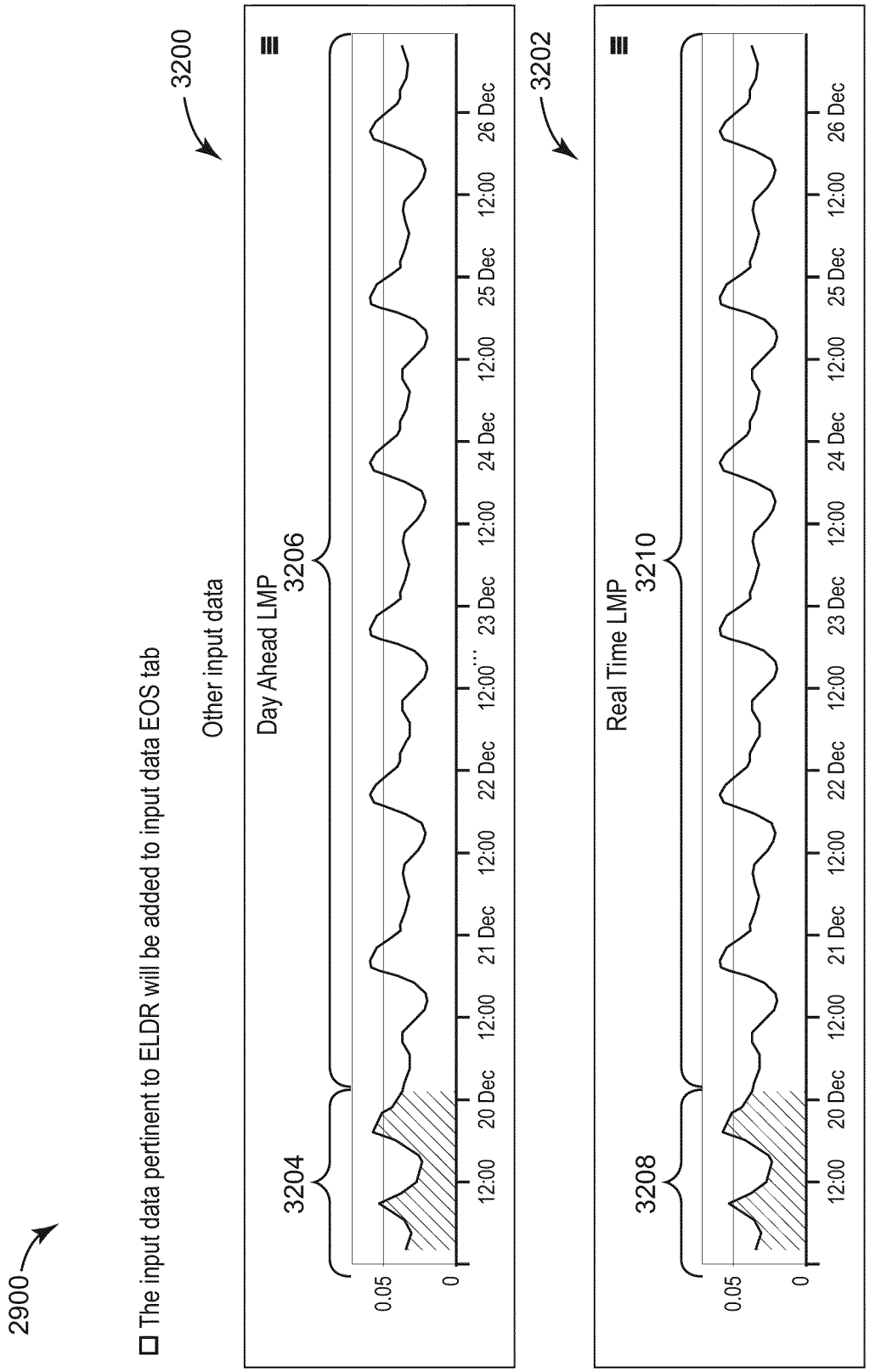

2900
The input data pertinent to ELDR will be added to input data EOS tab
Other input data
3200
3202
Day Ahead LMP
3206
3204
Real Time LMP
3210
3208
0.05
0
12:00
20 Dec
21 Dec
22 Dec
23 Dec
24 Dec
25 Dec
26 Dec

FIG. 31

BUILDING ENERGY OPTIMIZATION SYSTEM WITH AUTOMATED AND DYNAMIC ECONOMIC LOAD DEMAND RESPONSE (ELDR) OPTIMIZATION

CROSS-REFERENCE TO RELATED PATENT APPLICATION

[0001] This application is a continuation-in-part of U.S. patent application Ser. No. 15/616,616 filed Jun. 7, 2017, the entire disclosure of which is incorporated by reference herein.

BACKGROUND

[0002] The present disclosure relates generally to an energy cost optimization system for a building, a collection of buildings, or a central plant. The present disclosure relates more particularly to an energy cost optimization system that accounts for revenue generated from participating in incentive-based demand response (IBDR) programs.

[0003] IBDR programs include various incentive-based programs such as frequency regulation (FR) and economic load demand response (ELDR). An ELDR program is typically operated by a regional transmission organization (RTO) and/or an independent system operator (ISO). The RTO and/or ISO may reward a customer for reducing their electric load during certain hours of the day. The RTO and/or ISO may operate with a bidding system in which various customers place bids with the RTO and/or ISO to reduce their electric load during selected hours. Based on the received bids, the RTO and/or ISO may dispatch awarded hours to the various customers.

[0004] Customers that participate in the ELDR program can either be awarded or penalized by the RTO and/or ISO based on the electric load of the customer during awarded hours (i.e., hours on which the customer has bid and been awarded). A customer may include a curtailment amount in their bid. A curtailment amount may be an amount that the customer will reduce their electric load with respect to a baseline load. If the customer curtails their electric load according to their bid during the awarded hours, the customer is compensated. However, if the customer does not curtail their electric load according to their bid during the awarded hours, the customer is penalized.

SUMMARY

[0005] One implementation of the present disclosure is an energy cost optimization system for a building. The system includes HVAC equipment configured to operate in the building and a controller. The controller is configured to generate a cost function defining a cost of operating the HVAC equipment over an optimization period as a function of one or more electric loads setpoints for the HVAC equipment. The electric load setpoints are decision variables of the cost function and are setpoints for each hour of the optimization period. The controller is further configured to generate participation hours. The participation hours indicate one or more hours that the HVAC equipment will participate in an economic load demand response (ELDR) program. The controller is further configured to generate an ELDR term based on the participation hours. The ELDR term indicates revenue generated by participating in the ELDR program. The controller is further configured to modify the cost function to include the ELDR term and perform an optimization using the modified cost function to determine optimal electric load setpoints for each hour of the participation hours.

[0006] In some embodiments, the controller is configured to generate a bid for participation in the ELDR program by subtracting the optimal electric load setpoints from a customer baseline load (CBL) for each hour of the participation hours and generating the bid to be the participation hours excluding certain hours of the participation hours. In some embodiments, the certain hours are hours where the difference of the CBL and the optimal electric load setpoint are less than or equal to zero. The controller can be further configured to send the bid to an incentive program. In some embodiments, the controller is configured to cause the HVAC equipment to operate based on awarded participation hours received from the incentive program and the optimal electric loads.

[0007] In some embodiments, the controller is configured to modify the cost function to include the ELDR term by representing participation in the ELDR program as an electric rate adjustment in the cost function. The electric rate adjustment may be dependent on at least one of the participation hours, a CBL, a predicted day-ahead locational marginal price (LMP), and a predicted real-time LMP. In some embodiments, the controller is configured to perform the optimization using the modified cost function to determine the optimal electric load for each hour of the participation hours based on the electric rate adjustment.

[0008] In some embodiments, the controller is configured to receive a net benefit test (NBT), a LMP, and a real-time LMP from an incentive program. The controller can further be configured to generate the participation hours by comparing the NBT to a predicted day-ahead LMP that is based on one or more received day-ahead LMPs and a predicted real-time LMP that is based on one or more received real-time LMP.

[0009] In some embodiments, the controller is configured to generate the participation hours by comparing an NBT to a predicted day-ahead LMP and a predicted real-time LMP and determining values for an event start hour and an event end hour that cause an equation to be minimized and determining that the participation hours are the hours between the event start hour and the event end hour. In some embodiments, the equation includes at least one of a customer baseline load (CBL), a predicted real-time LMP, and a predicted electric load. In some embodiments, the participation hours are used as the search space for minimizing the equation and are the hours generated by comparing the NBT to one or both of the predicted day-ahead LMP and the predicted real-time LMP.

[0010] In some embodiments, the CBL is dependent on the event start hour and the event end hour. The CBL may be at least one of a same day CBL and a symmetric additive adjustment (SAA) CBL.

[0011] In some embodiments, the CBL is an SAA CBL and the controller is configured to determine the SAA CBL by determining an average electric load to be the average electric load of four weekdays of five most recently occurring weekdays before the participation hours if the participation hours occur on a weekday, determining the average electric load to be the average electric load two weekends or holidays of three most recently occurring weekends or holidays, if the participation hours occur on a weekend or holiday, determining an adjustment based on predicted elec-

tric loads of three consecutive hours one hour before the event start hour, and determining the SAA CBL to be the sum of the average electric load and the adjustment.

[0012] In some embodiments, the CBL is a same day CBL. In some embodiments, the controller is configured to determine the same day CBL based on predicted electric loads three consecutive hours one hour before the participation hours and predicted electric loads two consecutive hours one hour after the participation hours.

[0013] In some embodiments, the participation hours are a vector of ones and zeros for a plurality of hours, a one indicates participation in the ELDR program for a particular hour while a zero indicates no participation in the ELDR program for a particular hour. In some embodiments, the modified cost function represents participation in the ELDR program as an electric rate adjustment.

[0014] Another implementation of the present disclosure is a method for optimizing energy costs for a building. The method includes generating a cost function defining a cost of operating HVAC equipment over an optimization period as a function of one or more electric loads for the HVAC equipment. The electric loads are decision variables of the cost function and include an electric load for each hour of the optimization period. The method further includes generating participation hours, the participation hours indicate one or more hours that the HVAC equipment will participate in an economic load demand response (ELDR) program. The method further includes generating an ELDR term based on the participation hours. The ELDR term indicates revenue generated by participating in the ELDR program. The method further includes modifying the cost function to include the ELDR term and performing an optimization using the modified cost function to determine an optimal electric load for each hour of the participation hours.

[0015] In some embodiments, the method further includes generating a bid for participation in the ELDR program by subtracting the optimal electric load from a customer baseline load (CBL) for each hour of the participation hours and generating the bid to be the participation hours excluding certain hours of the participation hours. In some embodiments, the certain hours are hours where the difference of the CBL and the optimal electric load is less than or equal to zero. In some embodiments, the method further includes sending the bid to an incentive program. In some embodiments, the method further includes causing the HVAC equipment to operate based on the awarded participation hours and the optimal electric load setpoints. In some embodiments, the modified cost function represents participation in the ELDR program as an electric rate adjustment.

[0016] In some embodiments, modifying the cost function to include the ELDR term comprises representing participation in the ELDR program as an electric rate adjustment in the cost function. The electric rate adjustment may be dependent on at least one of the participation hours, a CBL, a predicted day-ahead locational marginal price (LMP), and a predicted real-time LMP. In some embodiments, performing the optimization using the modified cost function to determine the optimal electric load for each hour of the participation hours is based on the electric rate adjustment.

[0017] In some embodiments, the method further includes receiving a net benefit test (NBT), a day-ahead LMP, and a real-time LMP from an incentive program. In some embodiments, the method further includes generating the participation hours by comparing the NBT to a predicted day-ahead LMP that is based on one or more received day-ahead LMPs and a predicted real-time LMP that is based on one or more received real-time LMP.

[0018] In some embodiments, the method includes determining the participation hours by comparing an NBT to at least one of a predicted day-ahead LMP and a predicted real-time LMP. In some embodiments, the method includes determining values for an event start hour and an event end hour that cause an equation to be minimized, the equation including at least one of a customer baseline load (CBL), a predicted real-time LMP, and a predicted electric load. The participation hours may be used as the search space for minimizing the equation and may be the hours generated by comparing the NBT to at least one of the predicted day-ahead LMP and the predicted real-time LMP. In some embodiments, the method includes determining that the participation hours are the hours between the event start hour and the event end hour.

[0019] In some embodiments, the method further includes determining the SAA CBL by determining an average electric load to be the average electric load of four weekdays of five most recently occurring weekdays before the participation hours if the participation hours occur on a weekday, determining the average electric load to be the average electric load of two weekends or holidays of three most recently occurring weekends or holidays if the participation hours occur on a weekend or holiday, determining an adjustment based on predicted electric loads of three consecutive hours one hour before the event start hour, and determining the SAA CBL to be the sum of the average electric load and the adjustment.

[0020] In some embodiments, the CBL is a same day CBL. In some embodiments, the method further includes determining the same day CBL based on predicted electric loads three consecutive hours one hour before the participation hours and predicted electric loads two consecutive hours one hour after the participation hours.

[0021] Another implementation of the present disclosure is an energy cost optimization system for a building. The system includes HVAC equipment configured to satisfy a building energy load of the building and a controller. The controller is configured to generate a cost function defining a cost of operating the HVAC equipment over an optimization period as a function of one or more electric loads for the HVAC equipment. The electric loads are decision variables of the cost function and include an electric load for each hour of the optimization period. The controller can be configured to receive a net benefit test (NBT), a day-ahead locational marginal price (LMP), and a real-time LMP from an incentive program. The controller can be configured to generate participation hours. The participation hours indicate one or more hours that the HVAC equipment will participate in an economic load demand response (ELDR) program. The controller can be configured to generate the participation hours by comparing the NBT to a predicted day-ahead LMP that is based on one or more received day-ahead LMPs and a predicted real-time LMP that is based on one or more received real-time LMP. The controller is configured to generate an ELDR term based on the participation hours. The ELDR term indicates revenue generated by participating in the ELDR program. The controller is configured to modify the cost function to include the ELDR term and perform an optimization using the modified

cost function to determine an optimal electric load for each hour of the participation hours.

[0022] In some embodiments, the controller is configured to generate a bid for participation in the ELDR program by subtracting the optimal electric load from a customer baseline load (CBL) for each hour of the participation hours and generating the bid to be the participation hours excluding certain hours of the participation hours. In some embodiments, the certain hours are hours where the difference of the CBL and the optimal electric load is less than or equal to zero. The controller can be configured to send the bid to an incentive program and cause the HVAC equipment to operate based on awarded participation hours received from the incentive program and the optimal electric loads.

[0023] In some embodiments, the controller is configured to determine the participation hours by determining values for an event start hour and an event end hour that cause an equation to be minimized. In some embodiments, the equation includes at least one of a customer baseline load (CBL), a predicted real-time LMP, and a predicted electric load. In some embodiments, the participation hours are used as the search space for minimizing the equation and are the hours generated by comparing the NBT to the predicted day-ahead LMP and the predicted real-time LMP. In some embodiments, the controller is configured to determine the participation hours by determining that the participation hours are the hours between the event start hour and the event end hour.

[0024] In some embodiments, the CBL is an SAA CBL or a same day CBL. In some embodiments, the controller is configured to determine the SAA CBL by determining an average electric load to be the average electric load of four weekdays of five most recently occurring weekdays before the participation hours, if the participation hours occur on a weekday, determining the average electric load to be the average electric load of two weekends or holidays of three most recently occurring weekends or holidays, if the participation hours occur on a weekend or holiday, determining an adjustment based on predicted electric loads of three consecutive hours one hour before the event start hour, and determining the SAA CBL to be the sum of the average electric load and the adjustment. The controller can be configured to determine the same day CBL based on predicted electric loads three consecutive hours one hour before the participation hours and predicted electric loads two consecutive hours one hour after the participation hours.

[0025] One implementation of the present disclosure is an energy optimization system for a building. The system includes a processing circuit configured to perform an optimization to generate one or more first participation hours and a first load reduction amount for reach of the one or more first participation hours and provide a first bid including the one or more first participation hours and the first load reduction amount for each of the one or more first participation hours to a computing system configured to facilitate an economic load demand response (ELDR) program. The processing circuit is configured to operate one or more pieces of building equipment to affect an environmental condition of the building based on one or more first equipment loads for participating in the ELDR program and receive one or more awarded or rejected participation hours from the computing system responsive to the first bid. The processing circuit is configured to generate one or more second participation hours for participating in the ELDR program, a second load reduction amount for each of the one or more second participation hours, and one or more second equipment loads for the one or more pieces of building equipment based on the one or more awarded or rejected participation hours by performing the optimization a second time and operate the one or more pieces of building equipment to affect the environmental condition of the building based on the one or more second equipment loads.

[0026] In some embodiments, the processing circuit is configured to generate a predicted campus electric load based on at least one of historical campus electric load values, predicted market resource prices, predicted equipment loads, or predicted chilled water loads and generate the one or more second participation hours for participating in the ELDR program, the second load reduction amount for each of the one or more second participation hours, and the one or more second equipment loads for the one or more pieces of building equipment based on the one or more awarded or rejected participation hours and on the predicted campus electric load by performing the optimization the second time.

[0027] In some embodiments, the processing circuit is configured to generate a second bid including the one or more second participation hours and the second load reduction amount for each of the one or more second participation hours, provide the second bid to the computing system configured to facilitate the ELDR program, and receive one or more second awarded or rejected hours from the computing system responsive to the second bid.

[0028] In some embodiments, the second bid is an update to the first bid, the one or more second participation hours are an update to the one or more first participation hours, and the second load reduction amount for each of the one or more second participation hours is an update to the first load reduction amount for each of the one or more first participation hours.

[0029] In some embodiments, the one or more awarded or rejected hours and the one or more second participation hours are hours of a particular day, wherein the processing circuit is configured to determine a revenue benefit for the particular day based on a benefit function and the one or more awarded or rejected hours and determine whether to participate in the ELDR program for the particular day based on a comparison of the revenue benefit to a predefined threshold.

[0030] In some embodiments, the processing circuit is configured to determine whether to participate in the ELDR program for the particular day based on the comparison of the revenue benefit to the predefined threshold by determining to participate in the ELDR program for the particular day in response to a determination that the revenue benefit is greater than the predefined threshold and determining not to participate in the ELDR program for the particular day in response to a determination that the revenue benefit is less than the predefined threshold.

[0031] In some embodiments, the processing circuit is configured to perform the optimization to generate the one or more first participation hours for participating in the ELDR program, the first load reduction amount for each of the one or more first participation hours, and the one or more first equipment loads for the one or more pieces of building equipment based on one or more ELDR parameters for the ELDR program.

[0032] In some embodiments, the one or more ELDR parameters include at least one of a day ahead locational marginal price which is an electricity price for a particular area on a future day, a real-time locational marginal price which is an electricity price at a current time, or a net benefits test which is a value indicating whether a particular hour should be a participation hour.

[0033] In some embodiments, the processing circuit is configured to periodically collect one or more ELDR parameters from the computing system configured to facilitate the ELDR program and generate the one or more second participation hours for participating in the ELDR program, the second load reduction amount for each of the one or more second participation hours, and the one or more second equipment loads for the one or more pieces of building equipment based on the one or more first awarded or rejected hours and the periodically collected ELDR parameters by performing the optimization the second time.

[0034] In some embodiments, the processing circuit is configured to generate one or more predictions of the one or more ELDR parameters based on the one or more ELDR parameters and generate the one or more second participation hours for participating in the ELDR program, the second load reduction amount for each of the one or more second participation hours, and the one or more second equipment loads for the one or more pieces of building equipment based on the one or more first awarded or rejected hours and the one or more predictions of the one or more ELDR parameters by performing the optimization the second time.

[0035] Another implementation of the present disclosure is a method for optimizing energy use of a building. The method includes performing an optimization to generate one or more first participation hours and a first load reduction amount for reach of the one or more first participation hours. The method includes providing a first bid including the one or more first participation hours and the first load reduction amount for each of the one or more first participation hours to a computing system configured to facilitate an economic load demand response (ELDR) program, operating one or more pieces of building equipment to affect an environmental condition of the building based on one or more first equipment loads for participating in the ELDR program, and receiving one or more awarded or rejected participation hours from the computing system in response to providing the first bid to the computing system. The method includes generating one or more second participation hours for participating in the ELDR program, a second load reduction amount for each of the one or more second participation hours, and one or more second equipment loads for the one or more pieces of building equipment based on the one or more awarded or rejected participation hours by performing the optimization a second time and operating the one or more pieces of building equipment to affect the environmental condition of the building based on the one or more second equipment loads.

[0036] In some embodiments, the method includes generating a predicted campus electric load based on at least one of historical campus electric load values, predicted market resource prices, predicted equipment loads, or predicted chilled water loads and generating the one or more second participation hours for participating in the ELDR program, the second load reduction amount for each of the one or more second participation hours, and the one or more second equipment loads for the one or more pieces of building equipment based on the one or more awarded or rejected participation hours and on the predicted campus electric load.

[0037] In some embodiments, the method includes generating a second bid including the one or more second participation hours and the second load reduction amount for each of the one or more second participation hours, providing the second bid to the computing system configured to facilitate the ELDR program, wherein the second bid is an update to the first bid, the one or more second participation hours are an update to the one or more first participation hours, and the second load reduction amount for each of the one or more second participation hours is an update to the first load reduction amount for each of the one or more first participation hours and receiving one or more second awarded or rejected hours from the computing system in response to providing the second bid.

[0038] In some embodiments, the one or more awarded or rejected hours and the one or more second participation hours are hours of a particular day. In some embodiments, the method includes determining a revenue benefit for the particular day based on a benefit function and the one or more awarded or rejected hours and determining whether to participate in the ELDR program for the particular day based on a comparison of the revenue benefit to a predefined threshold.

[0039] In some embodiments, determining whether to participate in the ELDR program for the particular day based on a comparison of the revenue benefit to a predefined threshold includes determining to participate in the ELDR program for the particular day in response to a determination that the revenue benefit is greater than the predefined threshold and determining not to participate in the ELDR program for the particular day in response to a determination that the revenue benefit is less than the predefined threshold.

[0040] In some embodiments, the method includes performing the optimization to generate the one or more first participation hours for participating in the ELDR program, the first load reduction amount for each of the one or more first participation hours, and the one or more first equipment loads for the one or more pieces of building equipment is based on one or more ELDR parameters for the ELDR program.

[0041] In some embodiments, the method includes periodically collecting the one or more ELDR parameters from the computing system configured to facilitate the ELDR program, generating one or more predictions of the one or more ELDR parameters based on the one or more ELDR parameters, and generating the one or more second participation hours for participating in the ELDR program, the second load reduction amount for each of the one or more second participation hours, and the one or more second equipment loads for the one or more pieces of building equipment based on the one or more first awarded or rejected hours and the one or more predictions of the one or more ELDR parameters by performing the optimization the second time.

[0042] Another implementation of the present disclosure is an energy optimization controller for a building. The controller includes a processing circuit configured to perform an optimization to generate one or more first participation hours and a first load reduction amount for each of the one or more first participation hours and provide a first bid

including the one or more first participation hours and the first load reduction amount for each of the one or more first participation hours to a computing system configured to facilitate an economic load demand response (ELDR) program. The processing circuit is configured to operate the one or more pieces of building equipment to affect an environmental condition of the building based on one or more first equipment loads for participating in the ELDR program, receive one or more awarded or rejected participation hours from the computing system, periodically collect one or more ELDR parameters from the computing system configured to facilitate the ELDR program, generate one or more predictions of the one or more ELDR parameters based on the one or more ELDR parameters, generate one or more second participation hours for participating in the ELDR program, a second load reduction amount for each of the one or more second participation hours, and one or more second equipment loads for the one or more pieces of building equipment based on the one or more awarded or rejected participation hours and the predicted one or more ELDR parameters, and operate the one or more pieces of building equipment to affect the environmental condition of the building based on the one or more second equipment loads.

[0043] In some embodiments, the one or more awarded or rejected hours and the one or more participation hours are hours of a particular day, wherein the processing circuit is configured to determine a revenue benefit for the particular day based on a benefit function and the one or more awarded or rejected hours and determine whether to participate in the ELDR program for the particular day based on a comparison of the revenue benefit to a predefined threshold.

[0044] In some embodiments, the processing circuit is configured to determine whether to participate in the ELDR program for the particular day based on a comparison of the revenue benefit to a predefined threshold by determining to participate in the ELDR program for the particular day in response to a determination that the revenue benefit is greater than the predefined threshold and determining not to participate in the ELDR program for the particular day in response to a determination that the revenue benefit is less than the predefined threshold.

[0045] Another implementation of the present disclosure is an energy optimization system for a building. The system includes a processing circuit configured to perform an optimization to generate one or more first participation hours and a first load reduction amount for each of the one or more first participation hours and generate a user interface including an indication of one or more economic load demand response (ELDR) operation parameters for an ELDR program, the one or more first participation hours, and the first load reduction amount for each of the one or more first participation hours. The processing circuit is configured to receive one or more overrides of the one or more first participation hours from the user interface, perform the optimization a second time to generate one or more second participation hours for participating in the ELDR program, a second load reduction amount for each of the one or more second participation hours, and one or more second equipment loads for the one or more pieces of building equipment based on the received one or more overrides, and operate the one or more pieces of building equipment to affect an environmental condition of the building based on the one or more second equipment loads.

[0046] In some embodiments, the processing circuit is configured to provide a first bid including the one or more first participation hours and the first load reduction amount for each of the one or more first participation hours to a computing system configured to facilitate the ELDR program and provide a second bid including the one or more second participation hours and the second load reduction amount for each of the one or more second participation hours to the computing system configured to facilitate the ELDR program, wherein the second bid is an update to the first bid, the one or more second participation hours are an update to the one or more first participation hours, and the second load reduction amount for each of the one or more second participation hours is an update to the first load reduction amount for each of the one or more first participation hours.

[0047] In some embodiments, the user interface includes a first interface element indicating values for the one or more ELDR parameters and a second interface element indicating the one or more first participation hours and the first load reduction amount for each of the one or more first participation hours.

[0048] In some embodiments, the second interface element is a chart indicating a plurality of hours for a plurality of days and an indication of which of the plurality of hours for the plurality of days are the first participation hours and the first load reduction amount for each of the one or more first participation hours.

[0049] In some embodiments, the processing circuit is configured to display a locked indication for each of the one or more first participation hours a predefined amount of time before each of the one or more participation hours occurs and prevent a user from overriding each of the one or more first participation hours within the predefined amount of time before each of the one or more first participation hours.

[0050] In some embodiments, the first interface element is a trend graph indicating a trend of the values for the one or more ELDR parameters for a plurality of times. In some embodiments, the processing circuit is configured to collect the values for the one or more ELDR operation parameters from a computing system configured to facilitate the ELDR program, generate the trend graph based on the collected values for the one or more ELDR operation parameters, and cause the user interface to include the generated trend graph.

[0051] In some embodiments, the one or more ELDR parameters include at least one of a day ahead locational marginal price which is an electricity price for a particular area on a future day, or a real-time locational marginal price which is an electricity price on at a current time.

[0052] In some embodiments, the processing circuit is configured to receive one or more electric consumption values from building equipment configured to measure the electrical consumption values, cause the trend graph to include a trend of the one or more electric consumption values, generate a baseline electrical load based on historic electric load consumption, and cause the trend graph to include an indication of the baseline electrical load.

[0053] Another implementation of the present disclosure is a method for optimizing energy use of a building. The method includes performing an optimization to generate one or more first participation hours and a first load reduction amount for each of the one or more first participation hours. The method includes generating a user interface including an indication of one or more economic load demand

response (ELDR) operation parameters for an ELDR program, the one or more first participation hours, and the first load reduction amount for each of the one or more first participation hours, receiving one or more overrides of the one or more first participation hours from the user interface, performing the optimization a second time to generate one or more second participation hours for participating in the ELDR program, a second load reduction amount for each of the one or more second participation hours, and one or more second equipment loads for the one or more pieces of building equipment based on the received one or more overrides, and operating the one or more pieces of building equipment to affect an environmental condition of the building based on the one or more second equipment loads.

[0054] In some embodiments, the method includes providing a first bid including the one or more first participation hours and the first load reduction amount for each of the one or more first participation hours to a computing system configured to facilitate the ELDR program and providing a second bid including the one or more second participation hours and the second load reduction amount for each of the one or more second participation hours to the computing system configured to facilitate the ELDR program, wherein the second bid is an update to the first bid, the one or more second participation hours are an update to the one or more first participation hours, and the second load reduction amount for each of the one or more second participation hours is an update to the first load reduction amount for each of the one or more first participation hours.

[0055] In some embodiments, the user interface includes a first interface element indicating values for the one or more ELDR parameters and a second interface element indicating the one or more first participation hours and the first load reduction amount for each of the one or more first participation hours.

[0056] In some embodiments, the one or more ELDR parameters include one or more awarded or rejected hours of the one or more first participation hours. In some embodiments, the processing circuit is configured to cause the second interface element to display an indication of which of the one or more first participation hours are awarded hours or which of the one or more first participation hours are rejected hours.

[0057] In some embodiments, the second interface element is a chart indicating a hours for a plurality of days and an indication of which of the plurality of hours for the plurality of days are the first participation hours and the first load reduction amount for each of the one or more first participation hours.

[0058] In some embodiments, the method includes displaying a locked indication for each of the one or more first participation hours a predefined amount of time before each of the one or more participation hours occurs and preventing a user from overriding each of the one or more first participation hours within the predefined amount of time before each of the one or more first participation hours.

[0059] In some embodiments, the first interface element is a trend graph indicating a trend of the values for the one or more ELDR parameters for a multiple times. In some embodiments, the method further includes collecting the values for the one or more ELDR operation parameters from a computing system configured to facilitate the ELDR program, generating the trend graph based on the collected values for the one or more ELDR operation parameters, and causing the user interface to include the generated trend graph.

[0060] In some embodiments, the one or more ELDR parameters include at least one of a day ahead locational marginal price which is an electricity price for a particular area on a future day, or a real-time locational marginal price which is an electricity price on at a current time.

[0061] In some embodiments, the method includes receiving one or more electric consumption values from building equipment configured to measure the electrical consumption values, causing the trend graph to include a trend of the one or more electric consumption values, generating a baseline electrical load based on historic electric load consumption, and causing the trend graph to include an indication of the baseline electrical load.

[0062] Another implementation of the present disclosure is an energy optimization controller for a building. The controller includes a processing circuit configured to perform an optimization to generate one or more first participation hours and a first load reduction amount for each of the one or more first participation hours and generate a user interface including an indication of one or more economic load demand response (ELDR) operation parameters for an ELDR program, the one or more first participation hours, and the first load reduction amount for each of the one or more first participation hours, wherein the user interface includes a first interface element indicating values for the one or more ELDR parameters and a second interface element indicating the one or more first participation hours and the first load reduction amount for each of the one or more first participation hours, receive one or more overrides of the one or more first participation hours from the user interface, perform the optimization a second time to generate one or more second participation hours for participating in the ELDR program, a second load reduction amount for each of the one or more second participation hours, and one or more second equipment loads for the one or more pieces of building equipment based on the received one or more overrides, and operate the one or more pieces of building equipment to affect an environmental condition of the building based on the one or more second equipment loads.

[0063] In some embodiments, the processing circuit is configured to provide a first bid including the one or more first participation hours and the first load reduction amount for each of the one or more first participation hours to a computing system configured to facilitate the ELDR program and provide a second bid including the one or more second participation hours and the second load reduction amount for each of the one or more second participation hours to the computing system configured to facilitate the ELDR program, wherein the second bid is an update to the first bid, the one or more second participation hours are an update to the one or more first participation hours, and the second load reduction amount for each of the one or more second participation hours is an update to the first load reduction amount for each of the one or more first participation hours.

[0064] In some embodiments, the second interface element is a chart indicating a plurality of hours for a plurality of days and an indication of which of the plurality of hours for the plurality of days are the first participation hours and the first load reduction amount for each of the one or more first participation hours.

[0065] In some embodiments, the processing circuit is configured to display a locked indication for each of the one or more first participation hours a predefined amount of time before each of the one or more participation hours occurs and prevent a user from overriding each of the one or more first participation hours within the predefined amount of time before each of the one or more first participation hours.

BRIEF DESCRIPTION OF THE DRAWINGS

[0066] Various objects, aspects, features, and advantages of the disclosure will become more apparent and better understood by referring to the detailed description taken in conjunction with the accompanying drawings, in which like reference characters identify corresponding elements throughout. In the drawings, like reference numbers generally indicate identical, functionally similar, and/or structurally similar elements.

[0067] FIG. **1** is a block diagram of a frequency response optimization system, according to an exemplary embodiment.

[0068] FIG. **2** is a graph of a regulation signal which may be provided to the system of FIG. **1** and a frequency response signal which may be generated by the system of FIG. **1**, according to an exemplary embodiment.

[0069] FIG. **3** is a block diagram of a photovoltaic energy system configured to simultaneously perform both ramp rate control and frequency regulation while maintaining the state-of-charge of a battery within a desired range, according to an exemplary embodiment.

[0070] FIG. **4** is a drawing illustrating the electric supply to an energy grid and electric demand from the energy grid which must be balanced in order to maintain the grid frequency, according to an exemplary embodiment.

[0071] FIG. **5**A is a block diagram of an energy storage system including thermal energy storage and electrical energy storage, according to an exemplary embodiment.

[0072] FIG. **5**B is a block diagram of an energy cost optimization system without thermal or electrical energy storage, according to an exemplary embodiment.

[0073] FIG. **6**A is block diagram of an energy storage controller which may be used to operate the energy storage system of FIG. **5**A, according to an exemplary embodiment.

[0074] FIG. **6**B is a block diagram of a controller which may be used to operate the energy cost optimization system of FIG. **5**B, according to an exemplary embodiment.

[0075] FIG. **7** is a block diagram of a planning tool which can be used to determine the benefits of investing in a battery asset and calculate various financial metrics associated with the investment, according to an exemplary embodiment.

[0076] FIG. **8** is a drawing illustrating the operation of the planning tool of FIG. **7**, according to an exemplary embodiment.

[0077] FIG. **9** is a block diagram of a high level optimizer which can be implemented as a component of the controllers of FIGS. **6**A-**6**B or the planning tool of FIG. **7**, according to an exemplary embodiment.

[0078] FIG. **10** is a block diagram of a controller including components for participating in an economic load demand response (ELDR) program, according to an exemplary embodiment.

[0079] FIG. **11**A is a flow diagram of a process for determining participation hours in the ELDR program and sending a bid to an incentive program, according to an exemplary embodiment.

[0080] FIG. **11**B is a flow diagram of a process for generating and modifying a cost function to determine optimal electric loads for participation in an ELDR program that can be performed by the controller of FIG. **10**, according to an exemplary embodiment.

[0081] FIG. **12** is a graph illustrating electric load reduction for participation in an ELDR program, according to an exemplary embodiment.

[0082] FIG. **13** is a graph illustrating a same day customer baseline load (CBL) that can be determined by the controller of FIG. **10**, according to an exemplary embodiment.

[0083] FIG. **14** is a graph illustrating a symmetric additive adjustment (SAA) CBL that can be determined by the controller of FIG. **10**, according to an exemplary embodiment.

[0084] FIG. **15** is an interface for a user to adjust participation in an ELDR program, according to an exemplary embodiment.

[0085] FIG. **16** is an interface for a user to adjust participation in an ELDR program, the interface illustrating revenue generated by the ELDR program, according to an exemplary embodiment.

[0086] FIG. **17** is a block diagram of an ELDR module for participating in the ELDR program, according to an exemplary embodiment.

[0087] FIG. **18**A is a flow diagram of a process for dynamically and automatically participating in the ELDR program via the ELDR module of FIG. **17**, according to an exemplary embodiment.

[0088] FIG. **18**B is flow diagram of the process of FIG. **18**A, according to an exemplary embodiment.

[0089] FIG. **19** is a flow diagram of a process that can be performed by the ELDR module of FIG. **17** for determining whether to participate in the ELDR program in response to receiving rejected bids, according to an exemplary embodiment.

[0090] FIG. **20** is a timeline of collection events for collecting ELDR parameters by the ELDR module of FIG. **17** and dispatch events received by the ELDR module of FIG. **17**, according to an exemplary embodiment.

[0091] FIG. **21** is another chart illustrating the participation in the ELDR program when the first hours of the ELDR program participation bid are rejected, according to an exemplary embodiment.

[0092] FIG. **22** is yet another chart illustrating the participation in the ELDR program when the first hours of the ELDR program participation bid are rejected, according to an exemplary embodiment.

[0093] FIG. **23** is an interface that the ELDR module of FIG. **17** can generate for the ELDR program, according to an exemplary embodiment.

[0094] FIG. **24** is the interface of FIG. **23** illustrating various participation hours and participation amounts for multiple days into the future for participating in the ELDR program, according to an exemplary embodiment.

[0095] FIG. **25** is the interface of FIG. **23** illustrating overridden participation hours and past participation hours, according to an exemplary embodiment.

[0096] FIG. **26** is the interface of FIG. **23** illustrating a small number of participation hours and participation amounts for some days, according to an exemplary embodiment.

[0097] FIG. **27** is the interface of FIG. **23** illustrating a large number of participation hours and participation amounts for some days, according to an exemplary embodiment.

[0098] FIG. **28** is another interface that the ELDR module of FIG. **17** can generate for the ELDR program, according to an exemplary embodiment.

[0099] FIG. **29** is an example of selecting and overriding various hours in the interface of FIG. **28**, according to an exemplary embodiment.

[0100] FIG. **30** is the interface of FIG. **28** illustrating a plot of ELDR parameters and an indication of overridden participation hours.

[0101] FIG. **31** is the interface of FIG. **28** illustrating plots of a real-time locational marginal price (LMP) and a day ahead LMP, according to an exemplary embodiment.

DETAILED DESCRIPTION

Overview

[0102] Referring generally to the FIGURES, systems, methods, and devices, are shown for a building energy optimization system, the optimization system configured to participate in an economic load demand response (ELDR) program. As illustrated herein, a controller for a building is configured to facilitate the participation in the ELDR program. The controller can be configured to determine a plurality of participation hours that the controller determines the building should participate in the ELDR program. Based on the determined participation hours, the controller can be configured to dispatch a bid to an incentive program. The incentive program may be a program managed by a curtailment service provider (CSP). The CSP may act as a medium between customers and the RTO and/or ISO. The CSP, RTO, and/or ISO may be one or more systems, servers, or computers that manage and/or operate the ELDR program. The incentive program may award some and/or all hours of the bid to the controller and transmit an indication of the awarded hours to the controller.

[0103] The controller can be configured to generate the participation hours based on values called "locational marginal prices" (LMPs). The LMPs may indicate a rate at which the controller will be compensated for curtailing an electric load of a building. The LMPs may be received by the controller. In various embodiments, the controller is configured to use the LMPs to determine which hours the controller should participate in the ELDR program. In some embodiments, based on LMP values received for past days, the controller can be configured to predict future LMP values and generate the participation hours based on the predicted LMP values.

[0104] The controller can be configured to determine optimal electric load based on the participation hours. HVAC equipment, lighting equipment, and/or any other electric consuming or producing equipment in a building can be operated to meet the electric load. In some embodiments, the controller is configured to generate a cost function which indicates the cost of operating HVAC equipment of a building over an optimization period (e.g., a single day). The participation hours may be hours during the optimization period i.e., particular hours of a day that the controller has determined it should participate in the ELDR program. The controller can be configured to optimize the cost function and determine a plurality of decision variables that indicate an electric load for the optimization period, including the participation hours.

[0105] Based on the optimal electric loads, the controller can be configured to determine a bid for particular participation hours of the optimization period. The bid may include hours that the controller has determined it should participate in the ELDR program and may further include a curtailment amount. The curtailment amount may be a difference between the buildings typical electric load (e.g., a baseline) and the optimal electric load determined by the controller. The typical electric load (e.g., baseline) may be determined based on a method specified by the RTO and/or ISO. The controller can be configured to receive awarded hours, one, some, or all of the hours included in the bid from the RTO and/or ISO. The controller can be configured to operate HVAC equipment of the building based on the awarded hours. The controller can be configured to operate the HVAC equipment so that the electric load of the building meets the optimal electric loads.

Frequency Response Optimization

[0106] Referring now to FIG. **1**, a frequency response optimization system **100** is shown, according to an exemplary embodiment. System **100** is shown to include a campus **102** and an energy grid **104**. Campus **102** may include one or more buildings **116** that receive power from energy grid **104**. Buildings **116** may include equipment or devices that consume electricity during operation. For example, buildings **116** may include HVAC equipment, lighting equipment, security equipment, communications equipment, vending machines, computers, electronics, elevators, or other types of building equipment.

[0107] In some embodiments, buildings **116** are served by a building management system (BMS). A BMS is, in general, a system of devices configured to control, monitor, and manage equipment in or around a building or building area. A BMS can include, for example, a HVAC system, a security system, a lighting system, a fire alerting system, and/or any other system that is capable of managing building functions or devices. An exemplary building management system which may be used to monitor and control buildings **116** is described in U.S. patent application Ser. No. 14/717,593 filed May 20, 2015, the entire disclosure of which is incorporated by reference herein.

[0108] In some embodiments, campus **102** includes a central plant **118**. Central plant **118** may include one or more subplants that consume resources from utilities (e.g., water, natural gas, electricity, etc.) to satisfy the loads of buildings **116**. For example, central plant **118** may include a heater subplant, a heat recovery chiller subplant, a chiller subplant, a cooling tower subplant, a hot thermal energy storage (TES) subplant, and a cold thermal energy storage (TES) subplant, a steam subplant, and/or any other type of subplant configured to serve buildings **116**. The subplants may be configured to convert input resources (e.g., electricity, water, natural gas, etc.) into output resources (e.g., cold water, hot water, chilled air, heated air, etc.) that are provided to buildings **116**. An exemplary central plant which may be used to satisfy the loads of buildings **116** is described U.S. patent application Ser. No. 14/634,609 filed Feb. 27, 2015, the entire disclosure of which is incorporated by reference herein.

[0109] In some embodiments, campus **102** includes energy generation **120**. Energy generation **120** may be configured to generate energy that can be used by buildings **116**, used by central plant **118**, and/or provided to energy grid **104**. In some embodiments, energy generation **120** generates electricity. For example, energy generation **120** may include an electric power plant, a photovoltaic energy field, or other types of systems or devices that generate electricity. The electricity generated by energy generation **120** can be used internally by campus **102** (e.g., by buildings **116** and/or central plant **118**) to decrease the amount of electric power that campus **102** receives from outside sources such as energy grid **104** or battery **108**. If the amount of electricity generated by energy generation **120** exceeds the electric power demand of campus **102**, the excess electric power can be provided to energy grid **104** or stored in battery **108**. The power output of campus **102** is shown in FIG. **1** as P_{campus}. P_{campus} may be positive if campus **102** is outputting electric power or negative if campus **102** is receiving electric power.

[0110] Still referring to FIG. **1**, system **100** is shown to include a power inverter **106** and a battery **108**. Power inverter **106** may be configured to convert electric power between direct current (DC) and alternating current (AC). For example, battery **108** may be configured to store and output DC power, whereas energy grid **104** and campus **102** may be configured to consume and generate AC power. Power inverter **106** may be used to convert DC power from battery **108** into a sinusoidal AC output synchronized to the grid frequency of energy grid **104**. Power inverter **106** may also be used to convert AC power from campus **102** or energy grid **104** into DC power that can be stored in battery **108**. The power output of battery **108** is shown as P_{bat}. P_{bat} may be positive if battery **108** is providing power to power inverter **106** or negative if battery **108** is receiving power from power inverter **106**.

[0111] In some embodiments, power inverter **106** receives a DC power output from battery **108** and converts the DC power output to an AC power output. The AC power output can be used to satisfy the energy load of campus **102** and/or can be provided to energy grid **104**. Power inverter **106** may synchronize the frequency of the AC power output with that of energy grid **104** (e.g., 50 Hz or 60 Hz) using a local oscillator and may limit the voltage of the AC power output to no higher than the grid voltage. In some embodiments, power inverter **106** is a resonant inverter that includes or uses LC circuits to remove the harmonics from a simple square wave in order to achieve a sine wave matching the frequency of energy grid **104**. In various embodiments, power inverter **106** may operate using high-frequency transformers, low-frequency transformers, or without transformers. Low-frequency transformers may convert the DC output from battery **108** directly to the AC output provided to energy grid **104**. High-frequency transformers may employ a multi-step process that involves converting the DC output to high-frequency AC, then back to DC, and then finally to the AC output provided to energy grid **104**.

[0112] System **100** is shown to include a point of interconnection (POI) **110**. POI **110** is the point at which campus **102**, energy grid **104**, and power inverter **106** are electrically connected. The power supplied to POI **110** from power inverter **106** is shown as P_{sup}. P_{sup} may be defined as $P_{bat}+P_{loss}$, where P_{batt} is the battery power and P_{loss} is the power loss in the battery system (e.g., losses in power inverter **106** and/or battery **108**). P_{bat} and P_{sup} may be positive if power inverter **106** is providing power to POI **110** or negative if power inverter **106** is receiving power from POI **110**. P_{campus} and P_{sup} combine at POI **110** to form P_{POI}. P_{POI} may be defined as the power provided to energy grid **104** from POI **110**. P_{POI} may be positive if POI **110** is providing power to energy grid **104** or negative if POI **110** is receiving power from energy grid **104**.

[0113] Still referring to FIG. **1**, system **100** is shown to include a frequency response controller **112**. Controller **112** may be configured to generate and provide power setpoints to power inverter **106**. Power inverter **106** may use the power setpoints to control the amount of power P_{sup} provided to POI **110** or drawn from POI **110**. For example, power inverter **106** may be configured to draw power from POI **110** and store the power in battery **108** in response to receiving a negative power setpoint from controller **112**. Conversely, power inverter **106** may be configured to draw power from battery **108** and provide the power to POI **110** in response to receiving a positive power setpoint from controller **112**. The magnitude of the power setpoint may define the amount of power P_{sup} provided to or from power inverter **106**. Controller **112** may be configured to generate and provide power setpoints that optimize the value of operating system **100** over a time horizon.

[0114] In some embodiments, frequency response controller **112** uses power inverter **106** and battery **108** to perform frequency regulation for energy grid **104**. Frequency regulation is the process of maintaining the stability of the grid frequency (e.g., 60 Hz in the United States). The grid frequency may remain stable and balanced as long as the total electric supply and demand of energy grid **104** are balanced. Any deviation from that balance may result in a deviation of the grid frequency from its desirable value. For example, an increase in demand may cause the grid frequency to decrease, whereas an increase in supply may cause the grid frequency to increase. Frequency response controller **112** may be configured to offset a fluctuation in the grid frequency by causing power inverter **106** to supply energy from battery **108** to energy grid **104** (e.g., to offset a decrease in grid frequency) or store energy from energy grid **104** in battery **108** (e.g., to offset an increase in grid frequency).

[0115] In some embodiments, frequency response controller **112** uses power inverter **106** and battery **108** to perform load shifting for campus **102**. For example, controller **112** may cause power inverter **106** to store energy in battery **108** when energy prices are low and retrieve energy from battery **108** when energy prices are high in order to reduce the cost of electricity required to power campus **102**. Load shifting may also allow system **100** reduce the demand charge incurred. Demand charge is an additional charge imposed by some utility providers based on the maximum power consumption during an applicable demand charge period. For example, a demand charge rate may be specified in terms of dollars per unit of power (e.g., $/kW) and may be multiplied by the peak power usage (e.g., kW) during a demand charge period to calculate the demand charge. Load shifting may allow system **100** to smooth momentary spikes in the electric demand of campus **102** by drawing energy from battery **108** in order to reduce peak power draw from energy grid **104**, thereby decreasing the demand charge incurred.

[0116] Still referring to FIG. **1**, system **100** is shown to include an incentive provider **114**. Incentive provider **114**

may be a utility (e.g., an electric utility), a regional transmission organization (RTO), an independent system operator (ISO), or any other entity that provides incentives for performing frequency regulation. For example, incentive provider **114** may provide system **100** with monetary incentives for participating in a frequency response program. In order to participate in the frequency response program, system **100** may maintain a reserve capacity of stored energy (e.g., in battery **108**) that can be provided to energy grid **104**. System **100** may also maintain the capacity to draw energy from energy grid **104** and store the energy in battery **108**. Reserving both of these capacities may be accomplished by managing the state-of-charge of battery **108**.

[0117] Frequency response controller **112** may provide incentive provider **114** with a price bid and a capability bid. The price bid may include a price per unit power (e.g., $/MW) for reserving or storing power that allows system **100** to participate in a frequency response program offered by incentive provider **114**. The price per unit power bid by frequency response controller **112** is referred to herein as the "capability price." The price bid may also include a price for actual performance, referred to herein as the "performance price." The capability bid may define an amount of power (e.g., MW) that system **100** will reserve or store in battery **108** to perform frequency response, referred to herein as the "capability bid."

[0118] Incentive provider **114** may provide frequency response controller **112** with a capability clearing price CP_{cap}, a performance clearing price CP_{perf}, and a regulation award Reg_{award}, which correspond to the capability price, the performance price, and the capability bid, respectively. In some embodiments, CP_{cap}, CP_{perf}, and Reg_{award} are the same as the corresponding bids placed by controller **112**. In other embodiments, CP_{cap}, CP_{perf}, and Reg_{award} may not be the same as the bids placed by controller **112**. For example, CP_{cap}, CP_{perf}, and Reg_{award} may be generated by incentive provider **114** based on bids received from multiple participants in the frequency response program. Controller **112** may use CP_{cap}, CP_{perf}, and Reg_{award} to perform frequency regulation.

[0119] Frequency response controller **112** is shown receiving a regulation signal from incentive provider **114**. The regulation signal may specify a portion of the regulation award Reg_{award} that frequency response controller **112** is to add or remove from energy grid **104**. In some embodiments, the regulation signal is a normalized signal (e.g., between −1 and 1) specifying a proportion of Reg_{award}. Positive values of the regulation signal may indicate an amount of power to add to energy grid **104**, whereas negative values of the regulation signal may indicate an amount of power to remove from energy grid **104**.

[0120] Frequency response controller **112** may respond to the regulation signal by generating an optimal power setpoint for power inverter **106**. The optimal power setpoint may take into account both the potential revenue from participating in the frequency response program and the costs of participation. Costs of participation may include, for example, a monetized cost of battery degradation as well as the energy and demand charges that will be incurred. The optimization may be performed using sequential quadratic programming, dynamic programming, or any other optimization technique.

[0121] In some embodiments, controller **112** uses a battery life model to quantify and monetize battery degradation as a function of the power setpoints provided to power inverter **106**. Advantageously, the battery life model allows controller **112** to perform an optimization that weighs the revenue generation potential of participating in the frequency response program against the cost of battery degradation and other costs of participation (e.g., less battery power available for campus **102**, increased electricity costs, etc.). An exemplary regulation signal and power response are described in greater detail with reference to FIG. **2**.

[0122] Referring now to FIG. **2**, a pair of frequency response graphs **200** and **250** are shown, according to an exemplary embodiment. Graph **200** illustrates a regulation signal Reg_{signal} **202** as a function of time. Reg_{signal} **202** is shown as a normalized signal ranging from −1 to 1 (i.e., $-1 \leq Reg_{signal} \leq 1$). Reg_{signal} **202** may be generated by incentive provider **114** and provided to frequency response controller **112**. Reg_{signal} **202** may define a proportion of the regulation award Reg_{award} **254** that controller **112** is to add or remove from energy grid **104**, relative to a baseline value referred to as the midpoint b **256**. For example, if the value of Reg_{award} **254** is 10 MW, a regulation signal value of 0.5 (i.e., $Reg_{signal}=0.5$) may indicate that system **100** is requested to add 5 MW of power at POI **110** relative to midpoint b (e.g., $P^*_{POI}=10MW\times0.5+b$), whereas a regulation signal value of −0.3 may indicate that system **100** is requested to remove 3 MW of power from POI **110** relative to midpoint b (e.g., $P^*_{POI}=10MW\times-0.3+b$).

[0123] Graph **250** illustrates the desired interconnection power P^*_{POI} **252** as a function of time. P^*_{POI} **252** may be calculated by frequency response controller **112** based on Reg_{signal} **202**, Reg_{award} **254**, and a midpoint b **256**. For example, controller **112** may calculate P^*_{POI} **252** using the following equation:

$$P^*_{POI}=Reg_{award}\times Reg_{signal}+b$$

where P^*_{POI} represents the desired power at POI **110** (e.g., $P^*_{POI}=P_{sup}+P_{campus}$) and b is the midpoint. Midpoint b may be defined (e.g., set or optimized) by controller **112** and may represent the midpoint of regulation around which the load is modified in response to Reg_{signal} **202**. Optimal adjustment of midpoint b may allow controller **112** to actively participate in the frequency response market while also taking into account the energy and demand charge that will be incurred.

[0124] In order to participate in the frequency response market, controller **112** may perform several tasks. Controller **112** may generate a price bid (e.g., S/MW) that includes the capability price and the performance price. In some embodiments, controller **112** sends the price bid to incentive provider **114** at approximately 15:30 each day and the price bid remains in effect for the entirety of the next day. Prior to beginning a frequency response period, controller **112** may generate the capability bid (e.g., MW) and send the capability bid to incentive provider **114**. In some embodiments, controller **112** generates and sends the capability bid to incentive provider **114** approximately 1.5 hours before a frequency response period begins. In an exemplary embodiment, each frequency response period has a duration of one hour; however, it is contemplated that frequency response periods may have any duration.

[0125] At the start of each frequency response period, controller **112** may generate the midpoint b around which controller **112** plans to perform frequency regulation. In some embodiments, controller **112** generates a midpoint b that will maintain battery **108** at a constant state of charge

(SOC) (i.e. a midpoint that will result in battery **108** having the same SOC at the beginning and end of the frequency response period). In other embodiments, controller **112** generates midpoint b using an optimization procedure that allows the SOC of battery **108** to have different values at the beginning and end of the frequency response period. For example, controller **112** may use the SOC of battery **108** as a constrained variable that depends on midpoint b in order to optimize a value function that takes into account frequency response revenue, energy costs, and the cost of battery degradation. Exemplary techniques for calculating and/or optimizing midpoint b under both the constant SOC scenario and the variable SOC scenario are described in detail in U.S. patent application Ser. No. 15/247,883 filed Aug. 25, 2016, U.S. patent application Ser. No. 15/247,885 filed Aug. 25, 2016, and U.S. patent application Ser. No. 15/247,886 filed Aug. 25, 2016. The entire disclosure of each of these patent applications is incorporated by reference herein.

[0126] During each frequency response period, controller **112** may periodically generate a power setpoint for power inverter **106**. For example, controller **112** may generate a power setpoint for each time step in the frequency response period. In some embodiments, controller **112** generates the power setpoints using the equation:

$$P^*_{POI}=\text{Reg}_{award}\times\text{Reg}_{signal}+b$$

where $P^*_{POI}=P_{sup}+P_{campus}$. Positive values of P^*_{POI} indicate energy flow from POI **110** to energy grid **104**. Positive values of P_{sup} and P_{campus} indicate energy flow to POI **110** from power inverter **106** and campus **102**, respectively.

[0127] In other embodiments, controller **112** generates the power setpoints using the equation:

$$P^*_{POI}=\text{Reg}_{award}\times\text{Res}_{FR}+b$$

where Res_{FR} is an optimal frequency response generated by optimizing a value function. Controller **112** may subtract P_{campus} from P^*_{POI} to generate the power setpoint for power inverter **106** (i.e., $P_{sup}=P^*_{POI}-P_{campus}$). The power setpoint for power inverter **106** indicates the amount of power that power inverter **106** is to add to POI **110** (if the power setpoint is positive) or remove from POI **110** (if the power setpoint is negative). Exemplary techniques which can be used by controller **112** to calculate power inverter setpoints are described in detail in U.S. patent application Ser. No. 15/247,793 filed Aug. 25, 2016, U.S. patent application Ser. No. 15/247,784 filed Aug. 25, 2016, and U.S. patent application Ser. No. 15/247,777 filed Aug. 25, 2016. The entire disclosure of each of these patent applications is incorporated by reference herein.

Photovoltaic Energy System with Frequency Regulation and Ramp Rate Control

[0128] Referring now to FIGS. **3-4**, a photovoltaic energy system **300** that uses battery storage to simultaneously perform both ramp rate control and frequency regulation is shown, according to an exemplary embodiment. Ramp rate control is the process of offsetting ramp rates (i.e., increases or decreases in the power output of an energy system such as a photovoltaic energy system) that fall outside of compliance limits determined by the electric power authority overseeing the energy grid. Ramp rate control typically requires the use of an energy source that allows for offsetting ramp rates by either supplying additional power to the grid or consuming more power from the grid. In some instances, a facility is penalized for failing to comply with ramp rate requirements.

[0129] Frequency regulation is the process of maintaining the stability of the grid frequency (e.g., 60 Hz in the United States). As shown in FIG. **4**, the grid frequency may remain balanced at 60 Hz as long as there is a balance between the demand from the energy grid and the supply to the energy grid. An increase in demand yields a decrease in grid frequency, whereas an increase in supply yields an increase in grid frequency. During a fluctuation of the grid frequency, system **300** may offset the fluctuation by either drawing more energy from the energy grid (e.g., if the grid frequency is too high) or by providing energy to the energy grid (e.g., if the grid frequency is too low). Advantageously, system **300** may use battery storage in combination with photovoltaic power to perform frequency regulation while simultaneously complying with ramp rate requirements and maintaining the state-of-charge of the battery storage within a predetermined desirable range.

[0130] Referring particularly to FIG. **3**, system **300** is shown to include a photovoltaic (PV) field **302**, a PV field power inverter **304**, a battery **306**, a battery power inverter **308**, a point of interconnection (POI) **310**, and an energy grid **312**. PV field **302** may include a collection of photovoltaic cells. The photovoltaic cells are configured to convert solar energy (i.e., sunlight) into electricity using a photovoltaic material such as monocrystalline silicon, polycrystalline silicon, amorphous silicon, cadmium telluride, copper indium gallium selenide/sulfide, or other materials that exhibit the photovoltaic effect. In some embodiments, the photovoltaic cells are contained within packaged assemblies that form solar panels. Each solar panel may include a plurality of linked photovoltaic cells. The solar panels may combine to form a photovoltaic array.

[0131] PV field **302** may have any of a variety of sizes and/or locations. In some embodiments, PV field **302** is part of a large-scale photovoltaic power station (e.g., a solar park or farm) capable of providing an energy supply to a large number of consumers. When implemented as part of a large-scale system, PV field **302** may cover multiple hectares and may have power outputs of tens or hundreds of megawatts. In other embodiments, PV field **302** may cover a smaller area and may have a relatively lesser power output (e.g., between one and ten megawatts, less than one megawatt, etc.). For example, PV field **302** may be part of a rooftop-mounted system capable of providing enough electricity to power a single home or building. It is contemplated that PV field **302** may have any size, scale, and/or power output, as may be desirable in different implementations.

[0132] PV field **302** may generate a direct current (DC) output that depends on the intensity and/or directness of the sunlight to which the solar panels are exposed. The directness of the sunlight may depend on the angle of incidence of the sunlight relative to the surfaces of the solar panels. The intensity of the sunlight may be affected by a variety of environmental factors such as the time of day (e.g., sunrises and sunsets) and weather variables such as clouds that cast shadows upon PV field **302**. When PV field **302** is partially or completely covered by shadow, the power output of PV field **302** (i.e., PV field power P_{PV}) may drop as a result of the decrease in solar intensity.

[0133] In some embodiments, PV field **302** is configured to maximize solar energy collection. For example, PV field

302 may include a solar tracker (e.g., a GPS tracker, a sunlight sensor, etc.) that adjusts the angle of the solar panels so that the solar panels are aimed directly at the sun throughout the day. The solar tracker may allow the solar panels to receive direct sunlight for a greater portion of the day and may increase the total amount of power produced by PV field 302. In some embodiments, PV field 302 includes a collection of mirrors, lenses, or solar concentrators configured to direct and/or concentrate sunlight on the solar panels. The energy generated by PV field 302 may be stored in battery 306 or provided to energy grid 312.

[0134] Still referring to FIG. 3, system 300 is shown to include a PV field power inverter 304. Power inverter 304 may be configured to convert the DC output of PV field 302 P_{PV} into an alternating current (AC) output that can be fed into energy grid 312 or used by a local (e.g., off-grid) electrical network. For example, power inverter 304 may be a solar inverter or grid-tie inverter configured to convert the DC output from PV field 302 into a sinusoidal AC output synchronized to the grid frequency of energy grid 312. In some embodiments, power inverter 304 receives a cumulative DC output from PV field 302. For example, power inverter 304 may be a string inverter or a central inverter. In other embodiments, power inverter 304 may include a collection of micro-inverters connected to each solar panel or solar cell. PV field power inverter 304 may convert the DC power output P_{PV} into an AC power output u_{PV} and provide the AC power output u_{PV} to POI 310.

[0135] Power inverter 304 may receive the DC power output P_{PV} from PV field 302 and convert the DC power output to an AC power output that can be fed into energy grid 312. Power inverter 304 may synchronize the frequency of the AC power output with that of energy grid 312 (e.g., 50 Hz or 60 Hz) using a local oscillator and may limit the voltage of the AC power output to no higher than the grid voltage. In some embodiments, power inverter 304 is a resonant inverter that includes or uses LC circuits to remove the harmonics from a simple square wave in order to achieve a sine wave matching the frequency of energy grid 312. In various embodiments, power inverter 304 may operate using high-frequency transformers, low-frequency transformers, or without transformers. Low-frequency transformers may convert the DC output from PV field 302 directly to the AC output provided to energy grid 312. High-frequency transformers may employ a multi-step process that involves converting the DC output to high-frequency AC, then back to DC, and then finally to the AC output provided to energy grid 312.

[0136] Power inverter 304 may be configured to perform maximum power point tracking and/or anti-islanding. Maximum power point tracking may allow power inverter 304 to produce the maximum possible AC power from PV field 302. For example, power inverter 304 may sample the DC power output from PV field 302 and apply a variable resistance to find the optimum maximum power point. Anti-islanding is a protection mechanism that immediately shuts down power inverter 304 (i.e., preventing power inverter 304 from generating AC power) when the connection to an electricity-consuming load no longer exists. In some embodiments, PV field power inverter 304 performs ramp rate control by limiting the power generated by PV field 302.

[0137] Still referring to FIG. 3, system 300 is shown to include a battery power inverter 308. Battery power inverter 308 may be configured to draw a DC power P_{bat} from battery 306, convert the DC power P_{bat} into an AC power u_{bat}, and provide the AC power u_{bat} to POI 310. Battery power inverter 308 may also be configured to draw the AC power u_{bat} from POI 310, convert the AC power u_{bat} into a DC battery power P_{bat}, and store the DC battery power P_{bat} in battery 306. The DC battery power P_{bat} may be positive if battery 306 is providing power to battery power inverter 308 (i.e., if battery 306 is discharging) or negative if battery 306 is receiving power from battery power inverter 308 (i.e., if battery 306 is charging). Similarly, the AC battery power u_{bat} may be positive if battery power inverter 308 is providing power to POI 310 or negative if battery power inverter 308 is receiving power from POI 310.

[0138] The AC battery power u_{bat} is shown to include an amount of power used for frequency regulation (i.e., u_{FR}) and an amount of power used for ramp rate control (i.e., u_{RR}) which together form the AC battery power (i.e., $u_{bat}=u_{FR}+u_{RR}$). The DC battery power P_{bat} is shown to include both u_{FR} and u_{RR} as well as an additional term P_{loss} representing power losses in battery 306 and/or battery power inverter 308 (i.e., $P_{bat}=u_{FR}+u_{RR}+P_{loss}$). The PV field power u_{PV} and the battery power u_{bat} combine at POI 110 to form P_{POI} (i.e., $P_{POI}=u_{PV}+u_{bat}$), which represents the amount of power provided to energy grid 312. P_{POI} may be positive if POI 310 is providing power to energy grid 312 or negative if POI 310 is receiving power from energy grid 312.

[0139] Still referring to FIG. 3, system 300 is shown to include a controller 314. Controller 314 may be configured to generate a PV power setpoint u_{PV} for PV field power inverter 304 and a battery power setpoint u_{bat} for battery power inverter 308. Throughout this disclosure, the variable u_{PV} is used to refer to both the PV power setpoint generated by controller 314 and the AC power output of PV field power inverter 304 since both quantities have the same value. Similarly, the variable u_{bat} is used to refer to both the battery power setpoint generated by controller 314 and the AC power output/input of battery power inverter 308 since both quantities have the same value.

[0140] PV field power inverter 304 uses the PV power setpoint u_{PV} to control an amount of the PV field power P_{PV} to provide to POI 110. The magnitude of u_{PV} may be the same as the magnitude of P_{PV} or less than the magnitude of P_{PV}. For example, u_{PV} may be the same as P_{PV} if controller 314 determines that PV field power inverter 304 is to provide all of the photovoltaic power P_{PV} to POI 310. However, u_{PV} may be less than P_{PV} if controller 314 determines that PV field power inverter 304 is to provide less than all of the photovoltaic power P_{PV} to POI 310. For example, controller 314 may determine that it is desirable for PV field power inverter 304 to provide less than all of the photovoltaic power P_{PV} to POI 310 to prevent the ramp rate from being exceeded and/or to prevent the power at POI 310 from exceeding a power limit.

[0141] Battery power inverter 308 uses the battery power setpoint u_{bat} to control an amount of power charged or discharged by battery 306. The battery power setpoint u_{bat} may be positive if controller 314 determines that battery power inverter 308 is to draw power from battery 306 or negative if controller 314 determines that battery power inverter 308 is to store power in battery 306. The magnitude of u_{bat} controls the rate at which energy is charged or discharged by battery 306.

[0142] Controller **314** may generate u_{PV} and u_{bat} based on a variety of different variables including, for example, a power signal from PV field **302** (e.g., current and previous values for P_{PV}), the current state-of-charge (SOC) of battery **306**, a maximum battery power limit, a maximum power limit at POI **310**, the ramp rate limit, the grid frequency of energy grid **312**, and/or other variables that can be used by controller **314** to perform ramp rate control and/or frequency regulation. Advantageously, controller **314** generates values for u_{PV} and u_{bat} that maintain the ramp rate of the PV power within the ramp rate compliance limit while participating in the regulation of grid frequency and maintaining the SOC of battery **306** within a predetermined desirable range.

[0143] An exemplary controller which can be used as controller **314** and exemplary processes which may be performed by controller **314** to generate the PV power setpoint u_{PV} and the battery power setpoint u_{bat} are described in detail in U.S. patent application Ser. No. 15/247,869 filed Aug. 25, 2016, U.S. patent application Ser. No. 15/247,844 filed Aug. 25, 2016, U.S. patent application Ser. No. 15/247,788 filed Aug. 25, 2016, U.S. patent application Ser. No. 15/247,872 filed Aug. 25, 2016, U.S. patent application Ser. No. 15/247,880 filed Aug. 25, 2016, and U.S. patent application Ser. No. 15/247,873 filed Aug. 25, 2016. The entire disclosure of each of these patent applications is incorporated by reference herein.

Energy Storage System with Thermal and Electrical Energy Storage

[0144] Referring now to FIG. **5**A, a block diagram of an energy storage system **500** is shown, according to an exemplary embodiment. Energy storage system **500** is shown to include a building **502**. Building **502** may be the same or similar to buildings **116**, as described with reference to FIG. **1**. For example, building **502** may be equipped with a HVAC system and/or a building management system that operates to control conditions within building **502**. In some embodiments, building **502** includes multiple buildings (i.e., a campus) served by energy storage system **500**. Building **502** may demand various resources including, for example, hot thermal energy (e.g., hot water), cold thermal energy (e.g., cold water), and/or electrical energy. The resources may be demanded by equipment or subsystems within building **502** or by external systems that provide services for building **502** (e.g., heating, cooling, air circulation, lighting, electricity, etc.). Energy storage system **500** operates to satisfy the resource demand associated with building **502**.

[0145] Energy storage system **500** is shown to include a plurality of utilities **510**. Utilities **510** may provide energy storage system **500** with resources such as electricity, water, natural gas, or any other resource that can be used by energy storage system **500** to satisfy the demand of building **502**. For example, utilities **510** are shown to include an electric utility **511**, a water utility **512**, a natural gas utility **513**, and utility M **514**, where M is the total number of utilities **510**. In some embodiments, utilities **510** are commodity suppliers from which resources and other types of commodities can be purchased. Resources purchased from utilities **510** can be used by generator subplants **520** to produce generated resources (e.g., hot water, cold water, electricity, steam, etc.), stored in storage subplants **530** for later use, or provided directly to building **502**. For example, utilities **510** are shown providing electricity directly to building **502** and storage subplants **530**.

[0146] Energy storage system **500** is shown to include a plurality of generator subplants **520**. In some embodiments, generator subplants **520** are components of a central plant (e.g., central plant **118**). Generator subplants **520** are shown to include a heater subplant **521**, a chiller subplant **522**, a heat recovery chiller subplant **523**, a steam subplant **524**, an electricity subplant **525**, and subplant N, where N is the total number of generator subplants **520**. Generator subplants **520** may be configured to convert one or more input resources into one or more output resources by operation of the equipment within generator subplants **520**. For example, heater subplant **521** may be configured to generate hot thermal energy (e.g., hot water) by heating water using electricity or natural gas. Chiller subplant **522** may be configured to generate cold thermal energy (e.g., cold water) by chilling water using electricity. Heat recovery chiller subplant **523** may be configured to generate hot thermal energy and cold thermal energy by removing heat from one water supply and adding the heat to another water supply. Steam subplant **524** may be configured to generate steam by boiling water using electricity or natural gas. Electricity subplant **525** may be configured to generate electricity using mechanical generators (e.g., a steam turbine, a gas-powered generator, etc.) or other types of electricity-generating equipment (e.g., photovoltaic equipment, hydroelectric equipment, etc.).

[0147] The input resources used by generator subplants **520** may be provided by utilities **510**, retrieved from storage subplants **530**, and/or generated by other generator subplants **520**. For example, steam subplant **524** may produce steam as an output resource. Electricity subplant **525** may include a steam turbine that uses the steam generated by steam subplant **524** as an input resource to generate electricity. The output resources produced by generator subplants **520** may be stored in storage subplants **530**, provided to building **502**, sold to energy purchasers **504**, and/or used by other generator subplants **520**. For example, the electricity generated by electricity subplant **525** may be stored in electrical energy storage **533**, used by chiller subplant **522** to generate cold thermal energy, provided to building **502**, and/or sold to energy purchasers **504**.

[0148] Energy storage system **500** is shown to include storage subplants **530**. In some embodiments, storage subplants **530** are components of a central plant (e.g., central plant **118**). Storage subplants **530** may be configured to store energy and other types of resources for later use. Each of storage subplants **530** may be configured to store a different type of resource. For example, storage subplants **530** are shown to include hot thermal energy storage **531** (e.g., one or more hot water storage tanks), cold thermal energy storage **532** (e.g., one or more cold thermal energy storage tanks), electrical energy storage **533** (e.g., one or more batteries), and resource type P storage **534**, where P is the total number of storage subplants **530**. The resources stored in subplants **530** may be purchased directly from utilities **510** or generated by generator subplants **520**.

[0149] In some embodiments, storage subplants **530** are used by energy storage system **500** to take advantage of price-based demand response (PBDR) programs. PBDR programs encourage consumers to reduce consumption when generation, transmission, and distribution costs are high. PBDR programs are typically implemented (e.g., by utilities **510**) in the form of energy prices that vary as a function of time. For example, utilities **510** may increase the

price per unit of electricity during peak usage hours to encourage customers to reduce electricity consumption during peak times. Some utilities also charge consumers a separate demand charge based on the maximum rate of electricity consumption at any time during a predetermined demand charge period.

[0150] Advantageously, storing energy and other types of resources in subplants **530** allows for the resources to be purchased at times when the resources are relatively less expensive (e.g., during non-peak electricity hours) and stored for use at times when the resources are relatively more expensive (e.g., during peak electricity hours). Storing resources in subplants **530** also allows the resource demand of building **502** to be shifted in time. For example, resources can be purchased from utilities **510** at times when the demand for heating or cooling is low and immediately converted into hot or cold thermal energy by generator subplants **520**. The thermal energy can be stored in storage subplants **530** and retrieved at times when the demand for heating or cooling is high. This allows energy storage system **500** to smooth the resource demand of building **502** and reduces the maximum required capacity of generator subplants **520**. Smoothing the demand also allows energy storage system **500** to reduce the peak electricity consumption, which results in a lower demand charge.

[0151] In some embodiments, storage subplants **530** are used by energy storage system **500** to take advantage of incentive-based demand response (IBDR) programs. IBDR programs provide incentives to customers who have the capability to store energy, generate energy, or curtail energy usage upon request. Incentives are typically provided in the form of monetary revenue paid by utilities **510** or by an independent service operator (ISO). IBDR programs supplement traditional utility-owned generation, transmission, and distribution assets with additional options for modifying demand load curves. For example, stored energy can be sold to energy purchasers **504** (e.g., an energy grid) to supplement the energy generated by utilities **510**. In some instances, incentives for participating in an IBDR program vary based on how quickly a system can respond to a request to change power output/consumption. Faster responses may be compensated at a higher level. Advantageously, electrical energy storage **533** allows system **500** to quickly respond to a request for electric power by rapidly discharging stored electrical energy to energy purchasers **504**.

[0152] Still referring to FIG. **5**A, energy storage system **500** is shown to include an energy storage controller **506**. Energy storage controller **506** may be configured to control the distribution, production, storage, and usage of resources in energy storage system **500**. In some embodiments, energy storage controller **506** performs an optimization process determine an optimal set of control decisions for each time step within an optimization period. The control decisions may include, for example, an optimal amount of each resource to purchase from utilities **510**, an optimal amount of each resource to produce or convert using generator subplants **520**, an optimal amount of each resource to store or remove from storage subplants **530**, an optimal amount of each resource to sell to energy purchasers **504**, and/or an optimal amount of each resource to provide to building **502**. In some embodiments, the control decisions include an optimal amount of each input resource and output resource for each of generator subplants **520**.

[0153] Controller **506** may be configured to maximize the economic value of operating energy storage system **500** over the duration of the optimization period. The economic value may be defined by a value function that expresses economic value as a function of the control decisions made by controller **506**. The value function may account for the cost of resources purchased from utilities **510**, revenue generated by selling resources to energy purchasers **504**, and the cost of operating energy storage system **500**. In some embodiments, the cost of operating energy storage system **500** includes a cost for losses in battery capacity as a result of the charging and discharging electrical energy storage **533**. The cost of operating energy storage system **500** may also include a cost of excessive equipment start/stops during the optimization period.

[0154] Each of subplants **520-530** may include equipment that can be controlled by energy storage controller **506** to optimize the performance of energy storage system **500**. Subplant equipment may include, for example, heating devices, chillers, heat recovery heat exchangers, cooling towers, energy storage devices, pumps, valves, and/or other devices of subplants **520-530**. Individual devices of generator subplants **520** can be turned on or off to adjust the resource production of each generator subplant. In some embodiments, individual devices of generator subplants **520** can be operated at variable capacities (e.g., operating a chiller at 10% capacity or 60% capacity) according to an operating setpoint received from energy storage controller **506**.

[0155] In some embodiments, one or more of subplants **520-530** includes a subplant level controller configured to control the equipment of the corresponding subplant. For example, energy storage controller **506** may determine an on/off configuration and global operating setpoints for the subplant equipment. In response to the on/off configuration and received global operating setpoints, the subplant controllers may turn individual devices of their respective equipment on or off, and implement specific operating setpoints (e.g., damper position, vane position, fan speed, pump speed, etc.) to reach or maintain the global operating setpoints.

[0156] In some embodiments, controller **506** maximizes the life cycle economic value of energy storage system **500** while participating in PBDR programs, IBDR programs, or simultaneously in both PBDR and IBDR programs. For the IBDR programs, controller **506** may use statistical estimates of past clearing prices, mileage ratios, and event probabilities to determine the revenue generation potential of selling stored energy to energy purchasers **504**. For the PBDR programs, controller **506** may use predictions of ambient conditions, facility thermal loads, and thermodynamic models of installed equipment to estimate the resource consumption of subplants **520**. Controller **506** may use predictions of the resource consumption to monetize the costs of running the equipment.

[0157] Controller **506** may automatically determine (e.g., without human intervention) a combination of PBDR and/or IBDR programs in which to participate over the optimization period in order to maximize economic value. For example, controller **506** may consider the revenue generation potential of IBDR programs, the cost reduction potential of PBDR programs, and the equipment maintenance/replacement costs that would result from participating in various combinations of the IBDR programs and PBDR

programs. Controller **506** may weigh the benefits of participation against the costs of participation to determine an optimal combination of programs in which to participate. Advantageously, this allows controller **506** to determine an optimal set of control decisions that maximize the overall value of operating energy storage system **500**.

[0158] In some instances, controller **506** may determine that it would be beneficial to participate in an IBDR program when the revenue generation potential is high and/or the costs of participating are low. For example, controller **506** may receive notice of a synchronous reserve event from an IBDR program which requires energy storage system **500** to shed a predetermined amount of power. Controller **506** may determine that it is optimal to participate in the IBDR program if cold thermal energy storage **532** has enough capacity to provide cooling for building **502** while the load on chiller subplant **522** is reduced in order to shed the predetermined amount of power.

[0159] In other instances, controller **506** may determine that it would not be beneficial to participate in an IBDR program when the resources required to participate are better allocated elsewhere. For example, if building **502** is close to setting a new peak demand that would greatly increase the PBDR costs, controller **506** may determine that only a small portion of the electrical energy stored in electrical energy storage **533** will be sold to energy purchasers **504** in order to participate in a frequency response market. Controller **506** may determine that the remainder of the electrical energy will be used to power chiller subplant **522** to prevent a new peak demand from being set.

[0160] In some embodiments, energy storage system **500** and controller include some or all of the components and/or features described in U.S. patent application Ser. No. 15/247,875 filed Aug. 25, 2016, U.S. patent application Ser. No. 15/247,879 filed Aug. 25, 2016, and U.S. patent application Ser. No. 15/247,881 filed Aug. 25, 2016. The entire disclosure of each of these patent applications is incorporated by reference herein.

Energy Cost Optimization System

[0161] Referring now to FIG. **5**B, a block diagram of an energy cost optimization system **550** is shown, according to an exemplary embodiment. Energy cost optimization system **550** is shown to include many of the same components as energy storage system **500** (described with reference to FIG. **5**A) with the exception of storage subplants **530**. System **550** is an example of a system without thermal or electrical energy storage in which the peak load contribution cost optimization techniques can be implemented.

[0162] Energy cost optimization system **550** is shown to include a building **502**. Building **502** may be the same or similar to buildings **116**, as described with reference to FIG. **1**. For example, building **502** may be equipped with a HVAC system and/or a building management system that operates to control conditions within building **502**. In some embodiments, building **502** includes multiple buildings (i.e., a campus) served by energy cost optimization system **550**. Building **502** may demand various resources including, for example, hot thermal energy (e.g., hot water), cold thermal energy (e.g., cold water), and/or electrical energy. The resources may be demanded by equipment or subsystems within building **502** or by external systems that provide services for building **502** (e.g., heating, cooling, air circulation, lighting, electricity, etc.). Energy cost optimization system **550** operates to satisfy the resource demand associated with building **502**.

[0163] Energy cost optimization system **550** is shown to include a plurality of utilities **510**. Utilities **510** may provide system **550** with resources such as electricity, water, natural gas, or any other resource that can be used by system **550** to satisfy the demand of building **502**. For example, utilities **510** are shown to include an electric utility **511**, a water utility **512**, a natural gas utility **513**, and utility M **514**, where M is the total number of utilities **510**. In some embodiments, utilities **510** are commodity suppliers from which resources and other types of commodities can be purchased. Resources purchased from utilities **510** can be used by generator subplants **520** to produce generated resources (e.g., hot water, cold water, electricity, steam, etc.) or provided directly to building **502**. For example, utilities **510** are shown providing electricity directly to building **502**.

[0164] Energy cost optimization system **550** is shown to include a plurality of generator subplants **520**. Generator subplants **520** are shown to include a heater subplant **521**, a chiller subplant **522**, a heat recovery chiller subplant **523**, a steam subplant **524**, an electricity subplant **525**, and subplant N, where N is the total number of generator subplants **520**. Generator subplants **520** may be configured to convert one or more input resources into one or more output resources by operation of the equipment within generator subplants **520**. For example, heater subplant **521** may be configured to generate hot thermal energy (e.g., hot water) by heating water using electricity or natural gas. Chiller subplant **522** may be configured to generate cold thermal energy (e.g., cold water) by chilling water using electricity. Heat recovery chiller subplant **523** may be configured to generate hot thermal energy and cold thermal energy by removing heat from one water supply and adding the heat to another water supply. Steam subplant **524** may be configured to generate steam by boiling water using electricity or natural gas. Electricity subplant **525** may be configured to generate electricity using mechanical generators (e.g., a steam turbine, a gas-powered generator, etc.) or other types of electricity-generating equipment (e.g., photovoltaic equipment, hydroelectric equipment, etc.).

[0165] The input resources used by generator subplants **520** may be provided by utilities **510** and/or generated by other generator subplants **520**. For example, steam subplant **524** may produce steam as an output resource. Electricity subplant **525** may include a steam turbine that uses the steam generated by steam subplant **524** as an input resource to generate electricity. The output resources produced by generator subplants **520** may be provided to building **502**, sold to energy purchasers **504**, and/or used by other generator subplants **520**. For example, the electricity generated by electricity subplant **525** may be used by chiller subplant **522** to generate cold thermal energy, provided to building **502**, and/or sold to energy purchasers **504**.

[0166] Still referring to FIG. **5**B, energy cost optimization system **550** is shown to include a controller **1000**. Controller **1000** may be configured to control the distribution, production, and usage of resources in system **550**. In some embodiments, controller **1000** performs an optimization process determine an optimal set of control decisions for each time step within an optimization period. The control decisions may include, for example, an optimal amount of each resource to purchase from utilities **510**, an optimal amount

of each resource to produce or convert using generator subplants **520**, an optimal amount of each resource to sell to energy purchasers **504**, and/or an optimal amount of each resource to provide to building **502**. In some embodiments, the control decisions include an optimal amount of each input resource and output resource for each of generator subplants **520**.

[0167] Controller **1000** may be configured to maximize the economic value of operating energy cost optimization system **550** over the duration of the optimization period. The economic value may be defined by a value function that expresses economic value as a function of the control decisions made by controller **1000**. The value function may account for the cost of resources purchased from utilities **510**, revenue generated by selling resources to energy purchasers **504**, and the cost of operating system **550**. In some embodiments, the cost of operating system **550** includes a cost of excessive equipment start/stops during the optimization period.

[0168] Each of subplants **520** may include equipment that can be controlled by controller **1000** to optimize the performance of system **550**. Subplant equipment may include, for example, heating devices, chillers, heat recovery heat exchangers, cooling towers, pumps, valves, and/or other devices of subplants **520**. Individual devices of generator subplants **520** can be turned on or off to adjust the resource production of each generator subplant. In some embodiments, individual devices of generator subplants **520** can be operated at variable capacities (e.g., operating a chiller at 10% capacity or 60% capacity) according to an operating setpoint received from controller **552**.

[0169] In some embodiments, one or more of subplants **520** includes a subplant level controller configured to control the equipment of the corresponding subplant. For example, controller **552** may determine an on/off configuration and global operating setpoints for the subplant equipment. In response to the on/off configuration and received global operating setpoints, the subplant controllers may turn individual devices of their respective equipment on or off, and implement specific operating setpoints (e.g., damper position, vane position, fan speed, pump speed, etc.) to reach or maintain the global operating setpoints.

[0170] In some embodiments, energy cost optimization system **550** and controller **552** include some or all of the components and/or features described in U.S. patent application Ser. No. 15/247,875 filed Aug. 25, 2016, U.S. patent application Ser. No. 15/247,879 filed Aug. 25, 2016, and U.S. patent application Ser. No. 15/247,881 filed Aug. 25, 2016. The entire disclosure of each of these patent applications is incorporated by reference herein.

Energy Storage Controller

[0171] Referring now to FIG. **6**A, a block diagram illustrating energy storage controller **506** in greater detail is shown, according to an exemplary embodiment. Energy storage controller **506** is shown providing control decisions to a building management system (BMS) **606**. In some embodiments, BMS **606** is the same or similar the BMS described with reference to FIG. **1**. The control decisions provided to BMS **606** may include resource purchase amounts for utilities **510**, setpoints for generator subplants **520**, and/or charge/discharge rates for storage subplants **530**.

[0172] BMS **606** may be configured to monitor conditions within a controlled building or building zone. For example, BMS **606** may receive input from various sensors (e.g., temperature sensors, humidity sensors, airflow sensors, voltage sensors, etc.) distributed throughout the building and may report building conditions to energy storage controller **506**. Building conditions may include, for example, a temperature of the building or a zone of the building, a power consumption (e.g., electric load) of the building, a state of one or more actuators configured to affect a controlled state within the building, or other types of information relating to the controlled building. BMS **606** may operate subplants **520-530** to affect the monitored conditions within the building and to serve the thermal energy loads of the building.

[0173] BMS **606** may receive control signals from energy storage controller **506** specifying on/off states, charge/discharge rates, and/or setpoints for the subplant equipment. BMS **606** may control the equipment (e.g., via actuators, power relays, etc.) in accordance with the control signals provided by energy storage controller **506**. For example, BMS **606** may operate the equipment using closed loop control to achieve the setpoints specified by energy storage controller **506**. In various embodiments, BMS **606** may be combined with energy storage controller **506** or may be part of a separate building management system. According to an exemplary embodiment, BMS **606** is a METASYS® brand building management system, as sold by Johnson Controls, Inc.

[0174] Energy storage controller **506** may monitor the status of the controlled building using information received from BMS **606**. Energy storage controller **506** may be configured to predict the thermal energy loads (e.g., heating loads, cooling loads, etc.) of the building for plurality of time steps in an optimization period (e.g., using weather forecasts from a weather service **604**). Energy storage controller **506** may also predict the revenue generation potential of IBDR programs using an incentive event history (e.g., past clearing prices, mileage ratios, event probabilities, etc.) from incentive programs **602**. Energy storage controller **506** may generate control decisions that optimize the economic value of operating energy storage system **500** over the duration of the optimization period subject to constraints on the optimization process (e.g., energy balance constraints, load satisfaction constraints, etc.). The optimization process performed by energy storage controller **506** is described in greater detail below.

[0175] According to an exemplary embodiment, energy storage controller **506** is integrated within a single computer (e.g., one server, one housing, etc.). In various other exemplary embodiments, energy storage controller **506** can be distributed across multiple servers or computers (e.g., that can exist in distributed locations). In another exemplary embodiment, energy storage controller **506** may be integrated with a smart building manager that manages multiple building systems and/or combined with BMS **606**.

[0176] Energy storage controller **506** is shown to include a communications interface **636** and a processing circuit **607**. Communications interface **636** may include wired or wireless interfaces (e.g., jacks, antennas, transmitters, receivers, transceivers, wire terminals, etc.) for conducting data communications with various systems, devices, or networks. For example, communications interface **636** may include an Ethernet card and port for sending and receiving data via an Ethernet-based communications network and/or a WiFi transceiver for communicating via a wireless communications network. Communications interface **636** may

be configured to communicate via local area networks or wide area networks (e.g., the Internet, a building WAN, etc.) and may use a variety of communications protocols (e.g., BACnet, IP, LON, etc.).

[0177] Communications interface **636** may be a network interface configured to facilitate electronic data communications between energy storage controller **506** and various external systems or devices (e.g., BMS **606**, subplants **520-530**, utilities **510**, etc.). For example, energy storage controller **506** may receive information from BMS **606** indicating one or more measured states of the controlled building (e.g., temperature, humidity, electric loads, etc.) and one or more states of subplants **520-530** (e.g., equipment status, power consumption, equipment availability, etc.). Communications interface **636** may receive inputs from BMS **606** and/or subplants **520-530** and may provide operating parameters (e.g., on/off decisions, setpoints, etc.) to subplants **520-530** via BMS **606**. The operating parameters may cause subplants **520-530** to activate, deactivate, or adjust a setpoint for various devices thereof.

[0178] Still referring to FIG. **6**A, processing circuit **607** is shown to include a processor **608** and memory **610**. Processor **608** may be a general purpose or specific purpose processor, an application specific integrated circuit (ASIC), one or more field programmable gate arrays (FPGAs), a group of processing components, or other suitable processing components. Processor **608** may be configured to execute computer code or instructions stored in memory **610** or received from other computer readable media (e.g., CDROM, network storage, a remote server, etc.).

[0179] Memory **610** may include one or more devices (e.g., memory units, memory devices, storage devices, etc.) for storing data and/or computer code for completing and/or facilitating the various processes described in the present disclosure. Memory **610** may include random access memory (RAM), read-only memory (ROM), hard drive storage, temporary storage, non-volatile memory, flash memory, optical memory, or any other suitable memory for storing software objects and/or computer instructions. Memory **610** may include database components, object code components, script components, or any other type of information structure for supporting the various activities and information structures described in the present disclosure. Memory **610** may be communicably connected to processor **608** via processing circuit **607** and may include computer code for executing (e.g., by processor **608**) one or more processes described herein.

[0180] Memory **610** is shown to include a building status monitor **624**. Energy storage controller **506** may receive data regarding the overall building or building space to be heated or cooled by system **500** via building status monitor **624**. In an exemplary embodiment, building status monitor **624** may include a graphical user interface component configured to provide graphical user interfaces to a user for selecting building requirements (e.g., overall temperature parameters, selecting schedules for the building, selecting different temperature levels for different building zones, etc.).

[0181] Energy storage controller **506** may determine on/off configurations and operating setpoints to satisfy the building requirements received from building status monitor **624**. In some embodiments, building status monitor **624** receives, collects, stores, and/or transmits cooling load requirements, building temperature setpoints, occupancy data, weather data, energy data, schedule data, and other building parameters. In some embodiments, building status monitor **624** stores data regarding energy costs, such as pricing information available from utilities **510** (energy charge, demand charge, etc.).

[0182] Still referring to FIG. **6**A, memory **610** is shown to include a load/rate predictor **622**. Load/rate predictor **622** may be configured to predict the thermal energy loads ($\hat{l}_k$) of the building or campus for each time step k (e.g., k=1 . . . n) of an optimization period. Load/rate predictor **622** is shown receiving weather forecasts from a weather service **604**. In some embodiments, load/rate predictor **622** predicts the thermal energy loads $\hat{l}_k$ as a function of the weather forecasts. In some embodiments, load/rate predictor **622** uses feedback from BMS **606** to predict loads $\hat{l}_k$. Feedback from BMS **606** may include various types of sensory inputs (e.g., temperature, flow, humidity, enthalpy, etc.) or other data relating to the controlled building (e.g., inputs from a HVAC system, a lighting control system, a security system, a water system, etc.).

[0183] In some embodiments, load/rate predictor **622** receives a measured electric load and/or previous measured load data from BMS **606** (e.g., via building status monitor **624**). Load/rate predictor **622** may predict loads $\hat{l}_k$ as a function of a given weather forecast ($\hat{\phi}_w$), a day type (day), the time of day (t), and previous measured load data (Y_{k-1}). Such a relationship is expressed in the following equation:

$$\hat{l}_k = f(\hat{\phi}_w, day, t | Y_{k-1})$$

[0184] In some embodiments, load/rate predictor **622** uses a deterministic plus stochastic model trained from historical load data to predict loads $\hat{l}_k$. Load/rate predictor **622** may use any of a variety of prediction methods to predict loads $\hat{l}_k$ (e.g., linear regression for the deterministic portion and an AR model for the stochastic portion). Load/rate predictor **622** may predict one or more different types of loads for the building or campus. For example, load/rate predictor **622** may predict a hot water load $\hat{l}_{Hot,k}$ and a cold water load $\hat{l}_{Cold,k}$ for each time step k within the prediction window. In some embodiments, load/rate predictor **622** makes load/rate predictions using the techniques described in U.S. patent application Ser. No. 14/717,593.

[0185] Load/rate predictor **622** is shown receiving utility rates from utilities **510**. Utility rates may indicate a cost or price per unit of a resource (e.g., electricity, natural gas, water, etc.) provided by utilities **510** at each time step k in the prediction window. In some embodiments, the utility rates are time-variable rates. For example, the price of electricity may be higher at certain times of day or days of the week (e.g., during high demand periods) and lower at other times of day or days of the week (e.g., during low demand periods). The utility rates may define various time periods and a cost per unit of a resource during each time period. Utility rates may be actual rates received from utilities **510** or predicted utility rates estimated by load/rate predictor **622**.

[0186] In some embodiments, the utility rates include demand charges for one or more resources provided by utilities **510**. A demand charge may define a separate cost imposed by utilities **510** based on the maximum usage of a particular resource (e.g., maximum energy consumption) during a demand charge period. The utility rates may define various demand charge periods and one or more demand charges associated with each demand charge period. In some instances, demand charge periods may overlap partially or

completely with each other and/or with the prediction window. Advantageously, demand response optimizer **630** may be configured to account for demand charges in the high level optimization process performed by high level optimizer **632**. Utilities **510** may be defined by time-variable (e.g., hourly) prices, a maximum service level (e.g., a maximum rate of consumption allowed by the physical infrastructure or by contract) and, in the case of electricity, a demand charge or a charge for the peak rate of consumption within a certain period. Load/rate predictor **622** may store the predicted loads $\hat{l}_k$ and the utility rates in memory **610** and/or provide the predicted loads $\hat{l}_k$ and the utility rates to demand response optimizer **630**.

[0187] Still referring to FIG. **6**A, memory **610** is shown to include an incentive estimator **620**. Incentive estimator **620** may be configured to estimate the revenue generation potential of participating in various incentive-based demand response (IBDR) programs. In some embodiments, incentive estimator **620** receives an incentive event history from incentive programs **602**. The incentive event history may include a history of past IBDR events from incentive programs **602**. An IBDR event may include an invitation from incentive programs **602** to participate in an IBDR program in exchange for a monetary incentive. The incentive event history may indicate the times at which the past IBDR events occurred and attributes describing the IBDR events (e.g., clearing prices, mileage ratios, participation requirements, etc.). Incentive estimator **620** may use the incentive event history to estimate IBDR event probabilities during the optimization period.

[0188] Incentive estimator **620** is shown providing incentive predictions to demand response optimizer **630**. The incentive predictions may include the estimated IBDR probabilities, estimated participation requirements, an estimated amount of revenue from participating in the estimated IBDR events, and/or any other attributes of the predicted IBDR events. Demand response optimizer **630** may use the incentive predictions along with the predicted loads $\hat{l}_k$ and utility rates from load/rate predictor **622** to determine an optimal set of control decisions for each time step within the optimization period.

[0189] Still referring to FIG. **6**A, memory **610** is shown to include a demand response optimizer **630**. Demand response optimizer **630** may perform a cascaded optimization process to optimize the performance of energy storage system **500**. For example, demand response optimizer **630** is shown to include a high level optimizer **632** and a low level optimizer **634**. High level optimizer **632** may control an outer (e.g., subplant level) loop of the cascaded optimization. High level optimizer **632** may determine an optimal set of control decisions for each time step in the prediction window in order to optimize (e.g., maximize) the value of operating energy storage system **500**. Control decisions made by high level optimizer **632** may include, for example, load setpoints for each of generator subplants **520**, charge/discharge rates for each of storage subplants **530**, resource purchase amounts for each type of resource purchased from utilities **510**, and/or an amount of each resource sold to energy purchasers **504**. In other words, the control decisions may define resource allocation at each time step. The control decisions made by high level optimizer **632** are based on the statistical estimates of incentive event probabilities and revenue generation potential for various IBDR events as well as the load and rate predictions.

[0190] Low level optimizer **634** may control an inner (e.g., equipment level) loop of the cascaded optimization. Low level optimizer **634** may determine how to best run each subplant at the load setpoint determined by high level optimizer **632**. For example, low level optimizer **634** may determine on/off states and/or operating setpoints for various devices of the subplant equipment in order to optimize (e.g., minimize) the energy consumption of each subplant while meeting the resource allocation setpoint for the subplant. In some embodiments, low level optimizer **634** receives actual incentive events from incentive programs **602**. Low level optimizer **634** may determine whether to participate in the incentive events based on the resource allocation set by high level optimizer **632**. For example, if insufficient resources have been allocated to a particular IBDR program by high level optimizer **632** or if the allocated resources have already been used, low level optimizer **634** may determine that energy storage system **500** will not participate in the IBDR program and may ignore the IBDR event. However, if the required resources have been allocated to the IBDR program and are available in storage subplants **530**, low level optimizer **634** may determine that system **500** will participate in the IBDR program in response to the IBDR event. The cascaded optimization process performed by demand response optimizer **630** is described in greater detail in U.S. patent application Ser. No. 15/247,885.

[0191] Still referring to FIG. **6**A, memory **610** is shown to include a subplant control module **628**. Subplant control module **628** may store historical data regarding past operating statuses, past operating setpoints, and instructions for calculating and/or implementing control parameters for subplants **520**-**530**. Subplant control module **628** may also receive, store, and/or transmit data regarding the conditions of individual devices of the subplant equipment, such as operating efficiency, equipment degradation, a date since last service, a lifespan parameter, a condition grade, or other device-specific data. Subplant control module **628** may receive data from subplants **520**-**530** and/or BMS **606** via communications interface **636**. Subplant control module **628** may also receive and store on/off statuses and operating setpoints from low level optimizer **634**.

[0192] Data and processing results from demand response optimizer **630**, subplant control module **628**, or other modules of energy storage controller **506** may be accessed by (or pushed to) monitoring and reporting applications **626**. Monitoring and reporting applications **626** may be configured to generate real time "system health" dashboards that can be viewed and navigated by a user (e.g., a system engineer). For example, monitoring and reporting applications **626** may include a web-based monitoring application with several graphical user interface (GUI) elements (e.g., widgets, dashboard controls, windows, etc.) for displaying key performance indicators (KPI) or other information to users of a GUI. In addition, the GUI elements may summarize relative energy use and intensity across energy storage systems in different buildings (real or modeled), different campuses, or the like. Other GUI elements or reports may be generated and shown based on available data that allow users to assess performance across one or more energy storage systems from one screen. The user interface or report (or underlying data engine) may be configured to aggregate and categorize operating conditions by building, building type, equipment type, and the like. The GUI elements may include charts or histograms that allow the user to visually analyze the

operating parameters and power consumption for the devices of the energy storage system.

[0193] Still referring to FIG. **6**A, energy storage controller **506** may include one or more GUI servers, web services **612**, or GUI engines **614** to support monitoring and reporting applications **626**. In various embodiments, applications **626**, web services **612**, and GUI engine **614** may be provided as separate components outside of energy storage controller **506** (e.g., as part of a smart building manager). Energy storage controller **506** may be configured to maintain detailed historical databases (e.g., relational databases, XML databases, etc.) of relevant data and includes computer code modules that continuously, frequently, or infrequently query, aggregate, transform, search, or otherwise process the data maintained in the detailed databases. Energy storage controller **506** may be configured to provide the results of any such processing to other databases, tables, XML files, or other data structures for further querying, calculation, or access by, for example, external monitoring and reporting applications.

[0194] Energy storage controller **506** is shown to include configuration tools **616**. Configuration tools **616** can allow a user to define (e.g., via graphical user interfaces, via prompt-driven "wizards," etc.) how energy storage controller **506** should react to changing conditions in the energy storage subsystems. In an exemplary embodiment, configuration tools **616** allow a user to build and store condition-response scenarios that can cross multiple energy storage system devices, multiple building systems, and multiple enterprise control applications (e.g., work order management system applications, entity resource planning applications, etc.). For example, configuration tools **616** can provide the user with the ability to combine data (e.g., from subsystems, from event histories) using a variety of conditional logic. In varying exemplary embodiments, the conditional logic can range from simple logical operators between conditions (e.g., AND, OR, XOR, etc.) to pseudo-code constructs or complex programming language functions (allowing for more complex interactions, conditional statements, loops, etc.). Configuration tools **616** can present user interfaces for building such conditional logic. The user interfaces may allow users to define policies and responses graphically. In some embodiments, the user interfaces may allow a user to select a pre-stored or pre-constructed policy and adapt it or enable it for use with their system.

Energy Cost Optimization Controller

[0195] Referring now to FIG. **6**B, a block diagram illustrating controller **552** in greater detail is shown, according to an exemplary embodiment. Controller **552** is shown providing control decisions to a building management system (BMS) **606**. In some embodiments, BMS **606** is the same or similar the BMS described with reference to FIG. **1**. The control decisions provided to BMS **606** may include resource purchase amounts for utilities **510** and/or setpoints for generator subplants **520**.

[0196] BMS **606** may be configured to monitor conditions within a controlled building or building zone. For example, BMS **606** may receive input from various sensors (e.g., temperature sensors, humidity sensors, airflow sensors, voltage sensors, etc.) distributed throughout the building and may report building conditions to controller **552**. Building conditions may include, for example, a temperature of the building or a zone of the building, a power consumption (e.g., electric load) of the building, a state of one or more actuators configured to affect a controlled state within the building, or other types of information relating to the controlled building. BMS **606** may operate subplants **520** to affect the monitored conditions within the building and to serve the thermal energy loads of the building.

[0197] BMS **606** may receive control signals from controller **552** specifying on/off states and/or setpoints for the subplant equipment. BMS **606** may control the equipment (e.g., via actuators, power relays, etc.) in accordance with the control signals provided by controller **552**. For example, BMS **606** may operate the equipment using closed loop control to achieve the setpoints specified by energy storage controller **552**. In various embodiments, BMS **606** may be combined with controller **552** or may be part of a separate building management system. According to an exemplary embodiment, BMS **606** is a METASYS® brand building management system, as sold by Johnson Controls, Inc.

[0198] Controller **552** may monitor the status of the controlled building using information received from BMS **606**. Controller **552** may be configured to predict the thermal energy loads (e.g., heating loads, cooling loads, etc.) of the building for plurality of time steps in an optimization period (e.g., using weather forecasts from a weather service **604**). Controller **552** may generate control decisions that optimize the economic value of operating system **550** over the duration of the optimization period subject to constraints on the optimization process (e.g., energy balance constraints, load satisfaction constraints, etc.). The optimization process performed by controller **552** is described in greater detail below.

[0199] Controller **552** is shown to include a communications interface **636** and a processing circuit **607** having a processor **608** and memory **610**. These components may be the same as described with reference to FIG. **6**A. For example, controller **552** is shown to include demand response optimizer **630**. Demand response optimizer **630** may perform a cascaded optimization process to optimize the performance of system **550**. For example, demand response optimizer **630** is shown to include a high level optimizer **632** and a low level optimizer **634**. High level optimizer **632** may control an outer (e.g., subplant level) loop of the cascaded optimization. High level optimizer **632** may determine an optimal set of control decisions for each time step in the prediction window in order to optimize (e.g., maximize) the value of operating energy storage system **500**. Control decisions made by high level optimizer **632** may include, for example, load setpoints for each of generator subplants **520**, resource purchase amounts for each type of resource purchased from utilities **510**, and/or an amount of each resource sold to energy purchasers **504**. In other words, the control decisions may define resource allocation at each time step.

[0200] Low level optimizer **634** may control an inner (e.g., equipment level) loop of the cascaded optimization. Low level optimizer **634** may determine how to best run each subplant at the load setpoint determined by high level optimizer **632**. For example, low level optimizer **634** may determine on/off states and/or operating setpoints for various devices of the subplant equipment in order to optimize (e.g., minimize) the energy consumption of each subplant while meeting the resource allocation setpoint for the subplant. The cascaded optimization process performed by demand response optimizer **630** is described in greater detail in U.S. patent application Ser. No. 15/247,885. These and other

components of controller **552** may be the same as previously described with reference to FIG. **6**A.

Planning Tool

[0201] Referring now to FIG. **7**, a block diagram of a planning system **700** is shown, according to an exemplary embodiment. Planning system **700** may be configured to use demand response optimizer **630** as part of a planning tool **702** to simulate the operation of a central plant over a predetermined time period (e.g., a day, a month, a week, a year, etc.) for planning, budgeting, and/or design considerations. When implemented in planning tool **702**, demand response optimizer **630** may operate in a similar manner as described with reference to FIGS. **6**A-**6**B. For example, demand response optimizer **630** may use building loads and utility rates to determine an optimal resource allocation to minimize cost over a simulation period. However, planning tool **702** may not be responsible for real-time control of a building management system or central plant.

[0202] Planning tool **702** can be configured to determine the benefits of investing in a battery asset and the financial metrics associated with the investment. Such financial metrics can include, for example, the internal rate of return (IRR), net present value (NPV), and/or simple payback period (SPP). Planning tool **702** can also assist a user in determining the size of the battery which yields optimal financial metrics such as maximum NPV or a minimum SPP. In some embodiments, planning tool **702** allows a user to specify a battery size and automatically determines the benefits of the battery asset from participating in selected IBDR programs while performing PBDR, as described with reference to FIG. **5**A. In some embodiments, planning tool **702** is configured to determine the battery size that minimizes SPP given the IBDR programs selected and the requirement of performing PBDR. In some embodiments, planning tool **702** is configured to determine the battery size that maximizes NPV given the IBDR programs selected and the requirement of performing PBDR.

[0203] In planning tool **702**, high level optimizer **632** may receive planned loads and utility rates for the entire simulation period. The planned loads and utility rates may be defined by input received from a user via a client device **722** (e.g., user-defined, user selected, etc.) and/or retrieved from a plan information database **726**. High level optimizer **632** uses the planned loads and utility rates in conjunction with subplant curves from low level optimizer **634** to determine an optimal resource allocation (i.e., an optimal dispatch schedule) for a portion of the simulation period.

[0204] The portion of the simulation period over which high level optimizer **632** optimizes the resource allocation may be defined by a prediction window ending at a time horizon. With each iteration of the optimization, the prediction window is shifted forward and the portion of the dispatch schedule no longer in the prediction window is accepted (e.g., stored or output as results of the simulation). Load and rate predictions may be predefined for the entire simulation and may not be subject to adjustments in each iteration. However, shifting the prediction window forward in time may introduce additional plan information (e.g., planned loads and/or utility rates) for the newly-added time slice at the end of the prediction window. The new plan information may not have a significant effect on the optimal dispatch schedule since only a small portion of the prediction window changes with each iteration.

[0205] In some embodiments, high level optimizer **632** requests all of the subplant curves used in the simulation from low level optimizer **634** at the beginning of the simulation. Since the planned loads and environmental conditions are known for the entire simulation period, high level optimizer **632** may retrieve all of the relevant subplant curves at the beginning of the simulation. In some embodiments, low level optimizer **634** generates functions that map subplant production to equipment level production and resource use when the subplant curves are provided to high level optimizer **632**. These subplant to equipment functions may be used to calculate the individual equipment production and resource use (e.g., in a post-processing module) based on the results of the simulation.

[0206] Still referring to FIG. **7**, planning tool **702** is shown to include a communications interface **704** and a processing circuit **706**. Communications interface **704** may include wired or wireless interfaces (e.g., jacks, antennas, transmitters, receivers, transceivers, wire terminals, etc.) for conducting data communications with various systems, devices, or networks. For example, communications interface **704** may include an Ethernet card and port for sending and receiving data via an Ethernet-based communications network and/or a WiFi transceiver for communicating via a wireless communications network. Communications interface **704** may be configured to communicate via local area networks or wide area networks (e.g., the Internet, a building WAN, etc.) and may use a variety of communications protocols (e.g., BACnet, IP, LON, etc.).

[0207] Communications interface **704** may be a network interface configured to facilitate electronic data communications between planning tool **702** and various external systems or devices (e.g., client device **722**, results database **728**, plan information database **726**, etc.). For example, planning tool **702** may receive planned loads and utility rates from client device **722** and/or plan information database **726** via communications interface **704**. Planning tool **702** may use communications interface **704** to output results of the simulation to client device **722** and/or to store the results in results database **728**.

[0208] Still referring to FIG. **7**, processing circuit **706** is shown to include a processor **710** and memory **712**. Processor **710** may be a general purpose or specific purpose processor, an application specific integrated circuit (ASIC), one or more field programmable gate arrays (FPGAs), a group of processing components, or other suitable processing components. Processor **710** may be configured to execute computer code or instructions stored in memory **712** or received from other computer readable media (e.g., CDROM, network storage, a remote server, etc.).

[0209] Memory **712** may include one or more devices (e.g., memory units, memory devices, storage devices, etc.) for storing data and/or computer code for completing and/or facilitating the various processes described in the present disclosure. Memory **712** may include random access memory (RAM), read-only memory (ROM), hard drive storage, temporary storage, non-volatile memory, flash memory, optical memory, or any other suitable memory for storing software objects and/or computer instructions. Memory **712** may include database components, object code components, script components, or any other type of information structure for supporting the various activities and information structures described in the present disclosure. Memory **712** may be communicably connected to processor

710 via processing circuit 706 and may include computer code for executing (e.g., by processor 710) one or more processes described herein.

[0210] Still referring to FIG. 7, memory 712 is shown to include a GUI engine 716, web services 714, and configuration tools 718. In an exemplary embodiment, GUI engine 716 includes a graphical user interface component configured to provide graphical user interfaces to a user for selecting or defining plan information for the simulation (e.g., planned loads, utility rates, environmental conditions, etc.). Web services 714 may allow a user to interact with planning tool 702 via a web portal and/or from a remote system or device (e.g., an enterprise control application).

[0211] Configuration tools 718 can allow a user to define (e.g., via graphical user interfaces, via prompt-driven "wizards," etc.) various parameters of the simulation such as the number and type of subplants, the devices within each subplant, the subplant curves, device-specific efficiency curves, the duration of the simulation, the duration of the prediction window, the duration of each time step, and/or various other types of plan information related to the simulation. Configuration tools 718 can present user interfaces for building the simulation. The user interfaces may allow users to define simulation parameters graphically. In some embodiments, the user interfaces allow a user to select a pre-stored or pre-constructed simulated plant and/or plan information (e.g., from plan information database 726) and adapt it or enable it for use in the simulation.

[0212] Still referring to FIG. 7, memory 712 is shown to include demand response optimizer 630. Demand response optimizer 630 may use the planned loads and utility rates to determine an optimal resource allocation over a prediction window. The operation of demand response optimizer 630 may be the same or similar as previously described with reference to FIGS. 6-8. With each iteration of the optimization process, demand response optimizer 630 may shift the prediction window forward and apply the optimal resource allocation for the portion of the simulation period no longer in the prediction window. Demand response optimizer 630 may use the new plan information at the end of the prediction window to perform the next iteration of the optimization process. Demand response optimizer 630 may output the applied resource allocation to reporting applications 730 for presentation to a client device 722 (e.g., via user interface 724) or storage in results database 728.

[0213] Still referring to FIG. 7, memory 712 is shown to include reporting applications 730. Reporting applications 730 may receive the optimized resource allocations from demand response optimizer 630 and, in some embodiments, costs associated with the optimized resource allocations. Reporting applications 730 may include a web-based reporting application with several graphical user interface (GUI) elements (e.g., widgets, dashboard controls, windows, etc.) for displaying key performance indicators (KPI) or other information to users of a GUI. In addition, the GUI elements may summarize relative energy use and intensity across various plants, subplants, or the like. Other GUI elements or reports may be generated and shown based on available data that allow users to assess the results of the simulation. The user interface or report (or underlying data engine) may be configured to aggregate and categorize resource allocation and the costs associated therewith and provide the results to a user via a GUI. The GUI elements may include charts or histograms that allow the user to visually analyze the results of the simulation. An exemplary output that may be generated by reporting applications 730 is shown in FIG. 8.

[0214] Referring now to FIG. 8, several graphs 800 illustrating the operation of planning tool 702 are shown, according to an exemplary embodiment. With each iteration of the optimization process, planning tool 702 selects an optimization period (i.e., a portion of the simulation period) over which the optimization is performed. For example, planning tool 702 may select optimization period 802 for use in the first iteration. Once the optimal resource allocation 810 has been determined, planning tool 702 may select a portion 818 of resource allocation 810 to send to plant dispatch 830. Portion 818 may be the first b time steps of resource allocation 810. Planning tool 702 may shift the optimization period 802 forward in time, resulting in optimization period 804. The amount by which the prediction window is shifted may correspond to the duration of time steps b.

[0215] Planning tool 702 may repeat the optimization process for optimization period 804 to determine the optimal resource allocation 812. Planning tool 702 may select a portion 820 of resource allocation 812 to send to plant dispatch 830. Portion 820 may be the first b time steps of resource allocation 812. Planning tool 702 may then shift the prediction window forward in time, resulting in optimization period 806. This process may be repeated for each subsequent optimization period (e.g., optimization periods 806, 808, etc.) to generate updated resource allocations (e.g., resource allocations 814, 816, etc.) and to select portions of each resource allocation (e.g., portions 822, 824) to send to plant dispatch 830. Plant dispatch 830 includes the first b time steps 818-824 from each of optimization periods 802-808. Once the optimal resource allocation is compiled for the entire simulation period, the results may be sent to reporting applications 730, results database 728, and/or client device 722, as described with reference to FIG. 7.

Resource Allocation Optimization

[0216] Referring now to FIG. 9, a block diagram illustrating high level optimizer 632 in greater detail is shown, according to an exemplary embodiment. In some embodiments, high level optimizer 632 may be implemented as a component of energy storage controller 506, as described with reference to FIGS. 5A and 6A. In other embodiments, high level optimizer 632 may be implemented as a component of controller 552, as described with reference to FIGS. 5B and 6B. In other embodiments, high level optimizer 632 may be implemented as a component of planning tool 702, as described with reference to FIGS. 7-8.

[0217] High level optimizer 632 may receive load and rate predictions from load/rate predictor 622, incentive predictions from incentive estimator 620, and subplant curves from low level optimizer 634. High level optimizer 632 may determine an optimal resource allocation across energy storage system 500 as a function of the load and rate predictions, the incentive predictions, and the subplant curves. The optimal resource allocation may include an amount of each resource purchased from utilities 510, an amount of each input and output resource of generator subplants 520, an amount of each resource stored or withdrawn from storage subplants 530, and/or an amount of each resource sold to energy purchasers 504. In some embodiments, the optimal resource allocation maximizes the economic value of operating energy storage system 500 while satisfying the predicted loads for the building or campus

[0218] High level optimizer **632** can be configured to optimize the utilization of a battery asset, such as battery **108**, battery **306**, and/or electrical energy storage subplant **533**. A battery asset can be used to participate in IBDR programs which yield revenue and to reduce the cost of energy and the cost incurred from peak load contribution charges. High level optimizer **632** can use an optimization algorithm to optimally allocate a battery asset (e.g., by optimally charging and discharging the battery) to maximize its total value. In a planning tool framework, high level optimizer **632** can perform the optimization iteratively to determine optimal battery asset allocation for an entire simulation period (e.g., an entire year), as described with reference to FIG. **8**. The optimization process can be expanded to include economic load demand response (ELDR) and can account for peak load contribution charges. High level optimizer **632** can allocate the battery asset at each time step (e.g., each hour) over a given horizon such that energy and demand costs are minimized and frequency regulation (FR) revenue maximized. These and other features of high level optimizer **632** are described in detail below.

Cost Function

[0219] Still referring to FIG. **9**, high level optimizer **632** is shown to include a cost function module **902**. Cost function module **902** can generate a cost function or objective function which represents the total operating cost of a system over a time horizon (e.g., one month, one year, one day, etc.). The system can include any of the systems previously described (e.g., frequency response optimization system **100**, photovoltaic energy system **300**, energy storage system **500**, planning system **700**, etc.) or any other system in which high level optimizer **632** is implemented. In some embodiments, the cost function can be expressed generically using the following equation:

$$\underset{x}{\operatorname{argmin}} J(x)$$

where J(x) is defined as follows:

$$J(x) = \sum_{sources} \sum_{horizon} \text{cost}(purchase_{resource,time}, \text{time}) - \sum_{incentives} \sum_{horizon} \text{revenue}(ReservationAmount)$$

[0220] The first term in the previous equation represents the total cost of all resources purchased over the optimization horizon. Resources can include, for example, water, electricity, natural gas, or other types of resources purchased from a utility or other outside entity. The second term in the equation represents the total revenue generated by participating in incentive programs (e.g., IBDR programs) over the optimization horizon. The revenue may be based on the amount of power reserved for participating in the incentive programs. Accordingly, the total cost function represents the total cost of resources purchased minus any revenue generated from participating in incentive programs.

[0221] High level optimizer **632** can optimize the cost function J(x) subject to the following constraint, which guarantees the balance between resources purchased, produced, discharged, consumed, and requested over the optimization horizon:

$$\sum_{sources} purchase_{resource,time} + \sum_{subplants} \text{produces}(x_{internal,time}, x_{external,time}, v_{uncontrolled,time}) - \sum_{subplants} \text{consumes}(x_{internal,time}, x_{external,time}, v_{uncontrolled,time}) + \sum_{storages} discharges_{resource}(x_{internal,time}, x_{external,time}) - \sum_{sinks} requests_{resource} = 0$$

$\forall$ resources, $\forall$ time $\in$ horizon

where $x_{internal,time}$ and $x_{external,time}$ are internal and external decision variables and $v_{uncontrolled,time}$ includes uncontrolled variables.

[0222] The first term in the previous equation represents the total amount of each resource (e.g., electricity, water, natural gas, etc.) purchased from each source (e.g., utilities **510**) over the optimization horizon. The second term represents the total consumption of each resource within the system (e.g., by generator subplants **520**) over the optimization horizon. The third term represents the total amount of each resource discharged from storage (e.g., storage subplants **530**) over the optimization horizon. Positive values indicate that the resource is discharged from storage, whereas negative values indicate that the resource is charged or stored. The fourth term represents the total amount of each resource requested by various resource sinks (e.g., building **502**, energy purchasers **504**, or other resource consumers) over the optimization horizon. Accordingly, this constraint ensures that the total amount of each resource purchased, produced, or discharged from storage is equal to the amount of each resource consumed, stored, or provided to the resource sinks.

[0223] In some embodiments, cost function module **902** separates the purchase cost of one or more resources into multiple terms. For example, cost function module **902** can separate the purchase cost of a resource into a first term corresponding to the cost per unit of the resource purchased (e.g., $/kWh of electricity, $/liter of water, etc.) and a second term corresponding to one or more demand charges. A demand charge is a separate charge on the consumption of a resource which depends on the maximum or peak resource consumption over a given period (i.e., a demand charge period). Cost function module **902** can express the cost function using the following equation:

$$J(x) = \sum_{sources} \left[\sum_{q \in demands_s} w_{demand,s,q} r_{demand,s,q} \max_{i \in demand_{s,q}} (purchase_{s,i}) + \sum_{horizon} r_{s,i} purchase_{s,i} \right] - \sum_{incentives} \sum_{horizon} \text{revenue}(ReservationAmount)$$

where $r_{demand,s,q}$ is the qth demand charge associated with the peak demand of the resource provided by source s over

the demand charge period, $w_{demand,s,q}$ is the weight adjustment of the qth demand charge associated with source s, and the max( ) term indicates the maximum amount of the resource purchased from source s at any time step i during the demand charge period. The variable $r_{s,i}$ indicates the cost per unit of the resource purchased from source s and the variable $purchase_{s,i}$ indicates the amount of the resource purchased from source s during the ith time step of the optimization period.

[0224] In some embodiments, the energy system in which high level optimizer **632** is implemented includes a battery asset (e.g., one or more batteries) configured to store and discharge electricity. If the battery asset is the only type of energy storage, cost function module **902** can simplify the cost function J(x) to the following equation:

$$J(x) = -\sum_{i=k}^{k+h-1} r_{e_i} P_{bat_i} - \sum_{i=k}^{k+h-1} r_{FR_i} P_{FR_i} + \sum_{i=k}^{k+h-1} r_{s_i} |P_{bat_i} - P_{bat_{i-1}}| + w_d r_d \max_i(-P_{bat_i} + eLoad_i)$$

where h is the duration of the optimization horizon, P_{bat_i} is the amount of power (e.g., kW) discharged from the battery asset during the ith time step of the optimization horizon for use in reducing the amount of power purchased from an electric utility, r_{e_i} is the price of electricity (e.g., $/kWh) at time step i, $P_{FR,i}$ is the battery power (e.g., kW) committed to frequency regulation participation during time step i, r_{FR_i} is the incentive rate (e.g., $/kWh) for participating in frequency regulation during time step i, r_d is the applicable demand charge (e.g., $/kWh) associated with the maximum electricity consumption during the corresponding demand charge period, w_d is a weight adjustment of the demand charge over the horizon, and the max( ) term selects the maximum amount electricity purchased from the electric utility (e.g., kW) during any time step i of the applicable demand charge period.

[0225] In the previous expression of the cost function J(x), the first term represents the cost savings resulting from the use of battery power to satisfy the electric demand of the facility relative to the cost which would have been incurred if the electricity were purchased from the electric utility. The second term represents the amount of revenue derived from participating in the frequency regulation program. The third term represents a switching penalty imposed for switching the battery power P_{bat} between consecutive time steps. The fourth term represents the demand charge associated with the maximum amount of electricity purchased from the electric utility. The amount of electricity purchased may be equal to the difference between the electric load of the facility $eLoad_i$ (i.e., the total amount of electricity required) at time step i and the amount of power discharged from the battery asset P_{bat_i} at time step i. In a planning tool framework, historical data of the electric load eLoad over the horizon can be provided as a known input. In an operational mode, the electric load eLoad can be predicted for each time step of the optimization period.

Optimization Constraints

[0226] Still referring to FIG. **9**, high level optimizer **632** is shown to include a power constraints module **904**. Power constraints module **904** may be configured to impose one or more power constraints on the objective function J(x). In some embodiments, power constraints module **904** generates and imposes the following constraints:

$$P_{bat_i} + P_{FR_i} \leq P_{eff}$$

$$-P_{bat_i} + P_{FR_i} \leq P_{eff}$$

$$P_{bat_i} + P_{FR_i} \leq eLoad_i$$

where P_{bat_i} is the amount of power discharged from the battery at time step i for use in satisfying electric demand and reducing the demand charge, P_{FR_i} is the amount of battery power committed to frequency regulation at time step i, P_{eff} is the effective power available (e.g., the maximum rate at which the battery can be charged or discharged), and $eLoad_i$ is the total electric demand at time step i.

[0227] The first two power constraints ensure that the battery is not charged or discharged at a rate that exceeds the maximum battery charge/discharge rate P_{eff}. If the system includes photovoltaic (PV) power generation, the effective power available P_{eff} can be calculated as follows:

$$P_{eff} = P_{rated} - P_{PV\ FirmingReserve}$$

where P_{rated} is the rated capacity of the battery and $P_{PV\ FirmingReserve}$ is the PV firming reserve power. The third power constraint ensures that energy stored in the battery is not sold or exported to the energy grid. In some embodiments, power constraints module **904** can remove the third power constraint if selling energy back to the energy grid is a desired feature or behavior of the system.

[0228] Still referring to FIG. **9**, high level optimizer **632** is shown to include a capacity constraints module **906**. Capacity constraints module **906** may be configured to impose one or more capacity constraints on the objective function J(x). The capacity constraints may be used to relate the battery power P_{bat} charged or discharged during each time step to the capacity and state-of-charge (SOC) of the battery. The capacity constraints may ensure that the SOC of the battery is maintained within acceptable lower and upper bounds and that sufficient battery capacity is available for frequency regulation. In some embodiments, the lower and upper bounds are based on the battery capacity needed to reserve the amount of power committed to frequency regulation P_{FR_i} during each time step i.

[0229] In some embodiments, capacity constraints module **906** generates two sets of capacity constraints. One set of capacity constraints may apply to the boundary condition at the end of each time step i, whereas the other set of capacity constraints may apply to the boundary condition at the beginning of the next time step i+1. For example, if a first amount of battery capacity is reserved for frequency regulation during time step i and a second amount of battery capacity is reserved for frequency regulation during time step i+1, the boundary point between time step i and i+1 may be required to satisfy the capacity constraints for both time step i and time step i+1. This ensures that the decisions made for the power committed to frequency regulation during the current time step i and the next time step i+1 represent a continuous change in the SOC of the battery.

[0230] In some embodiments, capacity constraints module **906** generates the following capacity constraints:

$$\begin{cases} C_a - \sum_{n=k}^{i} P_{bat_n} \le C_{eff} - C_{FR} P_{FR_i} \\ C_a - \sum_{n=k}^{i} P_{bat_n} \ge C_{FR} P_{FR_i} \end{cases} \quad \forall\, i = k \ \ldots\ k+h-1$$

$$\begin{cases} C_a - \sum_{n=k}^{i} P_{bat_n} \le C_{eff} - C_{FR} P_{FR_{i+1}} \\ C_a - \sum_{n=k}^{i} P_{bat_n} \ge C_{FR} P_{FR_{i+1}} \end{cases} \quad \forall\, i = k \ \ldots\ k+h-2$$

where C_a is the available battery capacity (e.g., kWh), C_{FR} is the frequency regulation reserve capacity (e.g., kWh/kW) which translates the amount of battery power committed to frequency regulation P_{FR} into an amount of energy needed to be reserved, and C_{eff} is the effective capacity of the battery.

[0231] The first set of constraints ensures that the battery capacity at the end of each time step i (i.e., available capacity C_a minus the battery power discharged through time step i) is maintained between the lower capacity bound $C_{FR}P_{FR_i}$ and the upper capacity bound $C_{eff}-C_{FR}P_{FR_i}$ for time step i. The lower capacity bound $C_{FR}P_{FR_i}$ represents the minimum capacity required to reserve P_{FR_i} for frequency regulation during time step i, whereas the upper capacity bound $C_{eff}-C_{FR}P_{FR_i}$ represents maximum capacity required to reserve P_{FR_i} for frequency regulation during time step i. Similarly, the second set of constraints ensures that the battery capacity at the end of each time step i (i.e., available capacity C_a minus the battery power discharged through time step i) is maintained between the lower capacity bound $C_{FR}P_{FR_{i+1}}$ and the upper capacity bound $C_{eff}-C_{FR}P_{FR_{i+1}}$ for time step i+1. The lower capacity bound $C_{FR}P_{FR_{i+1}}$ represents the minimum capacity required to reserve $P_{FR_{i+1}}$ for frequency regulation during time step i+1, whereas the upper capacity bound $C_{eff}-C_{FR}P_{FR_{i+1}}$ represents maximum capacity required to reserve $P_{FR_{i+1}}$ for frequency regulation during time step i+1.

[0232] In some embodiments, capacity constraints module **906** calculates the effective capacity of the battery C_{eff} as a percentage of the rated capacity of the battery. For example, if frequency regulation and photovoltaic power generation are both enabled and the SOC control margin is non-zero, capacity constraints module **906** can calculate the effective capacity of the battery C_{eff} using the following equation:

$$C_{eff}=(1-C_{FR}-2C_{socCM})C_{rated}-C_{PV\,FirmingReserve}$$

where C_{socCM} is the control margin and $C_{PV\,FirmingReserve}$ is the capacity reserved for photovoltaic firming.

[0233] Still referring to FIG. **9**, high level optimizer **632** is shown to include a switching constraints module **908**. Switching constraints module **908** may be configured to impose one or more switching constraints on the cost function J(x). As previously described, the cost function J(x) may include the following switching term:

$$\sum_{i=k}^{k+h-1} r_{s_i} |P_{bat_i} - P_{bat_{i-1}}|$$

which functions as a penalty for switching the battery power P_{bat} between consecutive time steps i and i−1. Notably, the switching term is nonlinear as a result of the absolute value function.

[0234] Switching constraints module **908** can impose constraints which represent the nonlinear switching term in a linear format. For example, switching constraints module **908** can introduce an auxiliary switching variable s_i and constrain the auxiliary switching variable to be greater than the difference between the battery power P_{bat_i} at time step i and the battery power $P_{bat_{i-1}}$ at time step i−1, as shown in the following equations:

$$\begin{aligned} s_i &> P_{bat_i} - P_{bat_{i-1}} \\ s_i &> P_{bat_{i-1}} - P_{bat_i} \end{aligned} \quad \forall\, i = k \ \ldots\ k+h-1$$

Switching constraints module **908** can replace the nonlinear switching term in the cost function J(x) with the following linearized term:

$$\sum_{i=k}^{k+h-1} r_{s_i} s_i$$

which can be optimized using any of a variety of linear optimization techniques (e.g., linear programming) subject to the constraints on the auxiliary switching variable s_i.

Demand Charge Incorporation

[0235] Still referring to FIG. **9**, high level optimizer **632** is shown to include a demand charge module **910**. Demand charge module **910** can be configured to modify the cost function J(x) and the optimization constraints to account for one or more demand charges. As previously described, demand charges are costs imposed by utilities **510** based on the peak consumption of a resource from utilities **510** during various demand charge periods (i.e., the peak amount of the resource purchased from the utility during any time step of the applicable demand charge period). For example, an electric utility may define one or more demand charge periods and may impose a separate demand charge based on the peak electric consumption during each demand charge period. Electric energy storage can help reduce peak consumption by storing electricity in a battery when energy consumption is low and discharging the stored electricity from the battery when energy consumption is high, thereby reducing peak electricity purchased from the utility during any time step of the demand charge period.

[0236] In some instances, one or more of the resources purchased from utilities **510** are subject to a demand charge or multiple demand charges. There are many types of potential demand charges as there are different types of energy rate structures. The most common energy rate structures are constant pricing, time of use (TOU), and real time pricing (RTP). Each demand charge may be associated with a demand charge period during which the demand charge is active. Demand charge periods can overlap partially or completely with each other and/or with the optimization period. Demand charge periods can include relatively long periods (e.g., monthly, seasonal, annual, etc.) or relatively short periods (e.g., days, hours, etc.). Each of these periods

OBM and Cholla Energy
Ex. 1038
Page 56 of 88

can be divided into several sub-periods including off-peak, partial-peak, and/or on-peak. Some demand charge periods are continuous (e.g., beginning Jan. 1, 2017 and ending Jan. 31, 2017), whereas other demand charge periods are non-continuous (e.g., from 11:00 AM-1:00 PM each day of the month).

[0237] Over a given optimization period, some demand charges may be active during some time steps that occur within the optimization period and inactive during other time steps that occur during the optimization period. Some demand charges may be active over all the time steps that occur within the optimization period. Some demand charges may apply to some time steps that occur during the optimization period and other time steps that occur outside the optimization period (e.g., before or after the optimization period). In some embodiments, the durations of the demand charge periods are significantly different from the duration of the optimization period.

[0238] Advantageously, demand charge module **910** may be configured to account for demand charges in the high level optimization process performed by high level optimizer **632**. In some embodiments, demand charge module **910** incorporates demand charges into the optimization problem and the cost function J(x) using demand charge masks and demand charge rate weighting factors. Each demand charge mask may correspond to a particular demand charge and may indicate the time steps during which the corresponding demand charge is active and/or the time steps during which the demand charge is inactive. Each rate weighting factor may also correspond to a particular demand charge and may scale the corresponding demand charge rate to the time scale of the optimization period.

[0239] As described above, the demand charge term of the cost function J(x) can be expressed as:

$$J(x) = \ldots \sum_{s \in sources} \sum_{q \in demands_s} w_{demand,s,q} r_{demand,s,q} \max_{i \in demand_{s,q}} (purchase_{s,i}) \ldots$$

where the max( ) function selects the maximum amount of the resource purchased from source s during any time step i that occurs during the optimization period. However, the demand charge period associated with demand charge q may not cover all of the time steps that occur during the optimization period. In order to apply the demand charge q to only the time steps during which the demand charge q is active, demand charge module **910** can add a demand charge mask to the demand charge term as shown in the following equation:

$$J(x) = \ldots \sum_{s \in sources} \sum_{q \in demands_s} w_{demand,s,q} r_{demand,s,q} \max_{i \in demand_{s,q}} (g_{s,q,i} purchase_{s,i}) \ldots$$

where $g_{s,q,i}$ is an element of the demand charge mask.

[0240] The demand charge mask may be a logical vector including an element $g_{s,q,i}$ for each time step i that occurs during the optimization period. Each element $g_{s,q,i}$ of the demand charge mask may include a binary value (e.g., a one or zero) that indicates whether the demand charge q for source s is active during the corresponding time step i of the optimization period. For example, the element $g_{s,q,i}$ may have a value of one (i.e., $g_{s,q,i}=1$) if demand charge q is active during time step i and a value of zero (i.e., $g_{s,q,i}=0$) if demand charge q is inactive during time step i. An example of a demand charge mask is shown in the following equation:

$$g_{s,q}=[0,0,0,1,1,1,1,0,0,0,1,1]^T$$

where $g_{s,q,1}$, $g_{s,q,2}$, $g_{s,q,3}$, $g_{s,q,8}$, $g_{s,q,9}$, and $g_{s,q,10}$ have values of zero, whereas $g_{s,q,4}$, $g_{s,q,5}$, $g_{s,q,6}$, $g_{s,q,7}$, $g_{s,q,11}$, and $g_{s,q,12}$ have values of one. This indicates that the demand charge q is inactive during time steps i=1, 2, 3, 8, 9, 10 (i.e., $g_{s,q,i}=0$ $\forall i=1, 2, 3, 8, 9, 10$) and active during time steps i=4, 5, 6, 7, 11, 12 (i.e., $g_{s,q,i}=1$ $\forall i=4, 5, 6, 7, 11, 12$). Accordingly, the term $g_{s,q,i}purchase_{s,i}$ within the max( ) function may have a value of zero for all time steps during which the demand charge q is inactive. This causes the max( ) function to select the maximum purchase from source s that occurs during only the time steps for which the demand charge q is active.

[0241] In some embodiments, demand charge module **910** calculates the weighting factor $W_{demand,s,q}$ for each demand charge q in the cost function J(x). The weighting factor $W_{demand,s,q}$ may be a ratio of the number of time steps the corresponding demand charge q is active during the optimization period to the number of time steps the corresponding demand charge q is active in the remaining demand charge period (if any) after the end of the optimization period. For example, demand charge module **910** can calculate the weighting factor $W_{demand,s,q}$ using the following equation:

$$w_{demand,s,q} = \frac{\sum_{i=k}^{k+h-1} g_{s,q,i}}{\sum_{i=k+h}^{period_end} g_{s,q,i}}$$

where the numerator is the summation of the number of time steps the demand charge q is active in the optimization period (i.e., from time step k to time step k+h−1) and the denominator is the number of time steps the demand charge q is active in the portion of the demand charge period that occurs after the optimization period (i.e., from time step k+h to the end of the demand charge period). The following example illustrates how demand charge module **910** can incorporate multiple demand charges into the cost function J(x). In this example, a single source of electricity (e.g., an electric grid) is considered with multiple demand charges applicable to the electricity source (i.e., q=1 . . . N, where N is the total number of demand charges). The system includes a battery asset which can be allocated over the optimization period by charging or discharging the battery during various time steps. Charging the battery increases the amount of electricity purchased from the electric grid, whereas discharging the battery decreases the amount of electricity purchased from the electric grid.

[0242] Demand charge module **910** can modify the cost function J(x) to account for the N demand charges as shown in the following equation:

$$J(x) = \ldots + w_{d_1} r_{d_1} \max_i (g_{1_i}(-P_{bat_i} + eLoad_i)) +$$

-continued

$$\ldots + w_{d_q} r_{d_q} \max_i (g_{q_i}(-P_{bat_i} + eLoad_i)) +$$

$$\ldots + w_{d_N} r_{d_N} \max_i (g_{N_i}(-P_{bat_i} + eLoad_i))$$

where the term $-P_{bat_i}+eLoad_i$ represents the total amount of electricity purchased from the electric grid during time step i (i.e., the total electric load $eLoad_i$ minus the power discharged from the battery P_{bat_i}). Each demand charge q=1 . . . N can be accounted for separately in the cost function J(x) by including a separate max( ) function for each of the N demand charges. The parameter r_{d_q} indicates the demand charge rate associated with the qth demand charge (e.g., \$/kW) and the weighting factor w_{d_q} indicates the weight applied to the qth demand charge.

[0243] Demand charge module **910** can augment each max( ) function with an element g_{q_i} of the demand charge mask for the corresponding demand charge. Each demand charge mask may be a logical vector of binary values which indicates whether the corresponding demand charge is active or inactive at each time step i of the optimization period. Accordingly, each max( ) function may select the maximum electricity purchase during only the time steps the corresponding demand charge is active. Each max( ) function can be multiplied by the corresponding demand charge rate r_{d_q} and the corresponding demand charge weighting factor w_{d_q} to determine the total demand charge resulting from the battery allocation P_{bat} over the duration of the optimization period.

[0244] In some embodiments, demand charge module **910** linearizes the demand charge terms of the cost function J(x) by introducing an auxiliary variable d_q for each demand charge q. In the case of the previous example, this will result in N auxiliary variables $d_1 \ldots d_N$ being introduced as decision variables in the cost function J(x). Demand charge module **910** can modify the cost function J(x) to include the linearized demand charge terms as shown in the following equation:

$$J(x) = \ldots + w_{d_1} r_{d_1} d_1 + \ldots + w_{d_q} r_{d_q} d_q + \ldots w_{d_N} r_{d_N} d_N$$

[0245] Demand charge module **910** can impose the following constraints on the auxiliary demand charge variables $d_1 \ldots d_N$ to ensure that each auxiliary demand charge variable represents the maximum amount of electricity purchased from the electric utility during the applicable demand charge period:

$$d_1 \geq g_{1_i}(-P_{bat_i} + eLoad_i) \quad \forall\, i = k \ldots k+h-1, \quad g_{1_i} \neq 0$$
$$d_1 \geq 0 \qquad \vdots$$
$$d_q \geq g_{q_i}(-P_{bat_i} + eLoud_i) \quad \forall\, i = k \ldots k+h-1, \quad g_{q_i} \neq 0$$
$$d_q \geq 0 \qquad \vdots$$
$$d_N \geq g_{N_i}(-P_{bat_i} + eLoud_i) \quad \forall\, i = k \ldots k+h-1, \quad g_{N_i} \neq 0$$
$$d_N \geq 0$$

[0246] In some embodiments, the number of constraints corresponding to each demand charge q is dependent on how many time steps the demand charge q is active during the optimization period. For example, the number of constraints for the demand charge q may be equal to the number of non-zero elements of the demand charge mask g_q. Furthermore, the value of the auxiliary demand charge variable d_q at each iteration of the optimization may act as the lower bound of the value of the auxiliary demand charge variable d_q at the following iteration.

[0247] Consider the following example of a multiple demand charge structure. In this example, an electric utility imposes three monthly demand charges. The first demand charge is an all-time monthly demand charge of 15.86 \$/kWh which applies to all hours within the entire month. The second demand charge is an on-peak monthly demand charge of 1.56 \$/kWh which applies each day from 12:00-18:00. The third demand charge is a partial-peak monthly demand charge of 0.53 \$/kWh which applies each day from 9:00-12:00 and from 18:00-22:00.

[0248] For an optimization period of one day and a time step of one hour (i.e., i=1 . . . 24), demand charge module **910** may introduce three auxiliary demand charge variables. The first auxiliary demand charge variable d_1 corresponds to the all-time monthly demand charge; the second auxiliary demand charge variable d_2 corresponds to the on-peak monthly demand charge; and the third auxiliary demand charge variable d_3 corresponds to the partial-peak monthly demand charge. Demand charge module **910** can constrain each auxiliary demand charge variable to be greater than or equal to the maximum electricity purchase during the hours the corresponding demand charge is active, using the inequality constraints described above.

[0249] Demand charge module **910** can generate a demand charge mask g_q for each of the three demand charges (i.e., q=1 . . . 3), where g_q includes an element for each time step of the optimization period (i.e., $g_q=[g_{q_1} \ldots g_{q24}]$). The three demand charge masks can be defined as follows:

$$g_{1_i}=1 \ \forall i=1 \ldots 24$$

$$g_{2_i}=1 \ \forall i=12 \ldots 18$$

$$g_{3_i}=1 \ \forall i=9 \ldots 12,18 \ldots 22$$

with all other elements of the demand charge masks equal to zero. In this example, it is evident that more than one demand charge constraint will be active during the hours which overlap with multiple demand charge periods. Also, the weight of each demand charge over the optimization period can vary based on the number of hours the demand charge is active, as previously described.

[0250] In some embodiments, demand charge module **910** considers several different demand charge structures when incorporating multiple demand charges into the cost function J(x) and optimization constraints. Demand charge structures can vary from one utility to another, or the utility may offer several demand charge options. In order to incorporate the multiple demand charges within the optimization framework, a generally-applicable framework can be defined as previously described. Demand charge module **910** can translate any demand charge structure into this framework. For example, demand charge module **910** can characterize each demand charge by rates, demand charge period start, demand charge period end, and active hours. Advantageously, this allows demand charge module **910** to incorporate multiple demand charges in a generally-applicable format.

[0251] The following is another example of how demand charge module **910** can incorporate multiple demand charges into the cost function J(x). Consider, for example, monthly demand charges with all-time, on-peak, partial-

peak, and off-peak. In this case, there are four demand charge structures, where each demand charge is characterized by twelve monthly rates, twelve demand charge period start (e.g., beginning of each month), twelve demand charge period end (e.g., end of each month), and hoursActive. The hoursActive is a logical vector where the hours over a year where the demand charge is active are set to one. When running the optimization over a given horizon, demand charge module **910** can implement the applicable demand charges using the hoursActive mask, the relevant period, and the corresponding rate.

[0252] In the case of an annual demand charge, demand charge module **910** can set the demand charge period start and period end to the beginning and end of a year. For the annual demand charge, demand charge module **910** can apply a single annual rate. The hoursActive demand charge mask can represent the hours during which the demand charge is active. For an annual demand charge, if there is an all-time, on-peak, partial-peak, and/or off-peak, this translates into at most four annual demand charges with the same period start and end, but different hoursActive and different rates.

[0253] In the case of a seasonal demand charge (e.g., a demand charge for which the maximum peak is determined over the indicated season period), demand charge module **910** can represent the demand charge as an annual demand charge. Demand charge module **910** can set the demand charge period start and end to the beginning and end of a year. Demand charge module **910** can set the hoursActive to one during the hours which belong to the season and to zero otherwise. For a seasonal demand charge, if there is an All-time, on-peak, partial, and/or off-peak, this translates into at most four seasonal demand charges with the same period start and end, but different hoursActive and different rates.

[0254] In the case of the average of the maximum of current month and the average of the maxima of the eleven previous months, demand charge module **910** can translate the demand charge structure into a monthly demand charge and an annual demand charge. The rate of the monthly demand charge may be half of the given monthly rate and the annual rate may be the sum of given monthly rates divided by two. These and other features of demand charge module **910** are described in greater detail in U.S. patent application Ser. No. 15/405,236 filed Jan. 12, 2017, the entire disclosure of which is incorporated by reference herein.

Incentive Program Incorporation

[0255] Referring again to FIG. **9**, high level optimizer **632** is shown to include an incentive program module **912**. Incentive program module **912** may modify the optimization problem to account for revenue from participating in an incentive-based demand response (IBDR) program. IBDR programs may include any type of incentive-based program that provides revenue in exchange for resources (e.g., electric power) or a reduction in a demand for such resources. For example, energy storage system **500** may provide electric power to an energy grid or an independent service operator as part of a frequency response program (e.g., PJM frequency response) or a synchronized reserve market. In a frequency response program, a participant contracts with an electrical supplier to maintain reserve power capacity that can be supplied or removed from an energy grid by tracking a supplied signal. The participant is paid by the amount of power capacity required to maintain in reserve. In other types of IBDR programs, energy storage system **500** may reduce its demand for resources from a utility as part of a load shedding program. It is contemplated that energy storage system **500** may participate in any number and/or type of IBDR programs.

[0256] In some embodiments, incentive program module **912** modifies the cost function J(x) to include revenue generated from participating in an economic load demand response (ELDR) program. ELDR is a type of IBDR program and similar to frequency regulation. In ELDR, the objective is to maximize the revenue generated by the program, while using the battery to participate in other programs and to perform demand management and energy cost reduction. To account for ELDR program participation, incentive program module **912** can modify the cost function J(x) to include the following term:

$$\min_{b_i, P_{bat_i}} \left(-\sum_{i=k}^{k+h-1} b_i r_{ELDR_i} (adjCBL_i - (eLoad_i - P_{bat_i})) \right)$$

where b_i is a binary decision variable indicating whether to participate in the ELDR program during time step i, r_{ELDR_i} is the ELDR incentive rate at which participation is compensated, and $adjCBL_i$ is the symmetric additive adjustment (SAA) on the baseline load. The previous expression can be rewritten as:

$$\min_{b_i, P_{bat_i}} \left(-\sum_{i=k}^{k+h-1} b_i r_{ELDR_i} \left(\sum_{l=1}^{4} \frac{e_{li}}{4} + \sum_{p=m-4}^{m-2} \frac{1}{3} \left(eLoad_p - P_{bat_p} - \sum_{l=1}^{4} \frac{e_{lp}}{4} \right) - (eLoad_i - P_{bat_i}) \right) \right)$$

where e_{li} and e_{lp} are the electric loads at the lth hour of the operating day.

[0257] In some embodiments, incentive program module **912** handles the integration of ELDR into the optimization problem as a bilinear problem with two multiplicative decision variables. In order to linearize the cost function J(x) and customize the ELDR problem to the optimization framework, several assumptions may be made. For example, incentive program module **912** can assume that ELDR participation is only in the real-time market, balancing operating reserve charges and make whole payments are ignored, day-ahead prices are used over the horizon, real-time prices are used in calculating the total revenue from ELDR after the decisions are made by the optimization algorithm, and the decision to participate in ELDR is made in advance and passed to the optimization algorithm based on which the battery asset is allocated.

[0258] In some embodiments, incentive program module **912** calculates the participation vector b_i as follows:

$$b_i = \begin{cases} 1 & \frac{\forall\, i}{r_{DA_i}} \geq NBT_i \text{ and } i \in S \\ 0 & \text{otherwise} \end{cases}$$

where r_{DA_i} is the hourly day-ahead price at the ith hour, NBT_i is the net benefits test value corresponding to the month to which the corresponding hour belongs, and S is the set of nonevent days. Nonevent days can be determined for the year by choosing to participate every x number of days with the highest day-ahead prices out of y number of days for a given day type. This approach may ensure that there are nonevent days in the 45 days prior to a given event day when calculating the CBL for the event day.

[0259] Given these assumptions and the approach taken by incentive program module **912** to determine when to participate in ELDR, incentive program module **912** can adjust the cost function J(x) as follows:

$$J(x) = -\sum_{i=k}^{k+h-1} r_{e_i} P_{bat_i} - \sum_{i=k}^{k+h-1} r_{FR_i} P_{FR_i} + \sum_{i=k}^{k+h-1} r_{s_i} s_i + w_d r_d d - \sum_{i=k}^{k+h-1} b_i r_{DA_i} \left(\sum_{p=m-4}^{m-2} -\frac{1}{3} P_{bat_p} + P_{bat_i} \right)$$

where b_i and m are known over a given horizon. The resulting term corresponding to ELDR shows that the rates at the ith participation hour are doubled and those corresponding to the SAA are lowered. This means it is expected that high level optimizer **632** will tend to charge the battery during the SAA hours and discharge the battery during the participation hours. Notably, even though a given hour is set to be an ELDR participation hour, high level optimizer **632** may not decide to allocate any of the battery asset during that hour. This is due to the fact that it may be more beneficial at that instant to participate in another incentive program or to perform demand management.

Peak Load Contribution Incorporation

[0260] Still referring to FIG. **9**, high level optimizer **632** is shown to include a peak load contribution module **914**. Peak load contribution (PLC) is a customer's contribution to regional demand peaks that occur in geographic area managed by a regional transmission organization (RTO) or independent system operator (ISO) at certain hours within a base period. The regional demand at a given hour may be the summation of the customer's demand during (i.e., the rate at which the customer purchases electricity or another resource from a utility) as well as the demand of other buildings in the geographic area during that hour. The customer may be billed based on its contribution to the peak regional demand (e.g., $/kW of the customer's PLC) in addition to the energy consumption charges and demand charges previously described.

[0261] PLC module **914** can be configured to modify the cost function J(x) to account for a cost associated with the customer's PLC. By incorporating PLC costs into the cost function J(x), PLC module **914** enables high level optimizer **632** to allocate resource consumption and resource purchases to reduce the customer's PLC. High level optimizer **632** can reduce PLC costs by shifting the customer's load to non-peak times or shaving the customer's peak load. This can be done, for example, by precooling the building during non-peak times, using thermal energy storage, and/or using electrical energy storage such as a battery asset.

[0262] Accounting for the cost associated with the customer's PLC can be more difficult than accounting for energy consumption costs and demand charges. Unlike demand charge which is calculated based on the customer's maximum demand during predetermined demand charge periods, the hours over which PLC is calculated may not be known in advance. The hours of peak regional demand (i.e., the coincidental peak (CP) hours) may not be known until the end of the base period over which PLC is calculated. For example, the CP hours for a given base period (e.g., one year) may be determined by a RTO at the end of the base period based on the demand of all the buildings within the geographic area managed by the RTO during the base period (e.g., by selecting the hours with the highest regional demand). The customer's PLC may then be determined based on the customer's demand during the designated CP hours and used to calculate a cost of the customer's PLC. This cost may then be billed to the customer during the next time period (e.g., the next year), referred to as the billing period.

[0263] Another difficulty in accounting for PLC costs is that the base period, billing period, CP hours, and other factors used to calculate the PLC cost may differ from one RTO to another. For example, a RTO for the Pennsylvania, Jersey, and Maryland (PJM) geographic area may define the base period (i.e., the peak-setting period) as June 1st of year Y to May 31st of year Y+1. The billing period (i.e., the delivery period) may be defined as June 1st of year Y+1 to May 31st of year Y+2. PJM may define the CP hours as the five hours with the highest loads over the five highest peak load days across the PJM geographic region.

[0264] A customer's PLC in the PJM region may be calculated as the product of the customer's average electric load during the five CP hours and a capacity loss factor (CLF), as shown in the following equation:

$$PLC_{customer} = CLF \times \sum_{i=1}^{5} \frac{eLoad_{cp_i}}{5}$$

where $PLC_{customer}$ is the customer's peak load contribution calculated during year Y, CLF is the capacity loss factor (e.g., CLF=1.05), and $eLoad_{cp_i}$ is the customer's electric load (e.g., kW) during the ith CP hour.

[0265] The customer's PLC cost in the PJM region can be calculated as the product of the customer's PLC during year Y and a PLC rate, as shown in the following equation:

$$PLC_{cost} = r_{PLC} \times PLC_{customer}$$

where PLC_{cost} is the customer's PLC charge billed over the delivery year Y+1 (e.g., $) and r_{PLC} is the rate at which the customer is charged for its PLC (e.g., $/kW).

[0266] An additional complication in the PJM region relates to the interaction between PLC costs and economic load demand response (ELDR) revenue. In some embodiments, a customer participating in ELDR in the PJM region during one of the CP hours may be prohibited from reducing its PLC while earning ELDR revenue at the same time. Accordingly, a customer wishing to reduce its load during an assumed CP hour for the purpose of reducing its capacity, transmission, and/or demand charge costs may be restricted from making a bid for the same assumed CP hour in the ELDR market.

[0267] Another example of an organization which imposes PLC costs is the independent electricity system operator (IESO) in Ontario, Canada. Relative to PJM, IESO may use a different base period, billing period, CP hours, and other factors used to calculate the PLC cost. For example, IESO may define the base period or peak-setting period as May 1^{st} of year Y to April 30^{th} of year Y+1. The billing period or adjustment period for IESO may be defined as July 1^{st} of year Y+1 to June 30^{th} of year Y+2. IESO may define the CP hours as the five hours with the highest regional demands across the IESO geographic region.

[0268] At the end of the base period, IESO may calculate the customer's peak demand factor (θ_{PDF}). The peak demand factor may be defined as the ratio of the sum of the customer's peak demand to the sum of the region-wide demand peaks during the five CP hours, as shown in the following equation:

$$\theta_{PDF} = \frac{\sum_{i=1}^{5} eLoad_{cp_i}}{\sum_{i=1}^{5} sysLoad_{cp_i}}$$

where sysLoad_{cp_i} is the region-wide peak load during the ith CP hour and eLoad_{cp_i} is the customer's peak load during the ith CP hour.

[0269] The customer's PLC cost in the IESO region is known as a global adjustment (GA) charge. The GA charge may be imposed as a monthly charge during the billing period. In some embodiments, the GA charge is calculated by multiplying the customer's peak demand factor by the monthly region-wide global adjustment costs, as shown in the following equation:

$$GA_{cost,month}=\theta_{PDF}\times GA_{total,month}$$

where $GA_{cost,month}$ is the customer's monthly PLC cost (e.g., \$) and $GA_{total,month}$ is the region-wide global adjustment cost (e.g., \$). The value of $GA_{total,month}$ may be specified by IESO. In some embodiments, $GA_{total,month}$ has a known value. In other embodiments, the value of $GA_{total,month}$ may not be known until the end of the base period.

[0270] In order to incorporate PLC costs into the cost function J(x) and allocate resource consumption/purchases in advance, PLC module **914** can generate or obtain a projection of the CP hours for an upcoming base period. The projected CP hours can then be used by high level optimizer **632** as an estimate of the actual CP hours. High level optimizer **632** can use the projected CP hours to allocate one or more assets (e.g., a battery, thermal energy storage, HVAC equipment, etc.) to minimize the customer's demand during the projected CP hours. These and other features of PLC module **914** are described in greater detail in U.S. patent application Ser. No. 15/405,234 filed Jan. 12, 2017, the entire disclosure of which is incorporated by reference herein.

Asset Sizing Incorporation

[0271] Still referring to FIG. **9**, high level optimizer **632** is shown to include an asset sizing module **916**. Asset sizing module **916** can be configured to determine the optimal sizes of various assets in a building, group of buildings, or a central plant. Assets can include individual pieces of equipment or groups of equipment. For example, assets can include boilers, chillers, heat recovery chillers, steam generators, electrical generators, thermal energy storage tanks, batteries, air handling units, or other types of equipment in a building or a central plant (e.g., HVAC equipment, BMS equipment, etc.). In some embodiments, assets include collections of equipment which form a subplant of a central plant (e.g., central plant **118**). For example, assets can include heater subplant **521**, chiller subplant **522**, heat recovery chiller subplant **523**, steam subplant **524**, electricity subplant **525**, or any other type of generator subplant **520**. In some embodiments, assets include hot thermal energy storage **531** (e.g., one or more hot water storage tanks), cold thermal energy storage **532** (e.g., one or more cold thermal energy storage tanks), electrical energy storage **533** (e.g., one or more batteries), or any other type of storage subplant **530**.

[0272] Asset sizes can include a maximum loading of the asset and/or a maximum capacity of the asset. Some assets such as storage subplants **530** may have both a maximum loading and a maximum capacity. For example, battery assets may have a maximum battery power (e.g., a maximum rate at which the battery can be charged or discharged) and a maximum state-of-charge (e.g., a maximum energy storage of the battery). Similarly, thermal energy storage assets may have a maximum charge/discharge rate and a maximum capacity (e.g., maximum fluid storage, etc.). Other assets such as generator subplants **520** may have only a maximum loading. For example, a chiller may have a maximum rate at which the chiller can produce cold thermal energy. Similarly, an electric generator may have a maximum rate at which the generator can produce electricity. Asset sizing module **916** can be configured to determine the maximum loading and/or the maximum capacity of an asset when determining the optimal size of the asset.

[0273] In some embodiments, asset sizing module **916** is implemented a component of planning tool **702**. In the planning tool framework, asset sizing module **916** can determine the optimal size of an asset for a given application. For example, consider the planning problem described with reference to FIGS. **7-8** in which the high level optimization is solved at a given time instant k over a given time horizon h. With each iteration of the high level optimization, the time horizon h can be shifted forward by a block size equivalent to b time steps and the first b sets of decision variables may be retained. In such a planning problem, the sizes of the assets to be optimally allocated are typically given along with historical load data, utility pricing, and other relative data. However, there are many cases in which the sizes of the assets to be allocated are unknown. For example, when purchasing a new asset for a given application (e.g., adding thermal energy storage or electrical energy storage to a building or central plant), a user may wish to determine the optimal size of the asset to purchase.

[0274] Asset sizing module **916** can be configured to determine the optimal size of an asset by considering the potential benefits and costs of the asset. Potential benefits can include, for example, reduced energy costs, reduced demand charges, reduced PLC charges, and/or increased revenue from participating in IBDR programs such as frequency regulation (FR) or economic load demand response (ELDR). Potential costs can include fixed costs (e.g., an initial purchase cost of the asset) as well as marginal costs

(e.g., ongoing costs of using the asset) over the time horizon. The potential benefits and costs of an asset may vary based on the application of the asset and/or the system in which the asset will be used. For example, a system that participates in FR programs may realize the benefit of increased IBDR revenue, whereas a system that does not participate in any IBDR programs may not realize such a benefit.

[0275] Some of the benefits and costs of an asset may be captured by the original cost function J(x). For example, the cost function J(x) may include terms corresponding to energy cost, multiple demand charges, PLC charges, and/or IBDR revenue, as previously described. Adding one or more new assets may affect the values of some or all of these terms in the original cost function J(x). For example, adding a battery asset may increase IBDR revenue and decrease energy cost, demand charges, and PLC charges. However, the original cost function J(x) may not account for the fixed and marginal costs resulting from new asset purchases. In order to account for these fixed and marginal costs, asset sizing module **916** may add new terms to the original cost function J(x).

[0276] Asset sizing module **916** can be configured to augment the cost function J(x) with two new terms that correspond to the cost of purchasing the new assets, resulting in an augmented cost function J_a (x). The additional terms are shown in the following equation:

$$J_a(x)=J(x)+c_f^T v+C_s^T s_a$$

where J(x) is the original cost function, x is the vector of decision variables of the optimization problem over the horizon, c_f is a vector of fixed costs of buying any size of asset (e.g., one element for each potential asset purchase), v is a vector of binary decision variables that indicate whether the corresponding assets are purchased, c_s is a vector of marginal costs per unit of asset size (e.g., cost per unit loading, cost per unit capacity), and s_a is a vector of continuous decision variables corresponding to the asset sizes. Advantageously, the binary purchase decisions and asset size decisions are treated as decision variables which can be optimized along with the decision variables in the vector x. This allows high level optimizer **632** to perform a single optimization to determine optimal values for all of the decision variables in the augmented cost function $J_a(x)$.

[0277] In some embodiments, asset sizing module **916** scales the asset purchase costs $c_f^T v$ and $c_s^T s_a$ to the duration of the optimization period h. The cost of purchasing an asset is typically paid over an entire payback period SPP, whereas the operational cost is only over the optimization period h. In order to scale the asset purchase costs to the optimization period, asset sizing module **916** can multiply the terms $c_f^T v$ and $c_s^T s_a$ by the ratio

$$\frac{h}{SPP}$$

as shown in the following equation:

$$J_a(x) = J(x) + \frac{h}{8760 \cdot SPP}(c_f^T v + c_s^T s_a)$$

where h is the duration of the optimization period in hours, SPP is the duration of the payback period in years, and **8760** is the number of hours in a year.

[0278] High level optimizer **632** can perform an optimization process to determine the optimal values of each of the binary decision variables in the vector v and each of the continuous decision variables in the vector s_a. In some embodiments, high level optimizer **632** uses linear programming (LP) or mixed integer linear programming (MILP) to optimize a financial metric such as net present value (NPV), simple payback period (SPP), or internal rate of return (IRR). Each element of the vectors c_f, v, c_s, and s_a may correspond to a particular asset and/or a particular asset size. Accordingly, high level optimizer **632** can determine the optimal assets to purchase and the optimal sizes to purchase by identifying the optimal values of the binary decision variables in the vector v and the continuous decision variables in the vector s_a.

Subplant Curve Incorporation

[0279] Still referring to FIG. **9**, high level optimizer **632** is shown to include a subplant curves module **930**. In the simplest case, it can be assumed that the resource consumption of each subplant is a linear function of the thermal energy load produced by the subplant. However, this assumption may not be true for some subplant equipment, much less for an entire subplant. Subplant curves module **930** may be configured to modify the high level optimization problem to account for subplants that have a nonlinear relationship between resource consumption and load production.

[0280] Subplant curves module **930** is shown to include a subplant curve updater **932**, a subplant curves database **934**, a subplant curve linearizer **936**, and a subplant curves incorporator **938**. Subplant curve updater **932** may be configured to request subplant curves for each of subplants **520-530** from low level optimizer **634**. Each subplant curve may indicate an amount of resource consumption by a particular subplant (e.g., electricity use measured in kW, water use measured in L/s, etc.) as a function of the subplant load.

[0281] In some embodiments, low level optimizer **634** generates the subplant curves by running the low level optimization process for various combinations of subplant loads and weather conditions to generate multiple data points. Low level optimizer **634** may fit a curve to the data points to generate the subplant curves and provide the subplant curves to subplant curve updater **832**. In other embodiments, low level optimizer **634** provides the data points to subplant curve updater **932** and subplant curve updater **932** generates the subplant curves using the data points. Subplant curve updater **932** may store the subplant curves in subplant curves database **934** for use in the high level optimization process.

[0282] In some embodiments, the subplant curves are generated by combining efficiency curves for individual devices of a subplant. A device efficiency curve may indicate the amount of resource consumption by the device as a function of load. The device efficiency curves may be provided by a device manufacturer or generated using experimental data. In some embodiments, the device efficiency curves are based on an initial efficiency curve provided by a device manufacturer and updated using experimental data. The device efficiency curves may be stored in

equipment models **618**. For some devices, the device efficiency curves may indicate that resource consumption is a U-shaped function of load. Accordingly, when multiple device efficiency curves are combined into a subplant curve for the entire subplant, the resultant subplant curve may be a wavy curve. The waves are caused by a single device loading up before it is more efficient to turn on another device to satisfy the subplant load.

[0283] Subplant curve linearizer **936** may be configured to convert the subplant curves into convex curves. A convex curve is a curve for which a line connecting any two points on the curve is always above or along the curve (i.e., not below the curve). Convex curves may be advantageous for use in the high level optimization because they allow for an optimization process that is less computationally expensive relative to an optimization process that uses non-convex functions. Subplant curve linearizer **936** may be configured to break the subplant curves into piecewise linear segments that combine to form a piecewise-defined convex curve. Subplant curve linearizer **936** may store the linearized subplant curves in subplant curves database **934**.

[0284] Subplant curve incorporator **938** may be configured to modify the high level optimization problem to incorporate the subplant curves into the optimization. In some embodiments, subplant curve incorporator **938** modifies the decision variables to include one or more decision vectors representing the resource consumption of each subplant. Subplant curve incorporator **938** may modify the inequality constraints to ensure that the proper amount of each resource is consumed to serve the predicted thermal energy loads. In some embodiments, subplant curve incorporator **938** formulates inequality constraints that force the resource usage for each resource in the epigraph of the corresponding linearized subplant curve. For example, chiller subplant **522** may have a linearized subplant curve that indicates the electricity use of chiller subplant **522** (i.e., input resource in_1) as a function of the cold water production of chiller subplant **522** (i.e., output resource out_1). The linearized subplant curve may include a first line segment connecting point $[u_1, Q_1]$ to point $[u_2, Q_2]$, a second line segment connecting point $[u_2, Q_2]$ to point $[u_3, Q_3]$, and a third line segment connecting point $[u_3, Q_3]$ to point $[u_4, Q_4]$.

[0285] Subplant curve incorporator **938** may formulate an inequality constraint for each piecewise segment of the subplant curve that constrains the value of the decision variable representing chiller electricity use to be greater than or equal to the amount of electricity use defined by the line segment for the corresponding value of the cold water production. Similar inequality constraints can be formulated for other subplant curves. For example, subplant curve incorporator **938** may generate a set of inequality constraints for the water consumption of chiller subplant **522** using the points defining the linearized subplant curve for the water consumption of chiller subplant **522** as a function of cold water production. In some embodiments, the water consumption of chiller subplant **522** is equal to the cold water production and the linearized subplant curve for water consumption includes a single line segment connecting point $[u_5, Q_5]$ to point $[u_6, Q_6]$. Subplant curve incorporator **938** may repeat this process for each subplant curve for chiller subplant **522** and for the other subplants of the central plant to define a set of inequality constraints for each subplant curve.

[0286] The inequality constraints generated by subplant curve incorporator **938** ensure that high level optimizer **632** keeps the resource consumption above all of the line segments of the corresponding subplant curve. In most situations, there is no reason for high level optimizer **632** to choose a resource consumption value that lies above the corresponding subplant curve due to the economic cost associated with resource consumption. High level optimizer **632** can therefore be expected to select resource consumption values that lie on the corresponding subplant curve rather than above it.

[0287] The exception to this general rule is heat recovery chiller subplant **523**. The equality constraints for heat recovery chiller subplant **523** provide that heat recovery chiller subplant **523** produces hot water at a rate equal to the subplant's cold water production plus the subplant's electricity use. The inequality constraints generated by subplant curve incorporator **938** for heat recovery chiller subplant **523** allow high level optimizer **632** to overuse electricity to make more hot water without increasing the amount of cold water production. This behavior is extremely inefficient and only becomes a realistic possibility when the demand for hot water is high and cannot be met using more efficient techniques. However, this is not how heat recovery chiller subplant **523** actually operates.

[0288] To prevent high level optimizer **632** from overusing electricity, subplant curve incorporator **938** may check whether the calculated amount of electricity use (determined by the optimization algorithm) for heat recovery chiller subplant **523** is above the corresponding subplant curve. In some embodiments, the check is performed after each iteration of the optimization algorithm. If the calculated amount of electricity use for heat recovery chiller subplant **523** is above the subplant curve, subplant curve incorporator **938** may determine that high level optimizer **632** is overusing electricity. In response to a determination that high level optimizer **632** is overusing electricity, subplant curve incorporator **938** may constrain the production of heat recovery chiller subplant **523** at its current value and constrain the electricity use of subplant **523** to the corresponding value on the subplant curve. High level optimizer **632** may then rerun the optimization with the new equality constraints. These and other features of subplant curves module **930** are described in greater detail in U.S. patent application Ser. No. 14/634,609 filed Feb. 27, 2015, the entire disclosure of which is incorporated by reference herein.

Economic Load Demand Response (ELDR)

[0289] An ELDR program is a type of IBDR program that allows a customer within a region managed by an RTO and/or ISO offering the ELDR program the ability to generate revenue by reducing the electric consumption of a building, facility, or campus owned by the customer during certain hours of a day. The customer can choose particular hours of a day during which the customer would like to participate in the ELDR program. These hours may be times that the electric load of a building owned by the customer will be reduced below a baseline load. FIG. **12** provides an illustration of an electric load over time for a building participating in an ELDR program.

[0290] In an ELDR program, a customer is compensated for a reduction in electric load based on an electric load of a building during the participation of the ELDR program with respect to a customer baseline load (CBL). The CBL

may be a load specific to a particular customer and the typical electric loads of the customer. Further, there may be different types of CBLs. In some cases, there are two types of CBLs, a same day CBL and a symmetric additive adjustment (SAA) CBL. A same day CBL may be entirely dependent on the electric load on the day that the customer participates in the ELDR program, the participation day. The SAA CBL may be dependent on electric loads of previous days in addition to the electric load of the participation day. The same day CBL is illustrated in FIG. **13** while the SAA CBL is illustrated FIG. **14**.

[0291] An ELDR program, such as the ELDR program discussed herein, may include multiple markets in which a customer can participate. In some cases, the markets are a day-ahead market and a real-time market.

Day-Ahead Market

[0292] In the day-ahead market, a customer may submit a bid to the RTO and/or ISO by a predefined time (e.g., 10:30 A.M.) for the following day, the participation day. The bid may be submitted via a curtailment service provider (CSP). The CSP may act as a medium between a customer and the RTO and/or ISO. The bid may include the hours that the customer would like to participate in the ELDR program, an amount that the customer will curtail their electric load by, a minimum number of hours that the customer wants to participate, and/or an amount or rate at which the customer would like to be compensated. In various cases, a customer is allowed to adjust their bid, but only before the predefined time (e.g., 10:30 A.M. on the day before participation in the day ahead market).

[0293] At a predefined time on the bidding day (e.g., 1:30 P.M. on the day before the participation day), the bid may become locked and a day-ahead locational marginal price (LMP) may be released by the RTO and/or ISO to the customer. Further, the RTO and/or ISO may indicate which of the participation hours of the customer's bid have been approved. The approved hours may indicate hours that the customer is required to reduce their electric load based on their bid. If the customer does not reduce their electric load during the approved hours, the customer may be subject to penalties.

[0294] The day-ahead LMP received by the customer indicates the price at which the customer will be compensated for the participation day. The revenue that a customer can generate may be based on reductions in customer's electric load, as committed in the customer's bid. This is illustrated by the piecewise function below. The piecewise function is shown to include term C_{DA_i} . . . C_{DA_i} may represent the amount of revenue that the customer generates during the participation day. The term P_{red_i} [kW] may represent the amount of power in kilowatts that the customer has lowered their electric load (at an i^{th} hour) while the term r_{DA_i} [$/kWh] may represent the day-ahead LMP with units of dollars per kilowatt hour (at an i^{th} hour). The value NBT (Net Benefits Test) is a threshold value that may have the same units as the day-ahead LMP. In some cases, the value is referred to as a "Net Benefits Threshold" (NBT) which may be the same as the "Net Benefits Test" (NBT) threshold. The NBT threshold may indicate a value at which it is beneficial for the RTO and/or ISO to allow the customer to participate in the ELDR program. The NBT threshold may be a point on a supply curve, the NBT threshold may indicate where net benefits exceeds a load cost. The NBT threshold may indicate elasticity of one for the supply curve. A customer may only be compensated for hours where the NBT threshold is less than or equal to the day-ahead LMP. Comparing these values may be referred to as a "Net Benefits Test." The NBT threshold may be a value that any customer can access via a website of the RTO, ISO, and/or CSP. In some embodiments, the RTO, ISO, and/or CSP posts the NBT threshold on a website on the 15^{th} day of every month for the following month.

$$C_{DA_i} = \begin{cases} P_{red_i} * r_{DA_i} & r_{DA_i} \geq NBT \\ 0 & \text{otherwise} \end{cases}$$

Real-Time Market

[0295] The real-time ELDR market that the RTO and/or ISO may provide to the customer may allow a customer to place a bid for and participate in the real-time ELDR market on the same day. The real-time ELDR market may require the bid (e.g., a bid similar and/or the same as the bid of the day-ahead market) to be submitted to the RTO and/or ISO at least three hours before the top of the start of a participation hour. The ELDR program may allow a customer to participate in both the real-time ELDR market and the day-ahead ELDR market. In some embodiments, the RTO and/or ISO may require that a bid for the real-time ELDR market be submitted before a predefined time on a day preceding the participation day (e.g., 6:00 P.M.) for a customer to be compensated for both the real-time ELDR market and the day-ahead ELDR market.

[0296] A customer may be compensated for participation in the real-time ELDR market based on the NBT previously described above, the P_{red_i} amount previously described above, and a real-time LMP. In some embodiments, in the real-time market, a customer will be awarded participation hours, or there will be a high probability of being awarded participation hours (e.g., 99%) if a customer bid includes a compensation rate that is greater than the NBT threshold. The real-time LMP may be the amount at which a customer is compensated for participation in the real-time ELDR market.

[0297] The real-time LMP may be referred to herein as r_{RT_i}[$/kWh], specifically, in the piecewise equation below which may indicate the compensation for participation in the real-time ELDR market. The term C_{RT_i}[$] below may indicate the amount by which a customer is compensated for participating in the ELDR program. In the equation below, P_{red_i} [kW] may be the amount which the customer reduces their electric load at hour i while C_{RT_i} may the amount at which a customer is compensated at hour i.

$$C_{RT_i} = \begin{cases} P_{red_i} * r_{RT_i} & r_{RT_i} \geq NBT \\ 0 & \text{otherwise} \end{cases}$$

[0298] In addition to receiving the revenue described with reference to the equation above, a customer may receive a "Make Whole Payment" (MWP). The MWP may be a payment made for a segment when particular conditions are met. The MWP may be available for a customer participating in either or both of the day-ahead ELDR market and the

real-time ELDR market. The conditions may be that the electric load curtailment of the customer is within 20% of the bid electric load curtailment. The segments may be contiguous participation hours (e.g., 11 A.M. through 3 P.M.). In the equation below, the term $C_{MWP_RT_i}$ [$] may represent the amount that a customer is compensated for a MWP at an i^{th} hour. The value v_{RT_i} [$] may represent the real-time load response bid at an i^{th} hour, v_{bal_i} [$] may represent a balancing synchronous reserve revenue above cost at an i^{th} hour, P_{disp_i} may represent a real-time dispatched power at an i^{th} hour, the electric load that may be bid by the customer.

$$C_{MWP_RT_i} = \begin{cases} v_{RT_i} - v_{bal_i} - C_{RT_i} & r_{bid_{RT_i}} \geq NBT \text{ and } |P_{red_i} - P_{disp_i}| \leq 0.2\ P_{disp_i} \\ 0 & \text{otherwise} \end{cases}$$

[0299] The term of the above equation, v_{RT_i} [$], may be calculated based on the equation below. The equation below minimizes two power values (i.e., P_{disp_i}[$] and P_{red_i} described above) multiplied by a value, $r_{bid_RT_i}$. The value $r_{bid_RT_i}$ may be a bid that a customer had previously sent to the RTO and/or ISO, indicating the rate at which the customer wants to be compensated.

$$v_{RT_i} = \min(P_{disp_i}, P_{red_i}) r_{bid_RT_i}$$

[0300] The entire payment for a MWP segment may be illustrated by the following equation. The term j may represent a particular segment while the term i may indicate a particular hour. The term $C_{seg_MWP_RT_j}$ [$] represents compensation to the customer for the j^{th} segment MWP while the term $C_{shutdown}$[$] may be a shutdown cost that may be submitted in a customer bid. The shutdown cost may not be available as compensation (e.g., the top term of the piecewise function below) if at least one hour of a segment has an electric load reduction deviation that is greater than 20% of the electric load bid (e.g., the power dispatched by a utility).

$$C_{Seg_MWP_RT_j} = \begin{cases} \max\left(\sum_{i \in Seq_j} C_{MWP_RT_i} + C_{shutdown}, 0\right) & \begin{cases} r_{bid_RT_i} \geq NBT \\ |P_{red_i} - P_{disp_i}| \leq 0.2\ P_{disp_i} \forall\ i \in Seg_j \end{cases} \\ \max\left(\sum_{i \in Seq_j} C_{MWP_RT_i}, 0\right) & \begin{cases} r_{bid_RT_i} \geq NBT \\ \exists\ i \in Seq_j / |P_{red_i} - P_{disp_i}| > 0.2\ P_{disp_i} \\ \text{otherwise} \end{cases} \end{cases}$$

[0301] For both the real-time ELDR market and the day-ahead ELDR market, there may be penalties if the customer fails to reduce their electric load by a proper amount. A balancing operating reserve (BOR) charge may be made by the RTO and/or ISO for hours when the electric load reduced of a customer deviates from the bid electric load (e.g., the power dispatched by the utility) by more than 20%. In some cases, a customer may be charged two BOR penalties, that is, a "RTO BOR" and one of an "East BOR" deviation rate or an "West BOR" deviation rate. The "East BOR" and the "West BOR" deviation rates may be applied based on the location of the customer. A BOR may be defined by the equation below. In the equation below, the term BOR_{ch_i}[$] represents a BOR penalty at a particular rate and hour. The term r_{BOR_i}[$1 kWh] represents the rate at which a customer is penalized for a particular hour, i. In some cases, one or more rates are applicable for a particular hour. In these cases, several charges may be calculated and summed for that hour. In many cases, the rates are less than a dollar per megawatt hour ($/MWh).

$$BOR_{ch_i} = \begin{cases} |P_{red_i} - P_{disp_i}| r_{BOR_i} & |P_{red_i} - P_{disp_i}| > 0.2 P_{disp_i} \\ 0 & \text{otherwise} \end{cases}$$

Economic Load Demand Response (ELDR) Program Optimization

[0302] Referring now to FIG. **10**, controller **1000** is shown in greater detail to include components configured to perform ELDR optimization, according to an exemplary embodiment. Controller **1000** may be the same and/or similar to energy storage controller **506** as described with reference to FIG. **6**A, controller **552** as described with reference to FIG. **6**B, and/or planning tool **702** as described with reference to FIG. **7**. FIG. **10** is further shown to include incentive program **1012** and user device **1013** in communication with controller **1000**. Incentive program **1012** may be a computer system or server of an RTO, ISO, and/or CSP that is configured to allow controllers, e.g., controller **1000**, to participate in an ELDR program that the RTO, ISO, and/or CSP may provide. In some cases, incentive program **1012** is a CSP that handles bidding and settlements for a RTO. User device **1013** may be a user device such as a smartphone, a laptop, a desktop, a tablet, and/or any other kind of computing device. The functions of controller **1000** with respect to participating in an ELDR program can be implemented by energy storage controller **506** and/or planning tool **702**.

[0303] Memory **610** is shown to include building status monitor **624**, as described with further reference to FIG. **6**. Building status monitor **624** is shown to provide information indicative of the electric load of a building (e.g., buildings **116**) to baseline generator **1002** and load/rate predictor **622**, historical electric load information. In some embodiments, building status monitor **624** provides historical electric load information to load/rate load predictor **1016**. Building status monitor **624**, may be in communication with a building management system. In some embodiments, building status monitor **624** communicates with building management system **606** and receives electric load information from building management system **606** (as shown in FIGS. **6**A-**6**B). Based on the electric load information that building status monitor **624** receives, building status monitor **624** can be configured to generate a log of electric load information for a plurality of years, months, days, hours, minutes, seconds, etc. The stored electric load log may be the historical electric load

information that building status monitor **624** provides to baseline generator **1002** and load/rate predictor **622**.

[0304] Load/rate predictor **622** is shown to include load predictor **1016**. Load predictor **1016** can be configured to receive electric load information from building status monitor **624**. In some embodiments, load predictor **1016** is configured to predict load information based on the historical electric load information received from building status monitor **624**. In some embodiments, the predicted load information indicates an electric load at a particular time in the future and/or a period of time in the future. In some embodiments, load predictor **1016** uses weather forecasts, load information and/or any other information that building status monitor **624** has logged, etc. Load/rate predictor **622** can be configured to predict an electric load based on the methods disclosed in U.S. application Ser. No. 14/717,593 filed on May 20, 2015, the entirety of which is incorporated by reference herein.

[0305] Load/rate predictor **622** is further shown to include locational marginal price (LMP) predictor **1014**. LMP predictor **1014** is shown to receive information indicative of an LMP from incentive program **1012**. In some embodiments, the LMP information includes one and/or both of a day-ahead LMP and a real-time LMP. The day-ahead LMP may be a price at which controller **522** may be compensated for reductions in energy use at based on participation in a day-ahead market, a ELDR market in which bids are submitted one day ahead of participation times. Similarly, the real-time LMP may be a price at which controller **1000** is compensated for reductions in energy use for a real-time ELDR market, a market that does not require bids to be submitted a day ahead but rather on the same day as participation. The day-ahead ELDR market and the real-time ELDR market are further illustrated above and elsewhere herein.

[0306] LMP predictor **1014** can be configured to generate a predicted LMP based on an LMP received from incentive program **1012**. LMP predictor **1014** can be configured to generate a predicted day-ahead LMP and a predicted real-time LMP. In some embodiments, LMP predictor **1014** stores a history of LNIPs received from incentive program **1012**. In some embodiments, based on the date, current weather, or other information, LMP predictor **1014** can be configured to generate a predicted real-time LMP and a predicted day-ahead LMP. LMP predictor **1014** can be configured to predict a real-time LMP and/or a day-ahead LMP based on weather forecasts and/or a historical log of past LNIPs. LMP predictor **1014** can be configured to predict the LMP (e.g., the real-time LMP and/or the day ahead LMP) based on the methods disclosed in U.S. application Ser. No. 14/717,593 filed on May 20, 2015. In some embodiments, LMP predictor **1014** uses a stochastic model to predict LMPs. For example, LMP predictor **1014** may use a prediction model and may train the prediction model to generate an LMP model based on historical LMPs to determine coefficients for the model. LMP predictor **1014** can be configured to provide the predicted LMP to participation predictor **1004**. In this example, LMP predictor **1014** may predict that an LMP for a weekday is the LMP for the most recently occurring weekday. Similarly, for a weekend, the LMP for the weekend may be the LMP for the most recently occurring weekend.

[0307] LMP predictor **1014** can be configured to generate a predicted LMP for each hour of a future day. For example, for one particular day in the future (e.g., the next day), LMP predictor **1014** can be configured to determine a predicted real-time LMP and a predicted day-ahead LMP at each hour of the day. The LMPs can be provided by LMP predictor **1014** to participation predictor **1004**. In this regard, the LMPs may be a vector of length **24**, with an LMP value for each hour indicated by an index, e.g., **1-24**. In some embodiments, LMP predictor **1014** can be configured to generate a predicted LMP for a plurality of days (e.g., for an optimization period that is a plurality of days). For example, LMP predictor **1014** can be configured to generate a predicted LMP for a week in the future, a month in the future, and/or a year in the future.

[0308] Incentive program module **912** can be configured to cause controller **1000** to participate in an ELDR program offered by incentive program **1012**. Incentive program module **912** can be configured to receive LMPs from incentive program **1012** (e.g., a real-time LMP and a day ahead LMP) and receive a NBT threshold from incentive program **1012**. Based on this information and electric load information, incentive program module **912** can be configured to generate a bid and send the bid to incentive program **1012**. The bid may include participation hours, a curtailment amount, and a bid amount. The bid amount may be a rate of compensation (e.g., $/kWh). Incentive program module **912** can be configured to receive awarded hours from incentive program **1012**, awarded to incentive program module **912** based on the bid provided to incentive program **1012**. During the awarded hours, incentive program module **912** can be configured to cause HVAC equipment to operate to meet the curtailment amount of the bid.

[0309] Incentive program module **912** can generate a bid (or modify a bid) at a particular interval. The interval may be once every 15 minutes, once every hour, or once every day. In some embodiments, incentive program module **912** generates a single bid for participating in the ELDR program when incentive program **1012** releases a day-ahead LMP. The bid may indicate decisions made by the incentive program module **912** regarding when to participate in the ELDR program (e.g., what hours of an event day or optimization period to participate in the ELDR program) and the amount that incentive program module **912** determines it will curtail an electric load (e.g., grid load) by. This may be at a particular time (e.g., after 1:30 P.M.).

[0310] Incentive program module **912**, described with reference to FIG. **9**, is shown in FIG. **10** to include baseline generator **1002**. Baseline generator **1002** can be configured to generate a CBL based on participation hours, a predicted electric load, and historical electric load information. In some embodiments, baseline generator **1002** communicates with participation predictor **1004** to determine an event start hour and an event end hour for participation in the ELDR program. In this regard, participation predictor **1004** may generate participation hours and use the participation hours as a search space to determine an event start hour and an event end hour. In this regard, baseline generator **1002** can be configured to generate a CBL value for a plurality of hours so that participation predictor **1004** can determine an event start hour and an event end hour.

[0311] Baseline generator **1002** can be configured to receive historical electric load information from building status monitor **624**. The historical electric load information may indicate an electric load of a building (e.g., buildings **116**), campus (e.g., campus **12**), a central plant (e.g., central

plant **118**), and energy generation equipment (e.g., energy generator **120**) (at one or more times on one or more days (e.g., hourly electric load, electric load for a day, average electric load for a day, etc.). Baseline generator **1002** is further shown to be configured to receive a predicted load from load predictor **1016**. The predicted load may predict a load in the future e.g., on a day that controller **522** will be participating in an ELDR program.

[0312] Baseline generator **1002** can be configured to generate a same-day CBL and/or an SAA CBL and provide the generated CBL to participation predictor **1004**. For an SAA CBL, baseline generator **1002** can be configured to generate a weekday SAA CBL or a weekend/holiday CBL. The differences between the weekday SAA CBL, the weekend/holiday CBL, and the same-day CBL are described below in Table 1.

[0313] A CBL may be the threshold from which incentive program **1012** determines how much a customer (e.g., controller **1000**) has reduced their electric load for each participation hour. For this reason, customers may be compensated by incentive program **1012** based on the CBL for particular participation days. The CBL may be a baseline for one particular participation day i.e., a CBL may change day to day. Generally, the CBL can be based on the hour at which participation ends and/or starts.

[0314] In Table 1, the differences between an SAA and a same-day CBL are illustrated. As can be seen, there are two different types of SAA CBLs, a weekday SAA CBL and a weekend/holiday SAA CBL. If the participation day falls on a weekday, the weekday SAA CBL may be appropriate while if the participation day falls on a weekend/holiday then the weekend/holiday SAA may be applicable.

TABLE 1

Differences in parameters between SAA and same-day CBL

Parameter	SAA		Same Day
Day Type	Weekday	Weekend/ Holiday	N/A
Calculation	Average	Average	Average
CBL Basis Days	5	3	N/A
CBL Basis Day Limit	45	45	N/A
Start Selection From X Days Prior To Event	X = 1	X = 1	N/A
Exclude Previous Curtailment Days?	Yes	Yes	N/A
Exclude Long and Short Daylight Saving Time (DST) Days	N/A	Yes	N/A
Exclude Average Event Period Usage Less Than A Threshold	Threshold = 25%	Threshold = 25%	N/A
Exclude X Number Of Low Usage Days	X = 1	X = 1	N/A
Use Previous Curtailment If CBL Basis Window Is Incomplete	Yes	Yes	N/A
Use Highest Or Recent Previous Curtailment Day	Highest	Highest	N/A
Adjustments	SAA	SAA	None
Allow Negative Adjustments	Yes	Yes	N/A
Adjustments Start (HE0-X)	X = 4	X = 4	N/A
Number Of Adjustment Basis Hours	3	3	N/A

[0315] For all three types of CBLs, the CBLs may be determined based on an average calculation. For the SAA CBLs, there may be a 45 day window (days prior to a participation day) for selecting days to use in generating the CBL (e.g., determining an average). Further, for the SAA CBLs, the days selected for generating the CBL may be at least one day prior to the participation day. For SAA CBLs, any participation days may be excluded from use in generating the CBL.

[0316] For weekend/holiday SAA CBLs, any days which are daylight saving time days may be excluded from use in generating a weekend/holiday SAA CBL. For both the weekday and weekend/holiday SAA CBLs, a threshold of 25% may be used in removing particular days from use in generating the SAA CBL. This is described in further detail below. When generating the weekday or weekend/holiday SAA CBLs, one lowest energy load participation day may be removed from use in generating the weekday or weekend/holiday SAA CBL. This is also further described below.

[0317] In the event that no days are available in the 45 day window for use in generating an SAA CBL, for the both weekday and the weekend/holiday SAA CBLs, days that include participation in the ELDR program may be used in generating the SAA CBL. The participation days used may be the highest electric load days that include participation in the ELDR program. For both SAA CBLs, Table 1 indicates that a particular offset may be used in the SAA CBL, an SAA offset. Table 1 further indicates that this offset may be negative. For a same-day CBL, there may be no offset. The adjustment may be determined based on hours starting four hours before the beginning of participation in the ELDR program. For an SAA CBL, three hours may be used in calculating the SAA adjustment.

[0318] Baseline generator **1002** can be configured to generate a customer baseline load (CBL). Baseline generator **1002** can be configured to generate an SAA baseline and/or a same day baseline. In some embodiments, a user may indicate via user device **1013**, a selection of SAA or same-day baseline. Based on the selection, baseline generator **1002** can be configured to generate a CBL indicative of the selected CBL type. In some embodiments, baseline generator **1002** receives a selection of CBL type from incentive program **1012**. In this regard, baseline generator **1002** can be configured to generate a CBL based on the CBL type indicated by the selection of the incentive program **1012**. In some embodiments, incentive program **1012** determines which baseline should be used by controller **1000**. Incentive program **1012** may provide a user with a tool (e.g., web tool) to determine which type of CBL (i.e., SAA CBL or same-day CBL) is applicable for a particular customer.

Same Day CBL

[0319] Baseline generator **1002** can be configured to generate a same day CBL based on a predicted load received from load predictor **1016** and/or participation hours received from participation predictor **1004**. The predicted load information may indicate the electric load of a building (e.g., buildings **116**) at various hours, minutes, seconds, days, weeks, months, etc. in the future.

[0320] Baseline generator **1002** can be configured to use the equation below to generate a same day CBL. The same-day CBL may be an average of three hours one hour prior to the first hour of participation and two hours one hour after participation. In some embodiments, baseline generator **1002** can be configured to use the equation below to generate a same-day CBL. In the equation below, e_{CBL} represents

the same-day CBL. The values ES and EE represent a starting hour (ES) and an ending hour (EE) for the time period of participation in the ELDR program (e.g., the first hour of participation and the last hour of participation in a participation day). The starting hour and the ending hour may be the starting and ending hours of the participation hours received from participation predictor **1004**. In some embodiments, participation predictor **1004** provides baseline generator **1002** with ES and EE hours of the participation hours in order to "search" the participation hours for hours that are optimal.

[0321] The term e_i may be the electric load during the i^{th} hour. In some embodiments, e_i is predicted electric load value received from load predictor **1016**. Similarly, e_1 may be a value indicative of the predicted electric load of building (e.g., buildings **116**) during the j^{th} hour. In some embodiments, e_1 is a predicted load value received from load predictor **1016**.

$$e_{CBL,k} = \frac{\sum_{i=ES-4}^{ES-2} e_i + \sum_{j=EE+2}^{EE+3} e_j}{5} \forall\, k = 1 \ldots 24$$

[0322] Incentive program module **912** can be configured to not participate in the earliest three hours of a day and the last two hours in the day. This may be a rule set by incentive program **1012** to make sure that there are enough hours to be used by baseline generator **1002** to generate the same-day CBL. For this reason, the ELDR program may not allow a customer to participate in the first three hours of a day and the last two hours of a day to make sure that a same day CBL can be calculated for any day. The same day CBL may be a constant CBL, i.e., the CBL may be the same for every participation hour. This is illustrated in FIG. **13** where the same day CBL is shown as a horizontal line.

[0323] Baseline generator **1002** can be configured to generate an SAA CBL. An SAA CBL may be a CBL that is a standard tariff defined CBL which may be applicable for most non-variable economic demand resources. Baseline generator **1002** can be configured to generate the SAA CBL based on electric load information received from building status monitor **624**. In some embodiments, baseline generator **1002** stores electric load information received from building status monitor **624** and predicted load information received from load predictor **1016** and uses the electric load information and the predicted load information to generate the SAA CBL.

[0324] Baseline generator **1002** can be configured to generate an SAA CBL based on the day which the participation in the ELDR program occurs. Baseline generator **1002** can be configured to determine if the participation time in the ELDR program occurs on a weekday or a weekend and/or holiday and generate an SAA CBL based on whether the participation in the ELDR program falls on a weekday, weekend, or holiday (i.e., generate a weekday SAA CBL or a weekend/holiday CBL).

[0325] The SAA CBL may average a different number of days based on what type of day (e.g., weekday, weekend, or holiday), participation in the ELDR program occurs (see Table 1, CBL Basis Days). If the day that participation in the ELDR program occurs is a weekday, baseline generator **1002** can be configured to average four days with the highest electric load out of five days that are the most recent weekdays in which controller **1000** has not participated in the ELDR program. If the day that participation in the ELDR Program occurs is a weekend or holiday, baseline generator **1002** can be configured to average two weekends or holidays with the highest electric load out of the three most recently occurring weekend or holiday days in which controller **1000** has not participated in the ELDR program (see Table 1, Exclude X Number Of Low Usage Days).

Weekday SAA CBL

[0326] The description below is an example of determining a weekday SAA CBL by baseline generator **1002**. Baseline generator **1002** can be configured to generate a weekday SAA CBL based on the equations illustrated below. The equation immediately below may indicate the five most recently occurring days with no participation in the ELDR program. Baseline generator **1002** can be configured to identify these five week days when the participation day is a weekday and three weekends or holidays when the participation day is a weekend or holiday. For this example, the participation day is a weekday and the term D is the set of weekdays (excluding weekday holidays), i.e., d_1, d_2, d_3, d_4, d_5. These days may be days that controller **1000** has not participated in the ELDR program and that are the most recently occurring weekdays. Baseline generator **1002** may store a historical log of weekdays, weekends, and holidays. The log may indicate whether a particular day included participation in the ELDR program. Baseline generator **1002** can be configured to retrieve the five most recent non-participation days from the historical log.

$$D=\{d_1,d_2,d_3,d_4,d_5\}$$

[0327] Baseline generator **1002** can be configured to receive electric loads for a plurality of days and hours for the past from building status monitor **624**. The equation below indicates the hours of each day of the set of days above, where d_i is an hourly load vector. Thus, the following equation can represent the electric load for each hour of a day, i.e., for each day of the set of days in the above equation. In the following equation, the day term, d_i, may be a day with a set of electric loads at each hour of an i^{th} day. The term e_{ij} may represent the electric load on the i^{th} day at the j^{th} hour which may be an electric load received from building status monitor **624**.

$$d_i=[e_{i1} \ldots e_{i24}]$$

[0328] Baseline generator **1002** can be configured to generate a daily average event period electric load for each day of the set of days, D. Baseline generator **1002** can be configured to use the equation below to generate the daily average for each day. For a particular day that controller **1000** is participating in the ELDR program, baseline generator **1002** can be configured to generate a daily average event period electric load. In the equation below, the term $\bar{d}_i$ represents the daily average event period electric load. The term $k \in$ participation represents the participation hours of the day that controller **1000** will be participating in the ELDR program, the participation hours received from participation predictor **1004**. These hours may not need to be contiguous. The term n may represent the total number of hours that that controller **1000** will be participating in the ELDR program (e.g., the total number of participation hours received from participation predictor **1004**). This may cause

the daily average event period electric load to be based on hours that controller **1000** will be participating in the ELDR program.

$$\bar{d}_i = \sum_{k \in participation} \frac{e_{ik}}{n} \forall\, i = 1, \ldots, 5$$

[0329] After determining the daily average event period electric load, baseline generator **1002** can be configured to average the daily average event period electric load for each of the five days of the set of days, D. The term $\bar{D}$ represents the average of each daily average event period electric load, $\bar{d}_i$.

$$\bar{D} = \sum_{i=1}^{5} \frac{\bar{d}_i}{5}$$

[0330] After determining the average $\bar{D}$, baseline generator **1002** can be configured to remove days from the set of days, D. Baseline generator **1002** can be configured to use the relationship, $\bar{d}_i < 0.25 \times \bar{D}$ to remove days from the set of days, D (see Table 1 for 0.25, Exclude Average Event Period Usage Less Than A Threshold). If any of the days $\bar{d}_i$ meets the requirement of the relationship, those days are removed from the set of days, D, and the most recent non-event day is used to determine $\bar{D}$ a second time. In some embodiments, baseline generator **1002** only uses the most recent non-event days that occur 45 days before the day which controller **1000** is participating in the ELDR program. Baseline generator **1002** can perform as many iterations of this process as necessary until all of the days of the set of days D are greater and/or equal to, 0.25×D.

[0331] Once, the set of days D is finally determined by baseline generator **1002**, baseline generator **1002** can be configured to determine an hourly average of four of the five days, the four days having the highest electric loads. If baseline generator **1002** cannot determine five days that do not meet the condition $\bar{d}_i < 0.25 \times \bar{D}$ 45 days prior to the day that controller **1000** will be participating in the ELDR program but can only find four days, baseline generator **1002** can average the four days and may not exclude any days from the average. If baseline generator **1002** only finds three or less days that do not meet the criteria within the forty five day window, then baseline generator **1002** can be configured to select the most recent event day (i.e., a day in which controller **1000** participated in the ELDR program) and use the event day in the determination of the CBL. These event days may be the highest electric load event days of the last 45 days. Baseline generator **1002** can be configured to use event days so that the set of days, D, has at least four days that do not meet the criteria $\bar{d}_i < 0.25 \times D$.

[0332] The following equation can be used by baseline generator **1002** to generate a preliminary CBL. The preliminary CBL may be an hourly average of the four days of five days that do not meet the criteria $d_i < 0.25 \times D$. The four days may be days that make the relationship $i \neq \arg_i \min(\bar{d}_i)$ true, i.e., the four days do not make $\bar{d}_i$ be a minimum. In the equation below, the term $\bar{e}_i$ represents the hourly average for a plurality of hours.

$$\bar{e}_j = \sum_i \frac{e_{ij}}{4} \quad i \neq \arg_i \min(\bar{d}_i)$$

[0333] Baseline generator **1002** can be configured to offset the preliminary CBL to determine the CBL, the "standard CBL" (e.g., the CBL that baseline generator **1002** provides to participation predictor **1004**). The standard CBL is represented by the term e_{CBL} below which is a set of CBL values for each hour of a day.

$$e_{CBL} = [e_{CBL,1} \ldots e_{CBL,24}]$$

[0334] Baseline generator **1002** can be configured to generate the CBL by offsetting the preliminary CBL, with an SAA value, e_{SAA}.

$$e_{CBL,j} = \bar{e}_j + e_{SAA}$$

[0335] Baseline generator **1002** can be configured to determine $e_{CBL,j}$ by first determining the SAA value, e_{SAA}. The equation below illustrates one method that baseline generator **1002** can be configured to use to determine e_{SAA}. In the equation below, the term EE may represent the starting hour of participation in the ELDR program by controller **1000** while ES may represent the ending hour of participation in the ELDR program (e.g., the hours defined by the participation hours). The time between EE-2 and ES-4 may represent the SAA hours (e.g., SAA hours **1406** of FIG. **14**). The term e_{0k} may represent the electric load at the k^{th} hour of the participation day while the value $\bar{e}_k$ may represent the average electric load over the hour. The values e_{0k} and $\bar{e}_k$ may be and/or be based on predicted load information received from load predictor **1016**. In some embodiments, the values e_{0k} and $\bar{e}_k$ are determined by baseline generator **1002** based on the predicted load information received from load predictor **1016**.

$$e_{SAA} = \sum_{k=ES-4}^{EE-2} \frac{e_{0k} - \bar{e}_k}{3}$$

[0336] It should be noted that the electric load during the SAA hours, i.e., between ES−4 and EE−2, impact the CBL, e_{CBL} such that a high electric load during the SAA hours results in a higher baseline. Thus, increasing the curtailment amount and increasing the revenue from participation in the EDLR program. Similarly, a low electric load during the SAA hours results in a lower baseline, thus decreasing the amount reduced and decreasing revenue earned in the participation in the ELDR program. For this reason, incentive program **1012** may have rules in place that prohibit controller **1000** from artificially raising the electric load of building (e.g., buildings **116**) during the SAA hours to artificially increase the CBL and thus increase revenue. Incentive program **1012** may use a plurality of rules to determine whether controller **1000** abnormally raised the electric load during the SAA hours and may reject settlements with controller **1000** where controller **1000** artificially raised the electric load. However, incentive program **1012** may allow controller **1000** to increase an electric load during the SAA in response to energy price changes without penalizing (i.e., rejecting a settlement) controller **1000**.

Weekend/Holiday SAA CBL

[0337] Baseline generator **1002** can be configured to generate weekend/holiday SAA CBL. Baseline generator **1002** can be configure to generate the weekend/holiday SAA CBL based on the electric load information received from building status monitor **624** and the predicted load information received from load predictor **1016**. Baseline generator **1002** may generate the weekend/holiday SAA CBL in the same way as it generates the weekday SAA CBL. However, baseline generator **1002** can be configured to use the three most recent Saturdays, Sundays, or Holidays that are not days that controller **522** has participated in the ELDR program as opposed to using weekdays. Of the three days selected by baseline generator **1002** for generating a weekend/holiday SAA CBL, baseline generator **1002** may use two of the three days with the highest electric load, in the same way the baseline generator **1002** uses four of the five days of the set D when generating a weekday CBL. The baseline generator **1002** may be configured to not use any Saturday, Sunday, or Holiday that falls on a daylight savings time day (e.g., the day begins a daylight savings time period or ends a daylight savings time period) (e.g., clocks are shifted backward or forward at the beginning or the ending of the day).

[0338] Incentive program module **912** is shown to include participation predictor **1004**. Participation predictor **1004** is shown to receive the CBL from baseline generator. Further, Participation predictor **1004** is shown to receive a predicted LMP from LMP predictor **1014** (e.g., a predicted day-ahead LMP and a predicted real-time LMP). Participation predictor **1004** can be configured to generate participation hours. Participation predictor **1004** can be configured to provide selector **1008** with the participation hours.

[0339] Participation predictor **1004** can be configured to generate and/or determine (e.g., predict) participation hours. In some embodiments, the participation hours are a vector or mask (e.g., a participation mask) of ones and zeros. The participation hours may represent a full day, e.g., the participation mask may include twenty four total ones and zeros where a one represents participation and a zero represents no participation at a particular hour. The participation hours are provided to selector **1008**. Participation predictor **1004** can further be configured to provide the participation hours to baseline generator **1002**. Participation predictor **1004** can be configured to use the CBL received from baseline generator **1002** to further determine the participation hours.

[0340] Participation predictor **1004** can be configured to set all hours of the participation hours to 0 (e.g., all hours of a particular day to no participation), indicating no participation in any of the hours. Based on a NBT threshold value received from incentive program **1012**, the predicted LMPs received from LMP predictor **1014**, and/or a CBL received from baseline generator **1002**, participation predictor **1004** can be configured to select hours that controller **1000** will participate in the ELDR program. In some embodiments, incentive program module **912** retrieves the NBT threshold value once every month after the 15^{th} of the month from incentive program **1012**, the NBT threshold being the NBT threshold for the next month. In some embodiments, participation predictor **1004** may set none, one, some, or all of the participation hours to 1, indicating participation except hours restricted by incentive program **1012** (e.g., hours restricted by incentive program **1012** based on CBL type).

[0341] Participation predictor **1004** can be configured to compare the predicted day-ahead LMP and the predicted real-time LMP for each hour of a day to the NBT threshold value to determine if the associated hour should be a participation hour. The steps below illustrate steps that participation predictor **1004** can be configured to perform to determine the participation hours. These steps are further illustrated in FIG. **11**A. In some embodiments, only one of the conditions of steps **1104** and **1106** need to be true to set an hour to participation. Participation predictor **1004** can be configured to perform steps **1102-1112** to generate the participation hours or only perform steps **1102-1108** to generate the participation hours. The participation mask generated by participation predictor **1004** can be provided to selector **1008**. The participation hours may be the hours where p_i=1.

[0342] Referring now to FIG. **11**A, a process **1100** for determining participation hours and transmitting a bid to incentive program **1012** is shown, according to an exemplary embodiment. Controller **1000** and the various components of controller **1000** can be configured to perform process **1100**. Further, energy storage controller **506**, controller **552**, and/or planning tool **702** can be configured to perform process **1101**. In some embodiments, planning tool **702** may not send any bid to incentive program **1012** i.e., may not perform step **1120** of process **1100**. In some embodiment, participation predictor **1004** can be configured to perform steps **1102-1108** or steps **1102-1112** of process **1100** to generate the participation hours based only on the NBT threshold and not on the CBL.

[0343] Step **1102**: Set all participation hours to no participation, i.e., initialize a participation mask p_i and set p_i=0

[0344] Step **1104**: Set p_i=1 where $r_{DA_i} \geq$NBT

[0345] Step **1106**: Set p_i=1 where $r_{RT_i} \geq$NBT

[0346] Step **1108**: The participation hours are the hours where the conditions in Step **1104** or Step **1106** are true

[0347] In step **1102**, participation predictor **1004** can set all participation hours to zero or otherwise to no participation. In some embodiments, the participation hours are represented by a participation mask, p_i. The participation mask may be a vector of ones and zeros which indicate either participation or no participation at various hours of an optimization period (e.g., a day). In step **1118**, participation predictor **1004** can initialize the participation mask and set the entire participation mask to zero (e.g., all hours of the participation mask to zero).

[0348] In steps **1104** and **1106**, participation predictor **1004** can determine that the participation hours are hours where the predicted day-ahead LMP received from LMP predictor **1014** is greater than the NBT threshold or the predicted real-time LMP received form the LMP predictor **1014** is greater than the NBT threshold. In some embodiments, process **1100** may include one or both of steps **1104** and **1106**. In this regard, the participation hours may be based on the predicted real-time LMP and/or the day ahead LMP. In step **1108**, participation predictor **1004** can determine that the participation hours are the hours where the conditions of step **1104** or **1106** are true.

[0349] In some embodiments, participation predictor **1004** can be configured to perform steps **1102-1112** to generate the participation hours. This approach may assume a constant maximum energy reduction.

[0350] Step **1102**: Set all participation hours to no participation, i.e., initialize a participation mask p_i and set $p_i=0$

[0351] Step **1104-1108**: Determine that the participation hours are hours where $r_{DA_i} \geq NBT$ or $r_{RT_i} \geq NBT$ are true

[0352] Step **1110**: Determine ES and EE from the equation:

$$\min_{ES,EE}\left(-\sum_{i=ES}^{EE}\hat{r}_{RT_i}(\hat{e}_{CBL,i}-\max((\hat{e}_i-P_{max}),P_{gridLimit}))\right)$$

with p_i as search hours

[0353] Step **1112**: The participation hours are the hours between the determined ES and EE

[0354] In steps **1102-1108** above, participation predictor **1004** can determine hours that participation is allowed. These hours may act as a search space for step **1110**. The search hours may be provided by participation predictor **1004** to baseline generator **1002** for determining $\bar{e}_{CBL,i}$ in order to determine ES and EE which are used to refine the participation hours.

[0355] In step **1110**, participation predictor **1004** can minimize the equation with the participation hours determined in steps **1120-1124**. The equation of step **1126** is shown to be dependent on a CBL, a predicted electric load, and a real-time LMP. Further, the equation is dependent on $P_{gridLimit}$ and P_{max}. Minimizing the equation can maximize potential revenue from participating the in ELDR program. The term, $\hat{e}_{CBL,i}$ may be a CBL determined by baseline generator **1002**. This may be a CBL for a plurality of hours based on the search hours determined in steps **1104-1108**. The CBL is a function of the event start, ES, and event end, EE hours. The CBL may be a CBL for a plurality of hours, e.g., the i^{th} hours. In some embodiments, the CBL is an SAA CBL, in other embodiments, the CBL is a same-day CBL. The term $\hat{r}_{RT_i}$ may be a real-time predicted LMP received from LMP predictor **1014** for a plurality of hours, e.g., the i^{th} hours while r_{DA_i} may be a day-ahead predicted LMP received from LMP predictor **1014** for a plurality of hours, e.g., the i^{th} hours

[0356] Further, the $\hat{e}_i$ term may represent a predicted electric load. The predicted electric load may be received from load predictor **1016**. Further, the equation of step **1110** is shown to include terms P_{max} and $P_{gridLimit}$. These may be constant values stored by participation predictor **1004**. In some embodiments, P_{max} is a customer based value. This amount may indicate the maximum amount a customer can reduce their electric load by. P_{max} may be based on equipment of a customer. For example, a value for P_{max} may be 12 MW for a customer that has two co-gens. In some embodiments, $P_{gridLimit}$ is a value received from a utility. The value $P_{gridLimit}$ may be a minimum imposed on the customer by the utility. In some embodiments, P_{max} and $P_{gridLimit}$ are constants over all hours. In various embodiments, P_{max} and $P_{gridLimit}$ are hourly values. Based on the ES and the EE values determined by participation predictor **1004**, participation predictor **1004** can determine, in step **1112**, that the participation hours are between the ES and the EE hours.

[0357] Referring again to FIG. **10**, selector **1008** can be configured to receive the participation hours from participation predictor **1004**. Selector **1008** can be configured to further receive user hours from user device **1013**. Selector **1008** can be a component that can be configured to select between user hours and participation hours. User hours may have a priority above the participation hours. When selector **1008** receives user hours but does not receive participation hours, selector **1008** can be configured to output participation hours as user hours, regardless of the participation hours received from participation predictor **1004**. If selector **1008** does not receive user hours, selector **1008** can be configured to output the participation hours received from participation predictor **1004**.

[0358] Selector **1008** can be configured to provide cost function modifier **1010** and bid controller **1006** with participation hours. Bid controller **1006** can be configured to receive participation hours from selector **1008** and load information from cost function modifier **1010**. Based on the load information and the participation hours, bid controller **1006** can be configured to generate a bid to send to incentive program **1012**.

[0359] Bid controller **1006** can be configured to generate a bid for participation in the ELDR program based on the participation hours received from selector **1008** and send the bid to incentive program **1012**. In some embodiments, bid controller **1006** is configured to refine the participation hours by determining, based on a CBL, whether a participation hour received from selector **1008** should be included in a bid. In some embodiments, the CBL is determined by bid controller **1006** based on the participation hours and an electric load received from cost function modifier **1010**, Since bid controller **1006** can be configured to generate a CBL for the participation hours it receives, bid controller **1006** may include an instantiation of baseline generator **1002** and/or may otherwise include all of the functionality of baseline generator **1002**.

[0360] Referring again to FIG. **11**A, bid controller **1006** can be configured to perform steps **1114-1120**. Bid controller **1006** can send bids to incentive program **1012** based on the rules of the ELDR program as described above. Bid controller **1006** can perform steps **1114-1120** of process **1101** to generate a bid and send the bid to incentive program **1012**.

[0361] Step **1114**: Determine a CBL based on the participation hours

[0362] Step **1116**: Subtract the load from the CBL values for the participation hours

[0363] Step **1118**: Remove participation hours where the difference is less than or equal to zero

[0364] Step **1120**: Transmit a bid to an incentive program

[0365] In step **1114**, bid controller **1006** can calculate CBL values for each hour of the participation hours received from selector **1008**. Bid controller **1006** is shown in FIG. **10** to include an instantiation of baseline generator **1002**. In this regard, bid controller **1006** can use the participation hours received from selector **1008** and baseline generator **1002** to generate the CBL. In some embodiments, bid controller **1006** uses the participation hours to determine a CBL for each hour of the participation hours. Bid controller **1006** can use the CBL it generates and the participation hours to determine CBL values for the participation hours.

[0366] In step **1116**, bid controller **1006** can subtract the load received from cost function modifier **1010** for each hour of the participation hours from the CBL load values. This may be the curtailment amount. In **1118**, in response to determining that the difference is less than or equal to zero

for a particular hour, bid controller **1006** can remove that hour from the participation hours. In step **1120**, based on the modified participation hours (or unmodified participation hours), bid controller **1006** can transmit a bid to incentive program **1012** indicative of the participation hours and/or the curtailment amount at each participation hour (e.g., a baseline amount minus the load received from cost function modifier **1010**).

[0367] Referring again to FIG. **10**, based on the bid transmitted by bid controller **1006** to incentive program **1012**, incentive program **1012** can be configured to approve or reject the bid. Any hours that incentive program **1012** determines are appropriate may be transmitted to participator **1018** as awarded hours. These may be hours that controller **1000** may be required to reduce the electric load of building (e.g., buildings **116**) based on the electric load and/or the electric load reduction for each hour of the awarded hours that was originally transmitted to incentive program **1012** via bid controller **1006**.

[0368] Participator **1018** can be configured to receive the awarded hours from incentive program **1012** and further receive an electric load for each awarded hour from cost function modifier **1010** (or from high level optimizer **632**). The awarded hours may indicate hours that controller **1000** must participate in the ELDR program at a particular electric load amount. These may be hours that controller **1000** cannot change a decision to participate or not participate in the ELDR program. In some embodiments, the awarded hours can be changed if the controller **1000** adjusts or otherwise changes a bid. Participator **1018** can be configured to cause HVAC equipment to operate to meet the electric loads during the awarded hours. In some embodiments, the HVAC equipment includes batteries, co-gens, lighting systems, gas turbines, chillers, air handlers, and/or any other piece of HVAC or building equipment that consumes electricity as described herein or known in the art.

[0369] High level optimizer **632** is shown to include cost function modifier **1010**. Cost function modifier **1010** can be configured to modify a cost function that high level optimizer **632** can be configured to generate. The cost function (e.g., cost function module **902**), further described in FIG. **9** may be a cost function that includes costs and benefits from operating various subplants and participating in various programs, e.g., a frequency regulation program and/or an ELDR program. As described elsewhere herein, the cost function may be in the form of the following equation.

$$J(x) = \sum_{sources}\sum_{horizon} \text{cost}(purchase_{resource,time}, \text{time}) - \sum_{incentives}\sum_{horizon} \text{revenue}(ReservationAmount)$$

[0370] As described elsewhere herein, the cost function can be optimized based on various constraints. These constraints may be the constraints illustrated below and/or elsewhere herein. These constraints may balance between resources purchased, produced, discharged, consumed, and requested over an optimization period.

$$\sum_{sources} purchase_{resource,time} +$$

-continued

$$\sum_{subplants} produces_{resource}(x_{subplants,internal\ decision,time}, x_{externaldecision,time}, \text{uncontrolled } variable_{time}) \ldots -$$

$$\sum_{subplants} consumes_{resource}(x_{subplant,internaldecision,time}, x_{externaldecision,time}, \text{uncontrolled } variable_{time}) \ldots +$$

$$\sum_{storages} discharges_{resource}(x_{storage,internaldecision,time}, x_{externaldecision,time}) -$$

$$\sum_{sinks} requests_{resource} =$$

$$0 \forall \text{ resources}, \forall \text{ time} \in \text{horizon}$$

[0371] Cost function modifier **1010** can be configured to generate a term for the cost function, the ELDR term. The ELDR term may have the following format, where k is the length of an optimization period hours (e.g., 24 for a full day), k is an instant in time of the optimization period (e.g., 1, 2, 3 . . . 24 for each hour of a day), his the length of the optimization period, p_i includes the participation hours (e.g., either 1 or 0) for each hour, $e_{CBL,i}$ is the value of CBL at each time interval, and e_i is the electric load at each time interval (e.g., at each hour) of the optimization period. In some embodiments, the CBL is a CBL received from bid controller **1006** that is a CBL based on the participation hours. In some embodiments, cost function modifier **1010** includes some and/or all of the functionality of baseline generator **1002** and can be configured to generate a CBL based on the participation hours received from selector **1008**. The term $\hat{r}_{RT_i}$ may be the predicted real-time LMP generated by LMP predictor **1014**.

$$-\sum_{i=k}^{k+h-1} p_i \hat{r}_{RT_i}(e_{CBL,i} - e_i)$$

[0372] The cost function may have any number of terms, terms relating to various programs (e.g. other MDR programs), resource consumption, etc. The cost function below highlights a cost function that includes an ELDR term. The ELDR term can be added to the cost function by cost function modifier **1010**, according to some embodiments. The term $\hat{r}_{e_i}$ may be an actual electric rate at each instant in time or a predicted electric rate at each instant in time. The term e_i may be electric load and may be a decision variable of the cost function that can be optimized for a plurality of hours by optimizing the cost function. The cost function may include other decision variables, for example, decision variables for battery allocation, chilled water production, and/or any other decision variable. In this regard, the electric load of the cost function may depend on other decision variables of the cost function.

$$J = \sum_{i=k}^{k+h-1} \hat{r}_{e_i} e_i \ldots - \sum_{i=k}^{k+h-1} p_i \hat{r}_{RT_i}(e_{CBL,i} - e_i)$$

[0373] The ELDR term may be a bilinear term since the term is a function of both the participation hours and the

electric load. The bilinear cost function can be solved using mixed integer linear programming (MILP). The cost function can be solved via a cascaded approach in some embodiments. In some embodiments, in order to solve the optimization problem using linear programming, it may be necessary to linearize the ELDR term. Linearization can be achieved by making the assumption that the participation hours are known and are not part of the decision variables of the optimization problem. For this reason, participation predictor **1004** can make a preliminary decision as to the participation hours and these hours are used by cost function modifier **1010**. This may be a cascaded approach to solving the optimization problem.

[0374] Cost function modifier **1010** (or high level optimizer **632**) can be configured to linearize the cost function so that the cost function can be optimized via linear programming or any other optimization. The cost function above can be linearized into the following equation.

$$J = \sum_{i=k}^{k+h-1} (\hat{r}_{e_i} + a_i)e_i$$

where

$a_i = f(\hat{r}_{RT_j}) < 0 \ \forall \ i \in CBL \text{ hours} / j \in \text{Participation Hours}$

$a_i = \hat{r}_{RT_j} \ \forall \ i \in \text{Participation Hours}$

$a_i = 0$ otherwise

[0375] It can be seen in the above equation that the term, a_i, is an adjustment to the electric rate, $\hat{r}_{e_i}$. For this reason, it can be understood that participation in the ELDR program is the equivalent of a rate adjustment, an adjustment a_i. Participation in the ELDR program may be represented in the cost function as an electric rate adjustment. The electric rate adjustment may be an electric rate adjustment during participation hours and hours used to determine a baseline. High level optimizer **632** can be configured to determine an electric load for various hours based on the rate adjustment. In some embodiments, the participation hours are used by cost function modifier **1010** to determine the necessary electric rate adjustment during the participation hours and/or during the baseline hours. In some embodiments, the electric rate adjustment is a function of the baseline, the participation hours, the predicted real-time LMP and/or the day-ahead LMP.

[0376] High level optimizer **632** can be configured to optimize the cost function modified by cost function modifier **1010**. In some embodiments, the optimization is based, at least in part, on the electric rate adjustment. In some embodiments, high level optimizer **632** can be configured to use linear programming to optimize the modified cost function. In various embodiments, high level optimizer **632** uses various constraints when optimizing the modified cost function. High level optimizer **632** can be configured to use optimization algorithms (e.g., linear programming, quadratic programming, etc.), iterative methods, global convergence, and/or heuristics and/or any other optimization algorithm or method to optimize the cost function. Optimization and the cost function are further described with reference to FIG. **9** and elsewhere herein. High level optimizer **632** can be configured to determine a plurality of decision variables (e.g., e_i, an electric load) and provide the electric load to bid controller **1006**. Further, controller **1000** (e.g. participator **1018**) can be configured to cause building equipment to be operated to meet the electric loads.

[0377] To illustrate the optimization, consider the following example. Cost function modifier **1010** may receive participation hours for a 24 hour optimization period from selector **1008**. The participation hours may indicate participation in the ELDR program at the tenth hour of the day through the eighteenth hour of the day. The participation hours can be represented by the vector p_j, and is illustrated below.

$$p_i = \begin{cases} 1 & \forall \ i = 10 - 18 \\ 0 & \text{otherwise} \end{cases}$$

[0378] In this example, the CBL is a constant CBL, a same day CBL. The CBL is illustrated by the equation below.

$$e_{CBL,i} = \frac{e_6 + e_7 + e_8 + e_{20} + e_{21}}{5}$$

[0379] Cost function modifier **1010** can be configured to modify a cost function generated by high level optimizer **632**. The modified cost function is shown in the equation below. The CBL received from baseline generator **1002**, $e_{CBL,i}$, is an input to the EDLR term of the cost function below. Further, the participation hours, p_i, is another binary input to the ELDR term. As can be seen in the cost function below, the optimization period is a day, i.e., 24 hours. For this reason, the summation functions below include indices 1-24. In various embodiments, the optimization period is a day, a month, a year, and/or any other length of time.

$$J = \sum_{i=1}^{24} \hat{r}_{e_i} e_i - \sum_{i=1}^{24} p_i \hat{r}_{RT_i} (e_{CBL,i} - e_i) + \ldots$$

[0380] As an example, the CBL illustrated in the above equation can be substituted directly into the cost function illustrated above. The result is the following equation.

$$J = \sum_{i=1}^{5} \hat{r}_{e_i} e_i + \left(\hat{r}_{e_6} - \frac{\sum_{i=10}^{18} \hat{r}_{RT_i}}{5} \right) e_6 + \left(\hat{r}_{e_7} - \frac{\sum_{i=10}^{18} \hat{r}_{RT_i}}{5} \right) e_7 +$$

$$\left(\hat{r}_{e_8} - \frac{\sum_{i=10}^{18} \hat{r}_{RT_i}}{5} \right) e_8 + \hat{r}_{e_9} e_9 + \sum_{i=10}^{18} (\hat{r}_{e_i} + \hat{r}_{RT_i}) e_i + \hat{r}_{e_{19}} e_{19} +$$

$$\left(\hat{r}_{e_{20}} - \frac{\sum_{i=10}^{18} \hat{r}_{RT_i}}{5} \right) e_{20} + \left(\hat{r}_{e_{21}} - \frac{\sum_{i=10}^{18} \hat{r}_{RT_i}}{5} \right) e_{21} + \sum_{i=22}^{24} \hat{r}_{e_i} e_i$$

[0381] As can be seen in the equation above, the electric rates, $\hat{r}_{e_i}$, are adjusted by either a negative rate adjustment, a positive rate adjustment, or are not adjusted. For CBL hours, the rate adjustment may be negative. For participation hours,

the rate adjustment may be positive. For hours that are neither CBL hours nor participation hours, there may be no rate adjustment. For example, based on the equation above, the rate adjustment may be

$$-\frac{\sum_{i=10}^{18}\hat{r}_{RT_i}}{5}$$

for hours 6-8 and 20 and 21 since these hours are CBL hours. The rate adjustment may be $\hat{r}_{RT_i}$ for hours 10-18 since these hours are participation hours. Further, for the hours that are neither CBL hours nor participation hours, there may be no rate adjustment.

[0382] In this example, since the electric rates are lower during the CBL hours and higher during the participation hours, it should be expected that the optimization will make the decision to lower the electric use during the participation hours. As a physical example, if a battery exists in building (e.g., buildings **116**), based on the optimization (e.g., the electric loads) controller **1000** will tend to charge the battery during the CBL hours and discharge it during the participation hours. Further, if a co-gen exists in the building, based on the optimization (e.g., the electric loads) controller **1000** will tend to turn the co-gen on during the participation hours and turn the co-gen off during the CBL hours.

[0383] Referring now to FIG. **11**B, a flow diagram of a process **1101** for using a cost function to determine optimal electric loads for participation in an ELDR program is shown, according to an exemplary embodiment. Controller **1000**, and the various components of controller **1000**, can be configured to perform process **1101**. In some embodiments, process **1101** is performed by various components of high level optimizer **632** (e.g., asset sizing module **916**, cost function module **902**, etc.) as described with reference to FIGS. **9-10**. Process **1101** can be performed by frequency response optimization system **100**, photovoltaic energy system **300**, energy storage system **500**, planning system **700**, or any other type of energy storage system.

[0384] In step **1122**, process **1101** is shown to include generating a cost function defining a cost of operating HVAC equipment as a function of electric loads (e.g., decision variables) for the HVAC equipment. In some embodiments, the cost function is the original cost function J(x). The cost function J(x) may include terms that accounts for energy purchase costs, demand charges, and peak load contribution (PLC) charges. In some embodiments, the cost function J(x) accounts for revenue from participating in IBDR programs such as frequency regulation (FR).

[0385] The HVAC equipment may include individual HVAC devices (e.g., chillers, boilers, fans, pumps, valves, batteries, co-gens, etc.) or collections of HVAC devices (e.g., a chiller subplant, a heater subplant, a cooling tower subplant, etc.). In some embodiments, the HVAC equipment include energy storage such as thermal energy storage and/or electrical energy storage (e.g., batteries). Although HVAC equipment is used as an example in process **1101**, it should be understood that any type of equipment can be used. For example, the cost function generated in step **1122** may account for the cost associated with operating any type of equipment.

[0386] In step **1124**, LMP predictor **1014** can generate a predicted real-time LMP and a predicted day-ahead LMP. In some embodiments, LMP predictor **1014** generates the predicted real-time LMP and the day-ahead LMP based on an actual real-time LMP and/or an actual day-ahead LMP received from incentive program **1012**. LMP predictor **1014** can be configured to retrieve and/or receive a real-time LMP from incentive program every fifteen minutes and/or a day ahead LMP once every day. In some embodiments, the prediction is made based on weather data (e.g., daily temperatures, humidities, rain forecasts, etc.) In some embodiments, LMP predictor **1014** stores historical LMP data based on LMP data received from incentive program **1012** and uses the historical LMP data to train a predictive model that LMP predictor **1012** can use to generate a predicted LMP.

[0387] In step **1126**, participation predictor **1004** can generate participation hours.

[0388] Participation predictor **1004** can use a CBL, the predicted real-time LMP, the predicted day-ahead LMP, the predicted electric load, and/or an NBT threshold value. In some embodiments, participation predictor **1004** determines the participation hours by determining that the participation hours are hours where the predicted real-time LMP is greater than or equal to the NBT threshold value or the predicted day-ahead LMP is greater than or equal to the NBT threshold value.

[0389] In some embodiments, participation predictor **1004** further refines the participation hours by using a CBL, the predicted electric load, a maximum power limit, and a grid power limit. Using the participation hours as a searching space (e.g., search hours) participation predictor **1004** can minimize the equation below to determine a starting time (e.g., event start ES) and an ending time (e.g., event end EE) that defines the participation hours.

$$\min_{ES,EE}\left(-\sum_{i=ES}^{EE}\hat{r}_{RT_i}(\hat{e}_{CBL,i}-\max((\hat{e}_i-P_{max}),P_{gridLimit}))\right)$$

[0390] In step **1128**, based on the participation hours, cost function modifier **1010** can generate an ELDR term for the cost function based on the participation hours and a CBL. Cost function modifier can replace the various terms of the ELDR term with the participation hours, a CBL based on the participation hours, and the predicted real-time LMP. The term $e_{CBL,i}$ may be replaced with the CBL, the term $\hat{r}_{RT_i}$ may be replaced with the predicted real-time LMP, while the term p_i may be replaced with the participation hours (e.g., a vector indicating participation at the i^{th} hour).

$$-\sum_{i=k}^{k+h-1}p_i\hat{r}_{RT_i}(e_{CBL,i}-e_i)$$

[0391] In step **1130**, cost function modifier **1010** can modify the cost function with the ELDR term generated in step **1110**. In some embodiments, modifying the cost function involves adding the ELDR term to the cost function. An example of a modified cost function including the ELDR term is the equation below.

$$J = \sum_{i=k}^{k+h-1} \hat{r}_{e_i} e_i - \sum_{i=k}^{k+h-1} p_i \hat{r}_{RT_i} (e_{CBL,i} - e_i)$$

[0392] In step **1132**, high level optimizer **632** optimizes the modified cost function of step **1130**. High level optimizer **632** can use one or more of a plurality of different types of optimizations known in the art. In some embodiments, the optimization is performed by linear programming and/or mixed integer linear programming. In some embodiments, high level optimizer **632** uses one or more constraints when performing the optimization. The result of the optimization may be one or more electric loads, e_i, wherein e_i is the electric load at a plurality of hours, i.

[0393] In step **1134**, bid controller **1006** can generate a bid to send to incentive program **1012**. The bid may be generated based on the participation hours and/or the electric loads. In some embodiments, the bid is further based on the predicted real-time LMP and the predicted day-ahead LMP. In some embodiments, the bid includes a curtailment amount which bid controller **1006** can determine. The curtailment amount may be the difference between a CBL and the electric load at each of a plurality of hours. The bid may further include the participation hours. Finally, the bid may include a compensation amount and/or rate for each hour. The compensation rate may be the predicted real-time LMP and/or the predicted same day LMP and/or a compensation amount determined based on the predicted real-time LMP and/or the predicted same day LMP. In some embodiments, bid controller **1006** can remove participation hours from the bid where the participation hours have a corresponding curtailment less than or equal to zero.

[0394] In step **1136**, participator **1018** can receive awarded hours. The awarded hours may be hours bid controller **1006** sends to incentive program **1012**. Participator **1018**, high level optimizer and/or otherwise controller **1000** can control the HVAC equipment based on the awarded hours and the electric loads that correspond to the awarded hours. In some embodiments, participator **1018** uses an operating constraint to operate the HVAC equipment based on the electric loads for the awarded hours.

[0395] Referring now to FIG. **12** a graph **1200** illustrating participation in the ELDR program is shown, according to an exemplary embodiment. Graph **1200** is shown to include electric load in kilowatts on the vertical y-axis and time in hours on the horizontal x-axis. The solid line, electric load **1202**, represents a typical electric load of a campus (e.g., campus **102**), building, or facility. The dotted line indicates the electric load, ELDR load **1204**, of the campus when participating in the ELDR program. Electric load **1202** may represent a typical electric load of campus **102**. As can be seen, ELDR load **1204** is a reduction in electric load as compared to the typical electric load, electric load **1202**. The ELDR load **1204**, indicates a reduction in electric load for the campus during the participation time **1206**

[0396] Referring now to FIG. **13**, a graph **1300** illustrating a same day CBL is shown, according to an exemplary embodiment. Graph **1300** is shown to include CBL **1302** and electric load **1304**. CBL **1302** is shown to be a constant value. Electric load **1304** may represent the electric load of a campus (e.g., campus **102**) over time. Start time **1306** and end time **1308** are shown as vertical lines marking the beginning and the end of a plurality of participation in the ELDR program. In graph **1300**, start time **1306** is hour 11 while end time **1308** is hour 20. CBL Hours **1310** represent the hours that baseline generator **1002** can be configured to use when calculating a same day CBL. CBL hours **1310** are the three hours one hour before the participation time begins. Similarly, CBL hours **1312** can be used by baseline generator **1002** to generate a same day CBL. These hours represent the two hours that occur one hour after the end of the participation period. The curtailment amount in indicted in FIG. **13**. The difference between electric load **1304** and same day CBL **1302** is the curtailment amount.

[0397] Referring now to FIG. **14**, a graph **1400** illustrating an SAA CBL **1402** is shown, according to an exemplary embodiment. SAA CBL **1402** may be an example of the CBL that baseline generator **1002** provides participation predictor **1004** with. In graph **1400**, SAA CBL **1402** is shown in addition to electric load **1404**. As can be seen, electric load **1404** is reduced between start time **1410** and end time **1412**. The length of time between start time **1410** and end time **1412** may represent the time that controller **1000** participates in the ELDR program, CBL hours **1408**. SAA CBL **1402** may be determined by baseline generator **1002**. The equation below may represent SAA CBL **1402**.

$$e_{CBL} = [e_{CBL,1} \ldots e_{CBL,24}]$$

[0398] Start time **1410** and end time **1412** may represent the time that a controller (e.g., controller **1000**) participates in an ELDR program. Graph **1400** is shown to include SAA hours **1406**. SAA hours **1406** may be the duration of three hours that occur one hour before start time **1410**. The electric load **1404** during SAA hours **1406** may be used to calculate e_{SAA} as described with reference to FIG. **10**, specifically baseline generator **1002**. Baseline generator **1002** may use the equation below to generate e_{SAA}. Start time **1410** may correspond to the term ES while end time **1412** may correspond to the term EE. The terms e_{0k} and $\bar{e}_k$ may be derived from electric load **1404**.

$$e_{SAA} = \sum_{k=ES-4}^{EE-2} \frac{e_{0k} - \bar{e}_k}{3}$$

[0399] CBL Hours **1408** may be the hours that are used by baseline generator **1002** to generate the average electric load for each day. CBL Hours **1408** may be represented by the term k∈participation in the equation below. However, it should be understood that the electric load at an hour of CBL Hours **1408**, e_{ik}, is not electric load **1404**. Rather, it is the electric load for the i^{th} day, which is a day prior to the day with participation in the ELDR program illustrated in graph **1400**.

$$\bar{d}_i = \sum_{k \in participation} \frac{e_{ik}}{n} \quad \forall\, i = 1, \ldots, 5$$

[0400] Referring now to FIGS. **15-16**, an interface **1500** for controller **1000** is shown for outputting information for participation in an ELDR program to a user and receiving user input is shown, according to an exemplary embodiment. Interface **1500** may be an interface generated by GUI engine **614**. In various embodiments, interface **1500** is an interface

displayed on a terminal connected to controller **1000** that GUI engine **614** is configured to operate. In various embodiments, interface **1500** is an interface of an application on a mobile device or computer (e.g., user device **1013**). FIG. **15** is an illustration of interface **1500** during participation in an ELDR program on a particular day. FIG. **16** is an illustration of interface **1500** of a previous day on which controller **1000** participated in the ELDR program.

[0401] In FIGS. **15-16**, interface **1500** illustrates electric loads at various hours of a particular day. The hours **1502**, located along the horizontal axis of the graph shown in interface **1500** includes a plurality of boxes for each hour of a day. The boxes allow a user to select one or more times that the user would like to controller **1000** to participate in the ELDR program. The user may only be able to select a time while controller **1000** can be configured to determine the curtailment for the selected time. In various embodiments, the user can also view the hours that controller **1000** has automatically determined it will participate in the ELDR program. In this regard, a user can "deselect" a box that indicates participation to override the participation on the ELDR program at a particular hour or hours. A user can view a plurality of different days in the future and/or in the past. A user may interact with program availability icon **1504** to navigate to a plurality of different days, weeks, months, or years to view the ELDR program participation information for a particular day, week, month, and/or year.

[0402] In interface **1500**, the vertical line, start time **1520**, indicates the start time of participation in the ELDR program while the vertical line, end time **1522** indicates the ending time of participation in the ELDR program. Current time line **1524** indicates the current time of day. The curtailment area **1510** indicates the difference between an actual electric load **1506** and baseline **1508**. In some embodiments, the participation hours are not contiguous, in this embodiment, there may be multiple curtailment areas. Predicted electric load **1512** graphically illustrates a predicted electric load. This may be a plurality of power setpoints that high level optimizer **632** determines by optimizing a cost function. Interface **1500** is further shown to include day-ahead LMP **1516**. Day-ahead LMP **1516** may be the actual day-ahead LMP that controller **1000** receives from incentive program **1012**. Real-time LMP **1514** shown in interface **1500** is a real-time LMP received from incentive program **1012**. Predicted real-time LMP **1518** may be a real-time LMP predicted by LMP predictor **1014**.

[0403] In some embodiments, interface **1500** indicates various information pertaining to the participation in the ELDR program. In some embodiments, a current operating day date is displayed on interface **1500**, a NBT threshold value for the operating day is displayed, and a predicted curtailment amount is displayed. In some embodiments, interface **1500** includes an indicator which indicates which hours are locked and cannot be modified by a user and which hours a user can modify (e.g., hours where the current time is at least three hours before the top of the hour). If a user override is available via interface **1500**, the hours that the user can override may be a particular color and/or have a particular shading. In some embodiments, when a user hovers over curtailment area **1510**, a popup may appear indicating the curtailment amount and a current revenue made (e.g., for the participation period and/or for a particular hour).

[0404] When a particular day is over and/or the ELDR participation is over, interface **1500** may display metrics regarding the performance in the ELDR participation. In some embodiments, the metrics include average curtailment amount and/or ELDR revenue (see FIG. **16**). In various embodiments, interface **1500**, specifically the current operating day, is a default home screen. In various embodiments, a user can select data to display on interface **1500** and can zoom in on various locations of interface **1500**.

[0405] In some embodiments, interface **1500** includes multiple settings that are set in the code of interface **1500** by a programmer or are set by interface **1500** based on the type of baseline that controller **1000** generates. The settings may include a "Calculation" setting. The calculation setting may be a setting to use a median or an average to calculate the CBL. The average or median may be used to calculate the CBL after the usage days have been identified and any low usage days excluded. The setting "CBL Basis Window" may be a display that indicates the typical electric load. The CBL basis window may be the electric load of five days, the five days is used to calculate the CBL. The five days may be all five days used to calculate the CBL or may include any day (e.g., low usage day, participation day, etc.) that would normally be excluded from the CBL calculation. The "CBL Basis Window Limit" may indicate the number of days that will be the pool of days that baseline generator **1002** selects from when determining the CBL. In some embodiments, the number of days prior to the participation day is 45 calendar days. This may be displayed to the user with the explanation that the 45 days ensure recent information is used when predicting future energy consumption e.g., generating a CBL.

[0406] A "Start Selection From Days Prior To Event" display may indicate to the user that baseline generator **1002** selects the most recent days with a similar day type (e.g., weekend, holiday, weekday) to the participation day. A display may indicate "1" or "2." A "1" may indicate that baseline generator **1002** would select the most recent day for calculating the CBL while "2" may indicate that baseline generator **1002** will skip the most recent day when selecting days to use in calculation the CBL.

[0407] An "Exclude Previous Curtailment Days" setting can be "Yes" or "No." When "Exclude Previous Curtailment Days" is "Yes," baseline generator **1002** may exclude any previous day which included at least one hour of participation in the ELDR program (e.g., pending or confirmed economic settlements for the days) from use in calculating the CBL. When it is "No," baseline generator **1002** may use previous days which include at least one hour of participation in the ELDR program when determining the CBL.

[0408] A setting "Exclude Long/Short DST Days" may be "Yes" or "No." If the setting is set to "Yes," baseline generator **1002** may exclude any DST days from being used to determine the CBL. If the setting is set to "No," baseline generator **1002** may be configured to use DST days when determining the CBL. A display "Exclude Average Event Period Usage Less Than Threshold" may indicate that if the Average Daily Event Period Usage for a CBL day selected is less than the threshold indicated, then that day will be excluded from a CBL basis window.

[0409] A setting "Exclude Number of Low Usage Days" may be a number of the days used to determine the CBL by baseline generator **1002** will be excluded i.e., the number (e.g., 1, 2, 3, or 4) of the lowest days that are to be excluded.

A setting "Use Previous Curtailment If CBL Basis Window Incomplete" may be set to "Yes" to use previous days that include participation in the ELDR program to determine the CBL if baseline generator **1002** cannot find enough non-participation days within the 45 day period to generate the CBL. If "Use Previous Curtailment If CBL Basis Window Incomplete" is "Yes" the setting "Exclude Previous Curtailment Days" may also need to be set to "Yes."

[0410] A setting "Use Highest or Recent Previous Curtailment Day" may be a setting that can be set if the setting "Use Previous Curtailment Day if CBL Incomplete" is "Yes." A setting of "Highest" for the "Use Highest Or Recent Previous Curtailment Day" may cause baseline generator **1002** to rank previous curtailment days based on event period usage within the CBL Basis Day Limit and add them to the CBL Basis Days in descending order until the CBL Basis Days contains the minimum number of days required to calculate CBL. The setting "Recent" may cause baseline generator **1002** to start adding days to the CBL Basis Days starting with the Most Recent Curtailment Day that was excluded until the CBL Basis Days contains the minimum number of days required to calculate CBL.

[0411] A display "Adjustments" may indicate that Symmetric Additive Adjustment is a CBL average usage for an event day divided by Adjustment Basis Hours for the same hours. The display may further indicate that a weather sensitivity adjustment compares weather over CBL days to weather on event days and then calculates the adjustment based on weather sensitivity.

[0412] A setting "Allow Negative Adjustments" may be set to "Yes" in which case adjustments may be either positive or negative. If this setting is not "Yes," adjustments may always be greater than zero. A display "Adjustments Start (HE0-x)" may indicate a starting point for hours to be used in calculating the Adjustments. If the event starts with HE13 and Adjustment Start is 4, then HE9 may be the first hour used to calculate Adjustments. A display "Adjustment Basis Hours" may indicate that the total number of hours used to determine the adjustment from "Adjustment Start." If the event is on HE13, "Adjustment Start" is 4, and "Adjustment Basis Hours" is 3, then the adjustment may be based on the load from HE9-HE11.

Automated and Dynamic Economic Load Demand Response (ELDR) Program Participation with ELDR User Interfaces

[0413] Referring now to FIG. **17**, a block diagram of system **1700** including an ELDR module **1706**, a Curtailment Service Provider (CSP) **1704**, and a regional transmission organization and/or independent system operator (RTO/ISO) **1702** are shown, according to an exemplary embodiment. ELDR module **1706** can be a module of incentive program module **912** and/or high level optimizer **632**. ELDR module **1706** can perform some and/or all of the ELDR related functions as described with reference to FIGS. **10-16** to participate in an ELDR program.

[0414] CSP **1704** may be one or more computing systems, servers, and/or devices configured to facilitate the ELDR program. CSP **1704** can be a system configured to facilitate participation in the ELDR program. In some embodiments, CSP **1704** is "CPower." RTO/ISO **1702** can include one or more computing systems, servers, and/or devices. RTO/ISO **1702** can be configured to perform the ELDR program by generating various ELDR parameters and providing the ELDR parameters to ELDR module **1706** via CSP **1704**. Furthermore, ELDR module **1706** can provide various load reduction bids to RTO/ISO **1702** via CSP **1704**. RTO/ISO **1702** can be, as an example, the Pennsylvania, New Jersey, and Maryland (PJM) RTO.

[0415] System **1700** provides a high-level description of an automated and dynamic participation process that ELDR module **1706** can be configured to perform for ELDR program participation. In some cases, participation in the ELDR program may be manual and involve human interaction. For example, a user associated with a power plant of a building and/or campus could make the participation decisions (e.g., participation hours and a constant kW load reduction amount) for an ELDR program for a following day. The user could make a selection manually through a user interface of CSP **1704**. Based on the participation decision, the user can determine the schedule of the plant equipment (e.g., Gas Turbines, chillers, boilers, etc.) in order to meet his ELDR commitment for the following day.

[0416] The schedule of the equipment and the kW participation amount do not change dynamically with the dynamic changes and/or updates of market prices, plant status the day of participation, awarded bids, etc. when manual selection of participation is used. In this regard, ELDR module **1706** can remove direct user interaction for participating in the ELDR program in order to automate the participation in the ELDR program, making the ELDR participation dynamic and adaptive to changes in prices, schedules, weather, etc. However, ELDR module **1706** can provide the user with a user interface and the ability to override various participation decisions of ELDR module **1706**. This allows a user to have control over participation in the ELDR program but participate in the ELDR program in an automated and dynamic manner such that the benefit of participation in the ELDR program is maximized.

[0417] The automated ELDR program participation provided by ELDR module **1706** can perform various functions to dynamically participate in the ELDR program. ELDR module **1706** can be configured to perform prediction of ELDR parameters. For example, ELDR module **1706** can be configured to perform predictions of real-time LMP and day-ahead LMP prices based on current prices (e.g., current values for real-time LMP and/or day-ahead LMP), weather forecast data, time of day, and/or day of week. The ELDR can be configured to dynamically respond to changes in market prices. For example, the participation hours and/or participation amounts may by dynamically adjusted throughout a particular day and/or preceding the particular day to account for changes in market prices so that ELDR module **1706** maximizes the potential revenue from participating in the ELDR program.

[0418] Furthermore, ELDR module **1706** can be configured to perform optimal allocation of equipment in order to minimize cost while maximizing the benefit of the ELDR program. ELDR module **1706** can be configured to perform automatic determination of the kW participation amount, automatically submit bids to CSP **1704**, automatically read the status (e.g., awarded or not awarded) of submitted participation hours, and/or dynamically update equipment allocation based on the awarded status of participation hours.

[0419] ELDR module **1706** is shown to include various "collectors" configured to collect ELDR parameters from CSP **1704** and/or receive awarded hours from CSP **1704**. The collectors may be one single module and/or multiple

modules. In FIG. **17**, multiple collector modules are shown. ELDR module **1706** is shown to include a real-time LMP collector **1708**, a day-ahead LMP collector **1710**, an awarded bids collector **1712**, and a NBT price collector **1714**. Furthermore, ELDR module **1706** is shown to include a bid submitter **1716** for submitting bids to CSP **1704**. CSP **1704** may include a specific application programing interface (API) for communicating ELDR data with ELDR module **1706**. In this regard, the collectors of ELDR module **1706** can be configured to integrate with the API of CSP **1704** to send and/or receive data from the CSP **1704**.

[0420] All settings of ELDR module **706** e.g., ELDR program settings, job scheduling (e.g., collection periods and/or frequencies of collectors **1708-1714**), and retry settings can be configurable at deployment time of ELDR module **1706** and/or after the deployment time. Collection jobs can be individually disabled if necessary, for example, during commissioning when ELDR module **1706** is not set up to submit bids. A technician could disable the scheduled collection of day-ahead LMP by day-ahead LMP collector **1710** but allow real-time LMP collector **1708** to continue to perform collection of the real-time LMP in order to perform trouble shooting. Setting changes to ELDR module **1706** may require a service restart.

[0421] Collectors **1708-1714** and bid submitter **1716** can each be configured (or can collectively be configured) to generate a log that details interactions with CSP **1704**. The log may indicate errors and/or error codes returned by CSP **1704** responsive to a message (e.g., a collection message). For example, if the awarded bids collector **1712** attempts to retrieve an indication of an awarded bid but instead receives an error, awarded bids collector **1712** can be configured to generate an error log and/or update an existing error log with an indication of the error and/or an error code. Collectors **1708-1714** and bid submitter **1716** may include various general settings used for collecting data from CSP **1704**. The settings may include an endpoint, a username, and/or a password for connecting with CSP **1704**. The settings can include an identification of RTO/ISO **1702**, "IsoName." An example of an "IsoName" may be "PJM." The settings can further include a "ZoneName," a "BidGroupName," a "ProductTypeName," and an "IsoTimeZoneId."

[0422] Real-time LMP collector **1708** can be configured to collect a sub-hourly real-time LMP from CSP **1704**. Real-time LMP collector **1708** can be configured to send a read command to CSP **1704** for a real-time LMP value and receive the value for the real-time LMP from CSP **1704** in response to sending the read command. In some embodiments, real-time LMP collector **1708** can be configured to periodically read the real-time LMP and store the real-time LMP in a database. In some embodiments, real-time LMP collector **1708** can collect the real-time LMP on an sub-hourly period (e.g., every minute, every ten minutes, every half hour, etc.) Real-time LMP collector **1708** can include a database configured to store collected real-time LMP values. In some embodiments, real-time LMP collector **1708** can share a database with the other collectors, e.g., an ELDR parameter database **1709**. The ELDR parameter database **1709** can act as a data repository for the various collected ELDR parameters, generated ELDR parameters (e.g., predicted ELDR parameters), and/or any other ELDR information.

[0423] CSP **1704** can include an endpoint for real-time LMP, e.g., "lmp/zoneinterval endpoint." Real-time LMP collector **1708** can use this endpoint to periodically collect (e.g., five minute) real-time LMP values. Real-time LMP collector **1708** can be configured to determine a sliding window average (e.g., a moving average window, an exponentially weighted moving average filter, etc.) which we use to calculate an average. In some embodiments, there may be gaps in the real-time LMP prices since RTO/ISO **1702** may withhold the prices to prevent market manipulation. The sliding window average allows ELDR module **1706** to handle these gaps in real-time LMP prices as well as smooth out sudden spikes in real-time LMP prices.

[0424] Real-time LMP collector **1708** may include specific configurable settings for collecting real-time LMP prices from CSP **1704**. The settings may include a "Job Scheduled Period" which defines the rate at which real-time LMP collector **1708** collects real-time LMP prices from the CSP **1704**. The settings may further include an "Offset" parameter providing an offset to the collected real-time LMP prices, and/or an enabled flag which causes real-time LMP collector **1708** to collect real-time LMP prices from CSP **1704** when enabled. The settings may include a "RealTimeLmpWindowSize" which may define the size of the moving average window (e.g., the number of samples used to determine the averaged real-time LMP price). Real-time LMP collector **1708** can include a "RealTimeLmpOutgoingSampleInterval" which may be a setting defining the rate at which real-time LMP collector **1708** determines an outgoing real-time LMP price for providing to predictor **1718** and/or storing in ELDR parameter database **1709**.

[0425] Day-ahead LMP collector **1710** can be configured to collect an hourly day-ahead LMP from CSP **1704**. Day-ahead LMP collector **1710** can be configured to send a read command to CSP **1704** for a day-ahead LMP and receive a value for the day-ahead LMP from CSP **1704**. In some embodiments, day-ahead LMP collector **1710** can be configured to periodically read the hourly day-ahead LMP and store the day-ahead LMP in a database. In some embodiments, day-ahead LMP collector **1710** can collect the day-ahead LMP on an hourly period. Day-ahead LMP collector **1710** can include a database configured to store the collected real-time LMP values. In some embodiments, day-ahead LMP collector **1710** can share a database with the other collectors, e.g., ELDR parameter database **1709**.

[0426] The day-ahead LMP prices may be made available by CSP **1704** for a following day after a particular time on a current day (e.g., 12:30 P.M.) Sometimes, CSP **1704** may post the day-ahead LMP prices late or may later revise the posted day-ahead LMP prices. To compensate in this uncertainty in posting time and/or updating, day-ahead LMP collector **1710** can be configured to periodically read the day-ahead LMP prices throughout the day. In some embodiments, CSP **1704** make the day-ahead LMP prices available at a specific endpoint, e.g., a "lmp/zone endpoint" where day-ahead LMP collector **1710** can be configured to retrieve the day-ahead LMP values from.

[0427] Day-ahead LMP collector **1710** can include multiple configurable settings. The settings may include a "Job Scheduled Period" which defines how frequently day-ahead LMP collector **1710** collects the day-ahead LMP prices. Day-ahead LMP collector **1710** can further include an offset parameter which can provide an offset to the collected day-ahead LMP prices. Day-ahead LMP collector **1710** can include an enabled flag which causes day-ahead LMP collector **1710** to collect the day-ahead LMP values from CSP

1704 whenever enabled. Day-ahead LMP collector **1710** may periodically collect the day-ahead LMP price after a particular time on a given day. This time may be configurable and may be a setting "DayAheadPriceAvailabilityTimeOfDay." After the particular set time passes, day-ahead LMP collector **1710** can be configured to periodically collect day-ahead LMP values for CSP **1704**.

[0428] Awarded bids collector **1712** can be configured to collect awarded bids from the CSP **1704**. The awarded bids may be indications that particular participation hours submitted in a bid by bid submitter **1716** have been approved. Awarded bids collector **1712** can be configured to send a read command to CSP **1704** for awarded bids and receive an indication of the awarded bids from the CSP **1704** responsive to submitting the read command. In some embodiments, the awarded bids collector **1712** can be configured to periodically read the awarded bids and store the awarded bids in a database. In some embodiments, awarded bids collector **1712** can collect the awarded bids on an hourly and/or sub-hourly period (e.g., every minute, every ten minutes, every half hour, every hour, every two hours, etc.). Awarded bids collector **1712** can include a database configured to store the collected awarded bids. In some embodiments, awarded bids collector **1712** can share a database with the other collectors, e.g., ELDR parameter database **1709**.

[0429] In response to RTO/ISO **1702** awarding the first bid of a particular day, CSP **1704** may indicate that all bids for all hours of the particular day are awarded even though RTO/ISO **1702** may later decline bids. Awarded bids collector **1712** can include multiple settings for collected awarded bids, e.g., the participation hours that have been awarded, from CSP **1704**. The settings may include a job scheduled period which causes awarded bids collector **1712** to collect bids at a particular rate. Awarded bids collector **1712** can also include an offset setting. Furthermore, awarded bids collector **1712** can include an "Enabled Flag" which causes awarded bids collector **1712** to collect awarded bids from CSP **1704** at a particular defined rate.

[0430] Awarded bids collector **1712** may include a "AwardedBidsHorizon" setting which defines a time span preceding a particular participation hour. Once a current time is within the timespan, the particular participation hour will be assumed to be awarded if the current status of the particular participation hour is awarded. Similarly, awarded bids collector **1712** can include a "NotAwardedBidsHorizon" which may define another timespan preceding a participation hour. If the current time is within the timespan and the status of the particular participation hour is not awarded, awarded bids collector **1712** can assume that the current participation hour is not awarded.

[0431] NBT price collector **1714** can be configured to collect NBT threshold values from CSP **1704**. Awarded bids collector **1712** can be configured to send a read command to CSP **1704** for an NBT threshold value and receive the NBT threshold value from CSP **1704** responsive to sending the read command to CSP **1704**. NBT price collector **1714** can be configured to periodically, e.g., every day, collect the NBT threshold value and store the collected NBT threshold value. NBT price collector **1714** can store the collected NBT threshold value by itself or otherwise store the NBT threshold value in ELDR parameter database **1709**.

[0432] RTO/ISO **1702** may provide CSP **1704** with an NBT threshold for a following month on a particular day of a current month (e.g., the 15^{th} of the current month). CSP **1704** may make the NBT threshold available at least a predefined amount of time before the next month, e.g., at least 10 days before the end of the month. CSP **1704** may include a particular endpoint where CSP **1704** can make the NBT threshold available. For example, the endpoint may be an "nbt/price" endpoint. In some cases, CSP **1704** may not provide an indication as to whether the NBT threshold value is available or not. Furthermore, in some cases, the NBT threshold can even be updated during a particular month for which the NBT threshold value applies. For this reason, NBT price collector **1714** can be configured to collect the NBT threshold value on a periodic basis e.g., daily.

[0433] NBT price collector **1714** can include one or multiple settings for collecting the NBT price value from CSP **1704**. The NBT setting can include a job scheduled period which defines the rate at which NBT price collector **1714** collects the NBT threshold from CSP **1704**. Furthermore, NBT price collector **1714** may include an offset which may provide an offset to the value of the NBT threshold. Furthermore, NBT price collector **1714** can include an enabled flag which enables or disables the operation of NBT price collector **1714**. In some embodiments, NBT price collector **1714** can include a retry sleep duration time and a retry count. The retry time may be a particular time which NBT price collector **1714** waits before retrying to collect the NBT threshold value from CSP **1704** in response to NBT price collector **1714** failing to collect the NBT threshold value. NBT price collector **1714** can be configured to count the number of retry attempts that NBT price collector **1714** attempts. If the number of attempted retries is greater than a predefined amount, NBT price collector **1714** may stop retrying to retrieve the NBT threshold value and may resume collecting the NBT price collector based on the job scheduled period.

[0434] Bid submitter **1716** can be configured to submit bids received from optimizer **1722** to CSP **1704**. In some embodiments, bid submitter **1716** can submit participation hours and estimated participation amounts for each participation hour. In some embodiments, bid submitter **1716** submits a bid in response to optimizer **1722** determining an estimated participation amount and/or participation hours. In some embodiments, optimizer **1722** may determine the estimated participation amount and/or participation hours on a periodic basis, e.g., every fifteen minutes. In this regard, bid submitter **1716** can be configured to submit a bid to CSP **1704** every fifteen minutes.

[0435] Bid submitter **1716** can sign up for a notification regarding when optimizer **1722** creates a dispatch for ELDR module **1706** (e.g., determine an estimated participation amount for participation hours determined by participation kernel **1720**). Bid submitter **1716** can be configured to generate a bid to provide to CSP **1704** based on the estimated participation amount and the participation hours received from optimizer **1722**. In some embodiments, the bid that bid submitter **1716** provides to CSP **1704** includes the estimated participation amount and/or the participation hours determined by optimizer **1722** and/or participation kernel **1720**. The dispatch results can include the participation hours and amounts that we should include in our bid.

[0436] Bid submitter **1716** can include multiple configurable settings for providing a bid to CSP **1704**. The settings may include a job enabled flag which indicates whether bid submitter **1716** should operate. The settings may further include a "MaximumBidQuantityMw" which may be a can

for the estimated participation amount so that the participation amount does not exceed a reasonable level. The settings may include a "MinimumBidQuantityMw" which acts as a bottom level for the estimated participation amount. Any participation hour associated with an estimated participation amount below the minimum level may be considered a non-participation hour and left out of the bid to CSP **1704**. Bid submitter **1716** can further include a "BidQuantityFractionalDigits" setting which defines the precision for the estimated participation amounts that CSP **1704** may be willing to accept. Bid submitter **1716** may also include a lockout period setting. This lockout period setting may also be implemented by user interface manager **1724**. This setting may define a time span preceding a particular participation hour within which the user is not allowed to override or otherwise change the participation hour, causing a change to the bids placed to CSP **1704**. Prior to the timespan, a user can be allowed to make changes to the participation hours via user interface manager **1724** and provide participation hour overrides to participation kernel **1720**. This may cause bid submitter **1716** to made adjustments to current bids by submitting a second bid. However, within the time span, both user interface manager **1724** and/or bid submitter **1716** may stop making adjustments or placing new bids for a particular participation hour.

[0437] Since the collection of ELDR parameters and/or awarded bids may be performed over a network (e.g., the communication between ELDR module **1706** and CSP **1704** may be performed over a network such as the Internet), ELDR module **1706** can be configured to detect and/or recover from transient network errors and/or longer network and service outages. Collectors **1708-1714** can implement retry mechanisms (e.g., sending a message a second time if the first message is not delivered) to recover from transient network errors. In some embodiments, ELDR module **1706** can be configured to perform a long retry mechanism for collectors that run infrequently, e.g., NBT price collector **1714**. The periodic scheduling of collection jobs and periodic nature of the optimization runs which trigger bid submission, provide another level of retries for handling longer outages. The collectors that read time series data (e.g., prices, NBT threshold, awarded bids) (e.g., collectors **1708-1714**) can be configured to backfill with past data to fill gaps in data collection caused by network outages. Furthermore, any call to a database of collectors **1708-1714** and/or ELDR parameter database **1709** can use a retry mechanism to protect from transient errors.

[0438] In some embodiments, ELDR module **1706** is implemented on a server. Each of collectors **1708-1714** and/or bid submitter **1716** may be a MICROSOFT WINDOWS® service that can automatically start whenever the server is restarted and can be configured to automatically restart if the service crashes. In some embodiments, upon a startup of ELDR module **1706**, each of collectors **1708-1714** can be configured to backfill time series data that may be missing from the time period where collectors **1708-1714** were not collecting data.

[0439] Predictor **1718** can be configured to receive real-time LMP values from real-time LMP collector **1708**, day-ahead LMP values from day-ahead LMP collector **1710**, and/or historic electric load data. Based on the received data, predictor **1718** can be configured to predict the received data into the future. Predictor **1718** is shown to generate a predicted day-ahead LMP, a predicted real-time LMP, and a predicted campus load. Predictor **1718** may be the same as and/or similar to load/rate predictor **622** as described with reference to FIG. **10** and elsewhere herein.

[0440] Participation kernel **1720** can be configured to generate participation hours to be used by optimizer **1722**. Participation kernel **1720** can be configured to generate the participation hours based on the predicted day-ahead LMP, the predicted real-time LMP, a predicted campus load, a measured imported electricity, awarded participation hours, and/or a NBT threshold value. Participation kernel **1720** can be and/or include the functionality of participation predictor **1004** and/or selector **1008**. Participation kernel **1720** can include some and/or all of the functionality for generating the participation hours as described with reference to FIGS. **10-16**.

[0441] Participation kernel **1720** can be configured to determine the participation hours and/or estimated participation amounts for hours of one day or multiple days into the future. In this regard, the participation decisions that are shown in the user interfaces generated by user interface manager **1724** can provide a user with insight into the current day or into multiple days into the future.

[0442] In some embodiments, participation kernel **1720** can be configured to determine the participation hours based on how likely hours of a particular day will be awarded by the CSP **1704**. For example, various modeling and/or classification techniques (e.g., neural networks, support vector machines, decision trees, etc.) can be used by participation kernel **1720** to determine the participation hours. For example, participation kernel **1720** can be configured to set a particular hour at as an hour to participate in the ELDR program based on a classification of whether or not the particular hour will be awarded based on historic hour data for real-time LMP, day-ahead LMP, weather data, past bid awards and/or rejections. If participation kernel **1720** determines, based on the classification, that it is unlikely that a particular hour is awarded, the participation kernel **1720** may not determine to participate in that hour.

[0443] Optimizer **1722** can be configured to generate an estimated participation amount for each of the participation hours generated by participation kernel **1720**. The estimated participation amount may be a curtailment amount for reducing an electric load by for a particular participation hour. Optimizer **1722** can include some and/or all of the functionality of high level optimizer **632** and/or cost function modifier **1010**. Optimizer **1722** can be configured to generate the objective function described herein with an ELDR term as generated by cost function modifier **1010**. Optimizer **1722** can be configured to optimize the generated objective function to determine the estimated participation amounts. Furthermore, the optimizer **1722** can, by optimizing the objective function, determine operating load amounts for building equipment and cause the building equipment to operate based on the operating load amounts.

[0444] User interface manager **1724** can be configured to generate a user interface to present a user with ELDR information (e.g., actual and/or predicted ELDR parameters, load usage, CBL values, etc.) and receive ELDR hour overrides from a user. User interface manager **1724** can be configured to generate the user interfaces of FIGS. **15-16** and/or FIGS. **23-31**. User interface manager **1724** can receive overridden participation hours from the user interface. The overridden participation hours may be hours that participation kernel **1720** has determined but a user does not

want to participate in. Furthermore, the overridden participation hours may be hours of a particular day that have not been determined to be participation hours but the user would like ELDR module **1706** to participate in. User interface manager **1724** can provide the overridden participation hours to participation kernel **1720** so that the user override decisions of the user are implemented by participation kernel **1720** as desired by the user.

[0445] Still referring to FIG. **17**, participation kernel **1720** can be configured to determine whether to participate in the ELDR program for a particular day in response to participation hours for the particular day not being awarded. ELDR module **1706** can be configured to maximize the revenue from participating in the ELDR program while minimizing the cost of operating equipment and purchasing resources. In the case of ELDR, the revenue may be a function of the CBL, which can be either a function of the first and last hour of participation, or the first hour of participation only. The CBL may be a "Same Day" CBL, a Same Day Three Before and Two After baseline is described with reference to FIG. **10** and elsewhere herein. For a same day CBL, both the first and last hour of participation of a particular day can determine the baseline hours used to generate the same day CBL.

[0446] To maximize revenue, ELDR module **1706** can be configured, via optimizer **1722**, to increase electrical import during baseline hours, while decreasing the electrical import during participation hours. This keeps the CBL at an optimally high value such that a difference of the same day CBL and the electric load consumption during participation hours is maximized. ELDR module **1706** may have a dynamic response to the awarded status of participation hours on a given day. When participating in the Real-Time ELDR Market, a participation hour may or may not get awarded for curtailment by RTO/ISO **1702**. The awarded status of a participation hour may be known by ELDR module **1706** an hour before the top of that hour.

[0447] When the first hour of participation does not get dispatched, ELDR module **1706**, via participation kernel **1720** and/or optimizer **1722**, can update its allocation decision in order to maintain a high CBL. This behavior may be advantageous since it maintains a high CBL. However, ELDR module **1706** may not be awarded for multiple "first hours" for which participation was bid on a particular day, i.e., it may be late in the day before a bid participation hour is awarded. This can be problematic since the CBL is being held high for a long period of time unnecessarily. The hours where ELDR module **1706** may be holding the electric load high are not turning out to actually be baseline hours.

[0448] This performance is shown in FIGS. **21** and **22**. For example, the optimization of the cost function may push the start of the gas turbines to later in the day in order to maintain the high CBL, but at the end of the day the cost of electrical import has surpassed the potential revenue from ELDR since optimizer **1722** has kept the energy usage high. This is because ELDR module **1706** makes its decision based on the current status of the plant and what is predicted over the horizon. Therefore, participation kernel **1720** can be configured to determine whether to abandon participation in the ELDR program if ELDR module **1706** does not receive a first awarded participation hour for an extended period of time on a particular day.

[0449] When the first hour of participation does not get dispatched, it affects the value of the CBL and consequently the revenue from ELDR for the day by ELDR module **1706**. In order to overcome the cost of not getting dispatched, participation kernel **1720** can be configured to determine a benefit by taking into account the revenue for the day and the cost of resources in order to generate this revenue. Participation kernel **1720** can be configured to determine whether the benefit is less than a predefined threshold. In response to determining that the benefit is less than the predefined threshold, participation kernel **1720** can be configured to abandon participation in the ELDR program for the remainder of the day. Participation kernel **1720** can be configured to determine the benefit based on the benefit function (an objective function):

$$J = \sum_{i=1}^{24} p_i r_{DA_i} \max(e_{CBL} - e_{grid_i}, 0) - \max\left(\sum_{i=1}^{24} (r_{e_i} - r_{ng_i}\eta_{GT})\max(e_{grid_i} - e_{gridLL}, 0), 0\right)$$

where p_i is the participation status of the i^{th} hour in the day. p_i=0 if it is not a participation hour or if the hour was not awarded and p_i=1 if it is a participation hour or the hour was awarded. r_{DA_i} [$/kWh] is the Day-Ahead LMP of the i^{th} hour. e_{CBL} [kW] is the customer baseline load. e_{grid_i} [kW] is the i^{th} electricity import in kW. It is the actual electricity import for the hours prior to the current time and the estimated electricity import for the hours in the remainder of the day. r_{e_i} [$/kWh]: is the electricity rate. r_{ng_i} [$/kWh] is the natural gas rate. η_{GT} is the estimated efficiency of the gas turbine. e_{gridLL} [kW]: is the lower limit on the electricity import.

[0450] The first term of the benefit function is the total estimated revenue for the day:

$$\sum_{i=1}^{24} p_i r_{DA_i} \max(e_{CBL} - e_{grid_i}, 0)$$

[0451] The second term is the benefit function of the additional electricity being imported in order to maintain a high baseline or in other words the opportunity cost. If this additional import were to be generated by gas turbines instead, that would result in a natural gas cost. This is why the equivalent natural gas cost is subtracted from the cost of electricity import. In the case where the opportunity cost is negative, it means that it would have cost us more to generate the additional import to make the revenue. This is why the term is maxed at zero.

[0452] In some embodiments, the opportunity cost can be calculated using the electrical import of the whole day. In other cases without any gas turbines, the opportunity cost can be calculated using only the electrical import outside of participation hours:

$$\max\left(\sum_{i=1}^{24} (r_{e_i} - r_{ng_i}\eta_{GT})\max(e_{grid_i} - e_{gridLL}, 0), 0\right)$$

[0453] At every dispatch, participation kernel **1720** can be configured to make its participation decision based on whether the benefit is above the threshold or not, and the

NBT threshold value, predicted real-time LMP, and day-ahead LMP. If the benefit is greater than the threshold, then participation kernel **1720** can be configured to continue to participate for the remainder of the day. If the benefit gets to a point where it is below the threshold, then the decision would be to quit participating for the remainder of the day. Participation kernel **1720** can be configured to abandon the remainder of the day by setting the participation mask to zeros and keeping the participation mask at zeros for the remainder of the day. Determining to abandon participation for a particular day may result in an updated bid being sent to CSP **1704**.

[0454] In some embodiments, participation kernel **1720** can perform the benefit test for the current day of operation and/or for every day over a particular horizon. The additional advantage of this approach is that the NBT threshold value can be continued to be used as is without a buffer and for those days where there only few hours of participation, the benefit would end up being lower than the pre-determined threshold and thus choose to opt out of participation.

[0455] In some embodiments, the benefit threshold is $1,000. Since the DA-LMP can be used in the determination of the benefit, it should be noted that at higher prices and if the first hour is not getting dispatched, it would take us couple of hours until participation for the day is abandoned.

[0456] Referring now to FIGS. **18**A-**18**B a process **1800** is shown for dynamically adapting control of building equipment for an ELDR program, according to an exemplary embodiment. Process **1800** can be performed by a computing device, e.g., ELDR module **1706**. Although process **1800** is described with reference to ELDR module **1706**, any computing device described herein can be configured to perform process **1800**.

[0457] In step **1802**, ELDR module **1706** can collect ELDR parameters from CSP **1704** and/or collect electric load values for a building. For example, the ELDR parameters may be real-time LMP values collected by real-time LMP collector **1708**, day-ahead LMP values collected by the day-ahead LMP collector **1710**, and/or NBT threshold values collected by NBT price collector **1714**. The electric load values may be historic load data collected by building status monitoring devices. For example, in FIG. **10**, a building status monitor **624** collects historic electric load data.

[0458] Step **1802** may be a periodic step, i.e., the ELDR parameters can be collected periodically. In some embodiments, each of the ELDR parameters is collected at a particular period. Process **1800** performs an optimization to determine bids, electric load reduction amounts, and optimal operating load values for building equipment. Since the ELDR parameters are collected periodically, the optimization of process **1800** can adapt to changes in the ELDR parameters over time.

[0459] In step **1804**, ELDR module **1706** can predict the ELDR parameters and/or the electric load values of the building into the future. Predictor **1718** can predict a day-ahead LMP into the future, a real-time LMP into the future, and/or the electric load values of the building. These predicted values can be provided by predictor **1718** to participation kernel **1720** for determination of the participation hours.

[0460] In step **1806**, based on the predicted ELDR parameters and the predicted electric load values, ELDR module **1706** can generate participation hours and determine participation amounts for each of the participation hours. The participation hours may be determined by participation kernel **1720** according to the methods described in FIGS. **10-12**. For each of the participation hours, optimizer **1722** can determine a participation amount, an amount that ELDR module **1706** will reduce its electric load by with reference to a CBL. Furthermore, optimizer **1722** can determine optimal electric loads for building equipment of the building. The electric loads of the building equipment may be loads which cause the building equipment to consume an amount of energy such that the participation amount for each of the participation hours is appropriately met and/or revenue generated by participating in the ELDR program is maximized.

[0461] In step **1808**, ELDR module **1706** can provide a bid to CSP **1704** based on the participation hours and participation amounts determined in step **1806**. More specifically, bid submitter **1716** can submit a bid, including the participation hours and the participation amount for each participation hour to CSP **1704**. In step **1810**, based on the determined optimal electric loads of the step **1808**, ELDR module **1706** can control the building equipment. Controlling the building equipment based on the determined optimal electric loads may cause the building equipment to operate at control parameters that cause the optimal electric load to be realized.

[0462] Responsive to submitting a bid, CSP **1704** may award some, none, or all of the bid participation hours. Awarded bids collector **1712** can collect the indication of whether an hour is awarded or not. Based on the awarded or rejected participation hours, future allocation of the building equipment and/or future participation in the ELDR program can be updated, steps **1814-1822** describe this dynamic adjustment in further detail.

[0463] In step **1814**, ELDR module **1706** can generate a user interface for displaying the received awarded bids of step **1812**, the actual and/or predicted ELDR parameters, the participation hours, and the estimated participation amounts. More specifically, user interface manager **1724** of ELDR module **1706** can generate the user interface. In some embodiments, the user interface is the same as and/or similar to the user interfaces shown in FIGS. **23-31**. The user interface may display information to a user and receive various overrides from the user. For example, the user interface may indicate that a particular hour of a particular day is a participation hour for participating in the ELDR program. If a user does not want to participate in that hour, the user can indicate an override of the hour and the optimization of step **1820** can reflect the updates to the user preferred participation. In step **1816**, user interface manager **1724** can receive the overridden participation hours from the user interface.

[0464] Based on submitted bid of step **1808**, awarded bids collector **1712** can receive awarded and/or rejected participation hours from CSP **1704**. More specifically, awarded bids collector **1712** can be configured to determine which hours are awarded or not awarded by reading the awarded hours from CSP **1704**.

[0465] Based on the awarded hours (step **1818**), overridden participation hours (step **1816**), and changes to the ELDR parameters which may be periodically collected (step **1802**), ELDR module **1706** can determine second participation hours, second participation amounts for the participation hours, and second optimal electric loads for the building equipment. Step **1820** may be similar to step **1806**.

but may be a second iteration of step **1806**. The determination of participation hours, participation amounts, and optimal electric loads may be performed on a periodic basis to account for changes in the ELDR parameters, awarded bids, and/or user overrides. Although only two iterations of the determination are shown in process **1800**, there may be any number of iterations performed. For example, after step **1820**, ELDR module **1706** can submit a second bid (e.g., perform step **1808** again), receive more awarded or rejected bids (e.g., perform step **1812** again), collect more ELDR parameters (e.g., perform step **1802** again), receive more overridden hours (e.g., perform step **1818** again) and finally perform step **1820** again.

[0466] In step **1822**, ELDR module **1706** can control the building equipment based on the second optimal electric loads. The second optimal electric loads may be the same as or different than the first electric loads. In this regard, the performance of the building equipment can adapt to changes in participation, awarded hours, overrides, changes in ELDR parameters, etc.

[0467] Referring now to FIG. **19**, a process **1900** for determining whether to continue participation in the ELDR program or abort participation in the ELDR program in response to receiving rejected participation hours is shown, according to an exemplary embodiment. Process **1900** can be performed by a computing device, e.g., ELDR module **1706**. Although process **1900** is described with reference to participation kernel **1720** of ELDR module **1706**, any computing device described herein can be configured to perform process **1900**.

[0468] When participating in the ELDR program, ELDR module **1706** may determine optimal electric load amounts for building equipment to be high during baseline hours. Baseline hours may be hours where the load of a facility during the baseline hours is used to determine the CBL for the facility. By raising the value of the CBL, the ELDR module **1706** can maximize revenue when curtailing energy usage. However, the baseline hours used to determine the CBL are based on the first awarded participation hour for a day. In this regard, if the first bid participation hour of ELDR module **1706** is not accepted, ELDR module **1706** has raised the optimal electric load for no benefit. In this regard, process **1900** determines how ELDR module **1706** should respond to participation hours being rejected by CSP **1704**.

[0469] In step **1902**, participation kernel **1720** can generate an ELDR benefit function. The ELDR benefit function can indicate revenue generated from participating in an ELDR program. The benefit function may be:

$$J = \sum_{i=1}^{24} p_i r_{DA_i} \max(e_{CBL} - e_{grid_i}, 0) - \max\left(\sum_{i=1}^{24} (r_{e_i} - r_{ng_i}\eta_{GT})\max(e_{grid_i} - e_{gridLL}, 0), 0\right)$$

where p_i is the participation status of the i^{th} hour in the day. p_i=0 if it is not a participation hour or if the hour was not awarded and p_i=1 if it is a participation hour or the hour was awarded. r_{DA_i} [$/kWh] is the Day-Ahead LMP of the i^{th} hour. e_{CBL} [kW] is the customer baseline load. e_{grid_i} [kW] is the i^{th} electricity import in kW, it is the actual electricity import for the hours prior to the current time and the estimated electricity import for the hours in the remainder of the day. r_{e_i} [$/kWh] is the electricity rate. r_{ng_i} [$/kWh] is the natural gas rate. η_{GT} is the estimated efficiency of the gas turbine. e_{gridLL} [kW]: is the lower limit on the electricity import.

[0470] In step **1904**, awarded bids collector **1712** can receive indications regarding whether particular bid participation hours have been awarded or rejected. The indication of the awarded or rejected participation hours can be provided by awarded bids collector **1712** to participation kernel **1720**. Step **1904** may be similar to and/or the same as step **1812** of process **1800** as described with reference to FIG. **18**A.

[0471] In step **1906**, participation kernel **1720** can determine the revenue from participating in the ELDR program based on the ELDR benefit function based on the received indications of whether participation hours were awarded or rejected. In step **1908**, participation kernel **1720** can continue participating in the ELDR program for the current day in response to determining that the revenue of step **1906** is greater than a predefined amount. However, if the revenue is less than the predefined amount, the participation kernel **1720** can determine to stop participating in the ELDR program for the particular day (step **1910**). To stop participating in the ELDR program for the particular day, participation kernel **1720** can set all of the participation statuses of all the participation hours to zero.

[0472] Referring now to FIG. **20**, a timeline **2000** illustrating the collection of various ELDR parameters by ELDR module **1706** is shown for a particular hour, according to an exemplary embodiment. Timeline **2000** illustrates the ELDR parameters collected by real-time LMP collector **1708**, day-ahead LMP collector **1710**, awarded bids collector **1712**, and awarded bids collector **1712**. Timeline **2000** illustrates collection events for real-time LMP (event **2002**), collection events for awarded bids, (collection event **2006**), collection events for day-ahead LMP (collection event **2008**), and a collection event for the NBT threshold (collection event **2004**). In timeline **2000**, the real-time LMP is shown to be collected by real-time LMP collector **1708** at five minute intervals with the first collection of the hour occurring at 12:01. However, the collection of the real-time LMP may occur at any interval. The collection of the NBT threshold value by NBT price collector **1714** is shown to occur once in a particular day, in the timeline **2000** at 12:05 P.M. Finally, day-ahead LMP collector **1710** can collect the day-ahead LMP values. In timeline **2000**, the day-ahead LMP values are shown to be collected at a thirty minute interval.

[0473] Referring now to FIGS. **21** and **22**, electric load levels are shown on a day where the CSP **1704** rejects participation hours at the beginning of the day and ELDR module **1706** attempts to keep the CBL high, according to an exemplary embodiment. FIGS. **21** and **22**, via graphs **2100**, **2200**, and **2300**, provide an example of the problem that may occur if participation kernel **1720** does not perform process **1900** to determine whether or not to abandon participation in the ELDR program for a particular day. For example, as shown in graphs **2100** and **2200**, all the participation hours were rejected except for hours 16:00 (e.g., 4:00 PM), 17:00 (e.g., 5:00 PM), 18:00 (e.g., 6:00 PM), and 19:00 (e.g., 7:00 PM). The electric load, indicated by marker **2102**, is shown to be kept high all day since the early morning participation hours were rejected. It may not be worthwhile to keep the electric load high for such a long time preceding the awarded

participation hours that occur late in the day. Therefore, process **1900** of FIG. **19** performed by participation kernel **1720** can identify whether or not to abandon participation in the ELDR program for a particular day.

[0474] Referring generally to FIGS. **23-31**, interfaces **2400** and **2900** are shown for providing ELDR information to a user and receiving hours overrides from the user, according to an exemplary embodiment. Interfaces **2400** and **2900** can be generated by user interface manager **1724**. A user, via a user device (e.g., user device **1013**) can view interfaces **2400** and/or **2900**. In some embodiments, interface manager **1724** causes user device **1013** to generate and display interfaces **2400-2900**. In some embodiments, interfaces **2400** and **2900** are accessed via a web browser of interface manager **1724**. In some embodiments, interfaces **2400** and **2900** are generated based on an application running on user device **1013**.

[0475] ELDR module **1706** can automate participation in the ELDR program. Therefore, a user interface may be necessary to view and/or override the automated decisions and participation of ELDR module **1706**. ELDR module **1706** may partially or fully remove the user from making decisions in the ELDR program. However, the user may be able to monitor the performance of ELDR module **1706** via user interfaces **2400** and/or **2900**. All and/or some of the data used to make the various participation hour decisions by participation kernel **1720** can be displayed in user interfaces **2400** and/or **2900** for user review. Furthermore, the participation hours overridden used by participation kernel **1720** to determine the participation hours can be generated by user interface manager **1724** based on the decisions input by the user via interfaces **2400** and/or **2900**.

[0476] Referring to FIG. **23**, interface **2400** is shown in greater detail, according to an exemplary embodiment. Interface **2400** is shown to include a graph **2402**. Graph **2402** can be a plot of ELDR parameters and actual and/or determined electric load values for a building and/or campus.

[0477] User interface manager **1724** can be configured to generate graph **2402** based on data collected by collectors **1708-1714** and/or bid submitter **1716**. Graph **2402** may display hourly and/or sub-hourly data. For example, the real-time LMP collected by real-time LMP collector **1708** can be plotted as real-time LMP **2408** in graph **2402**. The day-ahead LMP collected by day-ahead LMP collector **1710** is plotted as day-ahead LMP **2410** in graph **2402**. The electric load determined by optimizer **1722** and/or a monitored actual electric load (e.g., an electric load monitored by building status monitor **624**) can be plotted as electric load **2412** in graph **2402**. A baseline, a CBL, can be determined by interface manager **1724** and plotted as baseline **2414** so that a user viewing graph **2402** has a reference to see the load reduction. Finally, the curtailment amount, the difference between the baseline and the electric load for a participation hour, is marked by area **2416**.

[0478] Graph **2402** is shown to display the hours for a particular day. The particular day is indicated by date **2420**. In some embodiments, graph **2402** displays predicted data trends. For example, the predicted real-time LMP, the predicted day-ahead LMP, and/or the predicted campus load, all predicted by predictor **1718** can be displayed in graph **2402**. Graph **2402** can also display overridden pricing, e.g., an overridden real-time LMP and/or an overridden day-ahead LMP that a user may manually define. Furthermore, graph **2402** can display an indication of the NBT threshold value, the indication marked by **2418**.

[0479] Chart **2404** can display participation hours for participating in the ELDR program for multiple hours of a day and/or multiple hours of multiple days. The participation hours determined by participation kernel **1720** can be displayed in the chart along with an indication of the load reduction amount associated with the participation hour. Furthermore, chart **2404** may identify which hours, if any, were overridden by a user. For example, a user may add an override to cause participation kernel **1720** to define a particular hour as a participation hour even if it otherwise would not determine that the overridden hour is a participation hour. Similarly, the user can override a participation hour determined by participation kernel **1720** if the user does not want to participate in a particular hour that participation kernel **1720** determines.

[0480] In some embodiments, chart **2404** indicates which participation hours are awarded by CSP **1704** and/or which hours are rejected by CSP **1704**. In some embodiments, the current hour is highlighted to indicate the current time to the user. Furthermore, chart **2404** may indicate which hours are locked and cannot be overridden by a user. In some embodiments, the hours lock a predefined amount of time before they occur. For example, an hour may become locked three hours before the occurs.

[0481] In some embodiments, interface **2400** indicates a total revenue generated for a particular day. In some embodiments, interface **2400** may provide an indication of a predicted revenue for a particular day and continuously update the total revenue throughout the day. Similarly, interface **2400** may display a total and/or average curtailment amount for a day. The total and/or average curtailment amount can be a predicted and/or actual value. In some embodiments, the total and/or average curtailment amount is updated continuously throughout the day.

[0482] Both graph **2402** and chart **2404** can display data for part of or an entire day, i.e., from midnight to midnight. The user can view current and/or past information via the graph **2402** and chart **2404** (e.g., the past sixty days of information) and can navigate through the past information. Chart **2404** can display both the hours of the current day and the hours of days into the future (e.g., nine days into the future). Furthermore, chart **2404** can allow a user to perform a navigation action to display more days into the future (e.g., swipe up or scroll down). For example, user interface manger **1724** may store past data and/or may otherwise be able to retrieve past data (e.g., retrieve past data from the ELDR parameter database **1709**).

[0483] The overrides that the user can make via interface **2400** can include participation overrides and pricing overrides. The user can override participation hours on an hour by hour basis if the participation hours are not yet locked (e.g., the hours may become locked within at a predefined amount of time into the future). Interface **2400** may provide an indication of which hours are overridden and what the original decision for the hour was. Interface **2400** may simultaneously display the user override decision, whether to participate or not participate at the particular hour, and the decision to participate or not participate as determined by participation kernel **1720**.

[0484] Furthermore, a user can override the real-time LMP and/or the day-ahead LMP via interface **2400**. The user can override the values for the real-time LMP and/or the

day-ahead LMP on an hour by hour basis (or can input a constant value for a particular day). The user may only be able to override the prices for an hour a predefined amount of time before the hour occurs. Hours that are locked, e.g., the current hour plus the three following hours, the user may not be able to override with an overridden price. Interface **2400** may display both the user overridden price and/or the original and/or actual price. This data may be displayed simultaneously in the user interface.

[0485] Interface **2400** is shown to include a selector **2406** for operating in either an advisory mode or an auto mode. When the auto mode is selected, ELDR module **1706** can be configured to participate automatically without any user input. When the advisory mode is selected, ELDR module **1706** can be configured to participate automatically but take into account user overrides. In some embodiments, when the advisory mode is selected, the ELDR program may not be executed by ELDR module **1706**.

[0486] Referring now to FIG. **24**, interface **2400** is shown in greater detail display participation decisions for multiple hours and days into the future, according to an exemplary embodiment. As shown in FIG. **24**, participation decisions and participation amounts are shown in chart **2404**. Some of the hours are marked as participation hours with the associated participation amounts. The participation hours and the participation amounts can be determined by the participation kernel **1720** and optimizer **1722**. An example of a participation hour is the hour marked by **2506**. A user can be able to edit and override these participation hours, in addition to the hours where no participation has been determined.

[0487] Furthermore, a user can override an hour where no participation has been determined, for example, the hour marked by **2504**. However, some hours may be locked once they are within a predefined time into the future. For example, the hour marked by **2502** is a locked hour and a user cannot override the locked hour. An example of a past participation hour and an indication of the participation amount for the past participation hour is marked by **2500**. Graph **2402** is shown to include a pop-up window **2508**. When a user hovers over the graph **2402** at a particular location, the values for the plotted ELDR parameters can be displayed to the user based on the time associated with the location where the user hovered and the values of the ELDR parameters associated with the particular time can be displayed.

[0488] Referring now to FIG. **25**, interface **2400** to include overridden participation hours and past participation hours, according to an exemplary embodiment. An example of an overridden participation hour is hour **2602**. Hour **2602** can be an hour where the user indicated that participation should not occur. All of the hours shown in FIG. **25** are past hours, these are hours which have already occurred and ELDR module **1706** may have already participated in. Hour **2604** provides an example of a past hour where no participation in the ELDR program occurred. Referring now to FIG. **26**, another example of user interface **2400** is shown, according to an exemplary embodiment. FIG. **26** is an example where the ELDR module **1706** determines it is best to participate only a small amount of hours, six hours total in this case, for a particular day.

[0489] Referring now to FIG. **27**, yet another example of user interface **2400** is shown. In FIG. **27**, a large number of days are participated in, for the date of Jan. 31, 2018, every possible hour of participation is shown. In both FIGS. **26** and **27**, some hours of the days are permanently locked. Morning hours **2702** and the evening hours **2704** are shown to be locked. These hours may be unsupported hours, i.e., hours that the ELDR program does not allow participation. In some embodiments, the hours are between midnight and 4:00 A.M. (the morning hours **2702**) and between 9:00 P.M. and midnight (the evening hours **2704**). Furthermore, user interface **2400** can display a time **2706** which may correspond to a dispatch time. The dispatch time may be the next time that the awarded bids collector **1712** will attempt to collect the awarded bids from CSP **1704**.

[0490] Referring now to FIG. **28**, interface **2900** is shown in detail, according to an exemplary embodiment. Interface **2900** is shown to include multiple tabs, an input data tab **2912** and an economic load demand response tab **2914**. Input data tab **2912** is shown in greater detail in FIG. **31**. In economic load demand response tab **2914**, tables **2902-2906** are shown. Table **2902** illustrates the various participation hours. The hours may be marked as either a one or a zero, a one indicating participation while a zero indicates no participation. Hours that are locked may be displayed in a first color (red), e.g., hours **2916** are shown to be locked hours, hour **2918** is shown to be the current hour, while hours **2920** are shown to be past hours.

[0491] Table **2904** can display a curtailment amount for each of the participation hours. For an hour where there is no participation hour, where table **2902** indicates a zero, the corresponding entry of table **2904** may also be a zero. However, for an hour with participation, where table **2902** indicates a one, the corresponding entry of table **2904** may indicate the amount of the participation. Furthermore, table **2906** may indicate the revenue generated for each hour. Legend **2910** may indicate various colors, patterns, or other visual markers for actual past hours, the current hour, an overridden hour, and a locked in hour. Element **2908** may allow a user to navigate between various different days and view ELDR participation information for various different days.

[0492] Referring now to FIG. **29**, interface **2900** is shown to allow a user to select and override various hours, according to an exemplary embodiment. In FIG. **29**, non-participation hours **3002** are shown to be selected by a user. The user may interact with the participation button **3000** causing all of the selected hours to become participation hours. Likewise, the user could select participation hours and cause the participation hours to become non-participation hours.

[0493] Referring now to FIG. **30**, interface **2900** is shown to include a plot of ELDR parameters and an indication of overridden participation hours, according to an exemplary embodiment. The interface **2900** is shown to include plot **3100** which may plot various ELDR parameters. Plot **3100** may be similar to and/or the same as graph **2402** as described with reference to FIGS. **23-27**. Interface **2900** is shown to include override box **3104** which presents a user with an button to add an override and/or remove an override. If a user selects a particular hour of table **2902** and presses the override button, the hour may be overridden (e.g., overridden from a participation hour to a non-participation hour or from a non-participation hour to a participation hour). The user can also remove the override, returning the participation decision to the decision made by ELDR module **1706**.

[0494] In FIG. **30**, overridden hours **3108** are shown. These hours can be shaded a particular color to indicate to

a user which hours of table **2902** have been overridden. If the user hovers a cursor over overridden hours **3108**, a pop-up **3106** may be displayed indicating both the user override decision and the decision of ELDR module **1706**.

[0495] Referring now to FIG. **31**, input data tab **2912** is shown in greater detail, according to an exemplary embodiment. If the user interacts with input tab **2912**, interface **2900** may display graphs **3200** and **3202** as shown in FIG. **31**. The graphs may be graphs of ELDR parameters, in FIG. **31**, the graphs are of values for the day-ahead LMP and the real-time LMP. Each of the graphs **3299** and **3202** can be broken into two sections, past values **3204** and **3208**, and future values **3206** and **3210**. The past values may be actual values collected from CSP **1704** while future values may be values predicted by predictor **1718**.

[0496] Configuration of Exemplary Embodiments

[0497] The construction and arrangement of the systems and methods as shown in the various exemplary embodiments are illustrative only. Although only a few embodiments have been described in detail in this disclosure, many modifications are possible (e.g., variations in sizes, dimensions, structures, shapes and proportions of the various elements, values of parameters, mounting arrangements, use of materials, colors, orientations, etc.). For example, the position of elements can be reversed or otherwise varied and the nature or number of discrete elements or positions can be altered or varied. Accordingly, all such modifications are intended to be included within the scope of the present disclosure. The order or sequence of any process or method steps can be varied or re-sequenced according to alternative embodiments. Other substitutions, modifications, changes, and omissions can be made in the design, operating conditions and arrangement of the exemplary embodiments without departing from the scope of the present disclosure.

[0498] The present disclosure contemplates methods, systems and program products on any machine-readable media for accomplishing various operations. The embodiments of the present disclosure can be implemented using existing computer processors, or by a special purpose computer processor for an appropriate system, incorporated for this or another purpose, or by a hardwired system. Embodiments within the scope of the present disclosure include program products comprising machine-readable media for carrying or having machine-executable instructions or data structures stored thereon. Such machine-readable media can be any available media that can be accessed by a general purpose or special purpose computer or other machine with a processor. By way of example, such machine-readable media can comprise RAM, ROM, EPROM, EEPROM, CD-ROM or other optical disk storage, magnetic disk storage or other magnetic storage devices, or any other medium which can be used to carry or store desired program code in the form of machine-executable instructions or data structures and which can be accessed by a general purpose or special purpose computer or other machine with a processor. Combinations of the above are also included within the scope of machine-readable media. Machine-executable instructions include, for example, instructions and data which cause a general purpose computer, special purpose computer, or special purpose processing machines to perform a certain function or group of functions.

[0499] Although the figures show a specific order of method steps, the order of the steps may differ from what is depicted. Also two or more steps can be performed concurrently or with partial concurrence. Such variation will depend on the software and hardware systems chosen and on designer choice. All such variations are within the scope of the disclosure. Likewise, software implementations could be accomplished with standard programming techniques with rule based logic and other logic to accomplish the various connection steps, processing steps, comparison steps and decision steps.

What is claimed is:

1. An energy optimization system for a building, the system comprising:

a processing circuit configured to:

perform an optimization to generate one or more first participation hours and a first load reduction amount for each of the one or more first participation hours and provide a first bid comprising the one or more first participation hours and the first load reduction amount for each of the one or more first participation hours to a computing system configured to facilitate an economic load demand response (ELDR) program;

operate one or more pieces of building equipment to affect an environmental condition of the building based on one or more first equipment loads for participating in the ELDR program;

receive one or more awarded or rejected participation hours from the computing system responsive to the first bid;

generate one or more second participation hours for participating in the ELDR program, a second load reduction amount for each of the one or more second participation hours, and one or more second equipment loads for the one or more pieces of building equipment based on the one or more awarded or rejected participation hours by performing the optimization a second time; and

operate the one or more pieces of building equipment to affect the environmental condition of the building based on the one or more second equipment loads.

2. The system of claim **1**, wherein the processing circuit is configured to:

generate a predicted campus electric load based on at least one of historical campus electric load values, predicted market resource prices, predicted equipment loads, or predicted chilled water loads; and

generate the one or more second participation hours for participating in the ELDR program, the second load reduction amount for each of the one or more second participation hours, and the one or more second equipment loads for the one or more pieces of building equipment based on the one or more awarded or rejected participation hours and on the predicted campus electric load by performing the optimization the second time.

3. The system of claim **1**, wherein the processing circuit is configured to:

generate a second bid comprising the one or more second participation hours and the second load reduction amount for each of the one or more second participation hours;

provide the second bid to the computing system configured to facilitate the ELDR program; and

receive one or more second awarded or rejected hours from the computing system responsive to the second bid.

4. The system of claim **3**, wherein the second bid is an update to the first bid, the one or more second participation hours are an update to the one or more first participation hours, and the second load reduction amount for each of the one or more second participation hours is an update to the first load reduction amount for each of the one or more first participation hours.

5. The system of claim **1**, wherein the one or more awarded or rejected hours and the one or more second participation hours are hours of a particular day, wherein the processing circuit is configured to:

determine a revenue benefit for the particular day based on a benefit function and the one or more awarded or rejected hours; and

determine whether to participate in the ELDR program for the particular day based on a comparison of the revenue benefit to a predefined threshold.

6. The system of claim **5**, wherein the processing circuit is configured to determine whether to participate in the ELDR program for the particular day based on the comparison of the revenue benefit to the predefined threshold by:

determining to participate in the ELDR program for the particular day in response to a determination that the revenue benefit is greater than the predefined threshold; and

determining not to participate in the ELDR program for the particular day in response to a determination that the revenue benefit is less than the predefined threshold.

7. The system of claim **1**, wherein the processing circuit is configured to perform the optimization to generate the one or more first participation hours for participating in the ELDR program, the first load reduction amount for each of the one or more first participation hours, and the one or more first equipment loads for the one or more pieces of building equipment based on one or more ELDR parameters for the ELDR program.

8. The system of claim **7**, wherein the one or more ELDR parameters comprise at least one of a day ahead locational marginal price which is an electricity price for a particular area on a future day, a real-time locational marginal price which is an electricity price at a current time, or a net benefits test (NBT) threshold which is a value indicating whether a particular hour should be a participation hour.

9. The system of claim **1**, wherein the processing circuit is configured to:

periodically collect one or more ELDR parameters from the computing system configured to facilitate the ELDR program; and

generate the one or more second participation hours for participating in the ELDR program, the second load reduction amount for each of the one or more second participation hours, and the one or more second equipment loads for the one or more pieces of building equipment based on the one or more first awarded or rejected hours and the periodically collected ELDR parameters by performing the optimization the second time.

10. The system of claim **9**, wherein the processing circuit is configured to:

generate one or more predictions of the one or more ELDR parameters based on the one or more ELDR parameters; and

generate the one or more second participation hours for participating in the ELDR program, the second load reduction amount for each of the one or more second participation hours, and the one or more second equipment loads for the one or more pieces of building equipment based on the one or more first awarded or rejected hours and the one or more predictions of the one or more ELDR parameters by performing the optimization the second time.

11. A method for optimizing energy use of a building, the method comprising:

performing an optimization to generate one or more first participation hours and a first load reduction amount for each of the one or more first participation hours and providing a first bid comprising the one or more first participation hours and the first load reduction amount for each of the one or more first participation hours to a computing system configured to facilitate an economic load demand response (ELDR) program;

operating one or more pieces of building equipment to affect an environmental condition of the building based on one or more first equipment loads for participating in the ELDR program;

receiving one or more awarded or rejected participation hours from the computing system in response to providing the first bid to the computing system;

generating one or more second participation hours for participating in the ELDR program, a second load reduction amount for each of the one or more second participation hours, and one or more second equipment loads for the one or more pieces of building equipment based on the one or more awarded or rejected participation hours by performing the optimization a second time; and

operating the one or more pieces of building equipment to affect the environmental condition of the building based on the one or more second equipment loads.

12. The method of claim **11**, further comprising:

generating a predicted campus electric load based on at least one of historical campus electric load values, predicted market resource prices, predicted equipment loads, or predicted chilled water loads; and

generating the one or more second participation hours for participating in the ELDR program, the second load reduction amount for each of the one or more second participation hours, and the one or more second equipment loads for the one or more pieces of building equipment based on the one or more awarded or rejected participation hours and on the predicted campus electric load.

13. The method of claim **11**, further comprising:

generating a second bid comprising the one or more second participation hours and the second load reduction amount for each of the one or more second participation hours;

providing the second bid to the computing system configured to facilitate the ELDR program, wherein the second bid is an update to the first bid, the one or more second participation hours are an update to the one or more first participation hours, and the second load reduction amount for each of the one or more second

participation hours is an update to the first load reduction amount for each of the one or more first participation hours; and

receiving one or more second awarded or rejected hours from the computing system in response to providing the second bid.

14. The method of claim **11**, wherein the one or more awarded or rejected hours and the one or more second participation hours are hours of a particular day, wherein the method further comprises:

determining a revenue benefit for the particular day based on a benefit function and the one or more awarded or rejected hours; and

determining whether to participate in the ELDR program for the particular day based on a comparison of the revenue benefit to a predefined threshold.

15. The method of claim **14**, wherein determining whether to participate in the ELDR program for the particular day based on a comparison of the revenue benefit to a predefined threshold comprises:

determining to participate in the ELDR program for the particular day in response to a determination that the revenue benefit is greater than the predefined threshold; and

determining not to participate in the ELDR program for the particular day in response to a determination that the revenue benefit is less than the predefined threshold.

16. The method of claim **11**, wherein performing the optimization to generate the one or more first participation hours for participating in the ELDR program, the first load reduction amount for each of the one or more first participation hours, and the one or more first equipment loads for the one or more pieces of building equipment is based on one or more ELDR parameters for the ELDR program.

17. The method of claim **16**, further comprising:

periodically collecting the one or more ELDR parameters from the computing system configured to facilitate the ELDR program;

generating one or more predictions of the one or more ELDR parameters based on the one or more ELDR parameters; and

generating the one or more second participation hours for participating in the ELDR program, the second load reduction amount for each of the one or more second participation hours, and the one or more second equipment loads for the one or more pieces of building equipment based on the one or more first awarded or rejected hours and the one or more predictions of the one or more ELDR parameters by performing the optimization the second time.

18. An energy optimization controller for a building, the controller comprising:

a processing circuit configured to:

perform an optimization to generate one or more first participation hours and a first load reduction amount for each of the one or more first participation hours and provide a first bid comprising the one or more first participation hours and the first load reduction amount for each of the one or more first participation hours to a computing system configured to facilitate an economic load demand response (ELDR) program;

operate the one or more pieces of building equipment to affect an environmental condition of the building based on one or more first equipment loads for participating in the ELDR program;

receive one or more awarded or rejected participation hours from the computing system;

periodically collect one or more ELDR parameters from the computing system configured to facilitate the ELDR program;

generate one or more predictions of the one or more ELDR parameters based on the one or more ELDR parameters;

generate one or more second participation hours for participating in the ELDR program, a second load reduction amount for each of the one or more second participation hours, and one or more second equipment loads for the one or more pieces of building equipment based on the one or more awarded or rejected participation hours and the predicted one or more ELDR parameters; and

operate the one or more pieces of building equipment to affect the environmental condition of the building based on the one or more second equipment loads.

19. The controller of claim **18**, wherein the one or more awarded or rejected hours and the one or more participation hours are hours of a particular day, wherein the processing circuit is configured to:

determine a revenue benefit for the particular day based on a benefit function and the one or more awarded or rejected hours; and

determine whether to participate in the ELDR program for the particular day based on a comparison of the revenue benefit to a predefined threshold.

20. The controller of claim **19**, wherein the processing circuit is configured to determine whether to participate in the ELDR program for the particular day based on a comparison of the revenue benefit to a predefined threshold by:

determining to participate in the ELDR program for the particular day in response to a determination that the revenue benefit is greater than the predefined threshold;

determining not to participate in the ELDR program for the particular day in response to a determination that the revenue benefit is less than the predefined threshold.

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