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(54) BATTERY CHARGING BASED ON COST AND LIFE

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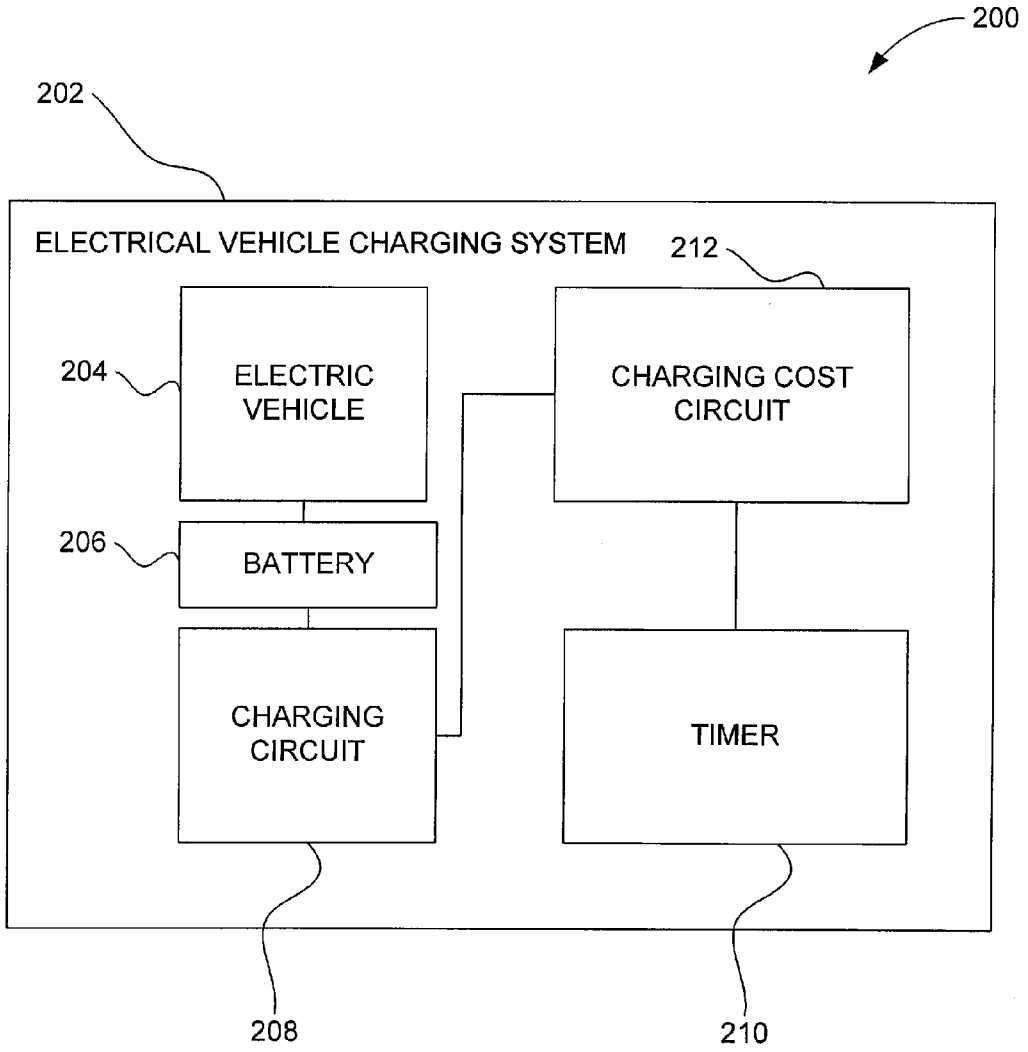
(57) **ABSTRACT**

One embodiment of the present subject matter includes a system that includes a battery, an electric vehicle, the battery coupled to the electric vehicle to propel the electric vehicle, and a charging circuit to charge the battery. The embodiment includes a charging cost circuit to estimate a charging cost rate and to turn on the charging circuit. The embodiment also includes a timer circuit to provide a time signal to the charging cost circuit. The embodiment is configured such that the charging cost circuit is to turn on the charging circuit during a first time period in which the charging cost rate is below a first threshold until the battery reaches a first energy stored level, and to turn on the charging circuit during a second time period in which the charging cost rate is above the first threshold.



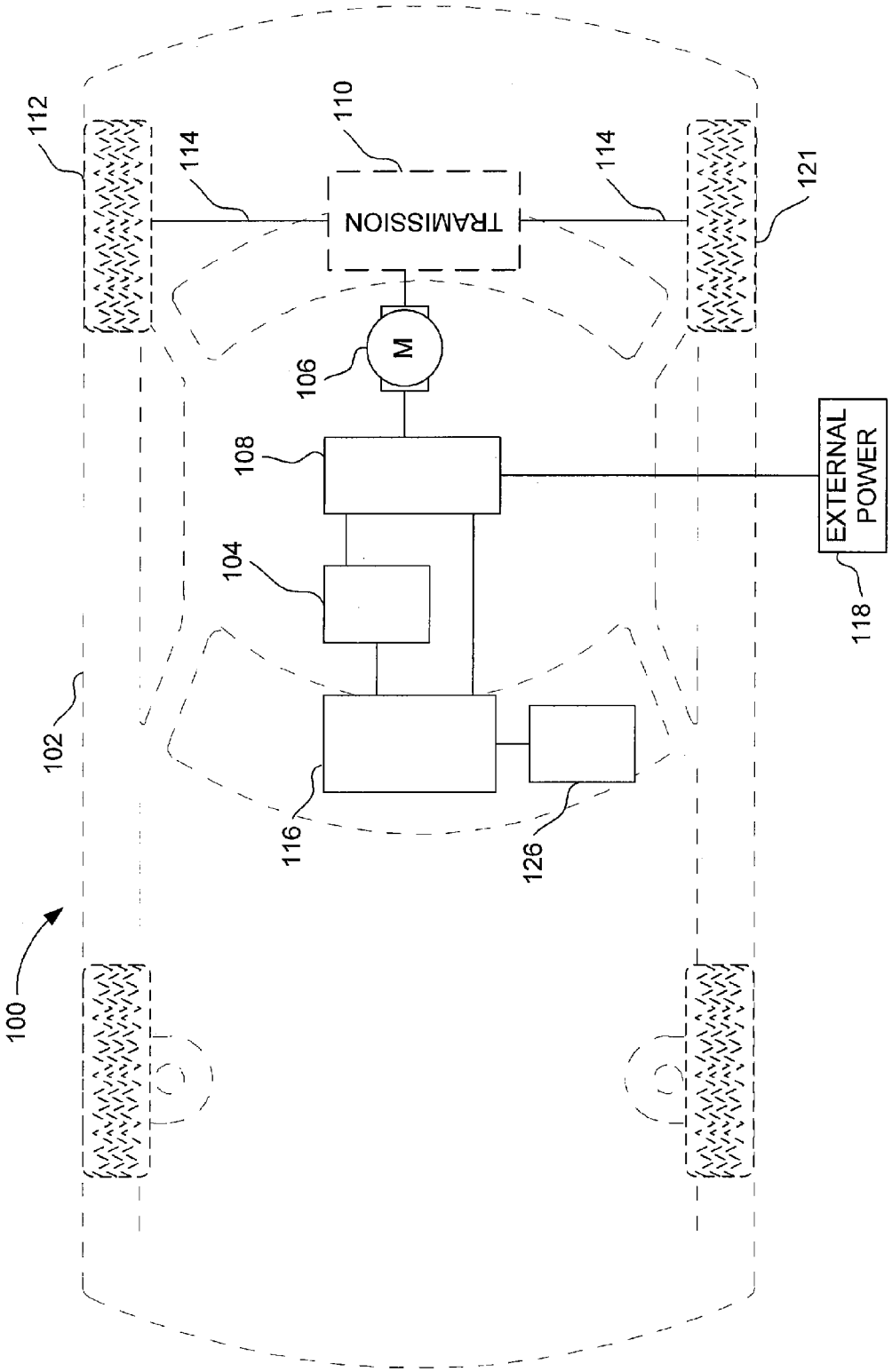

100
102
104
106
108
110
112
114
114
116
118
121
126
M
TRAMISSION
EXTERNAL POWER

FIG. 1

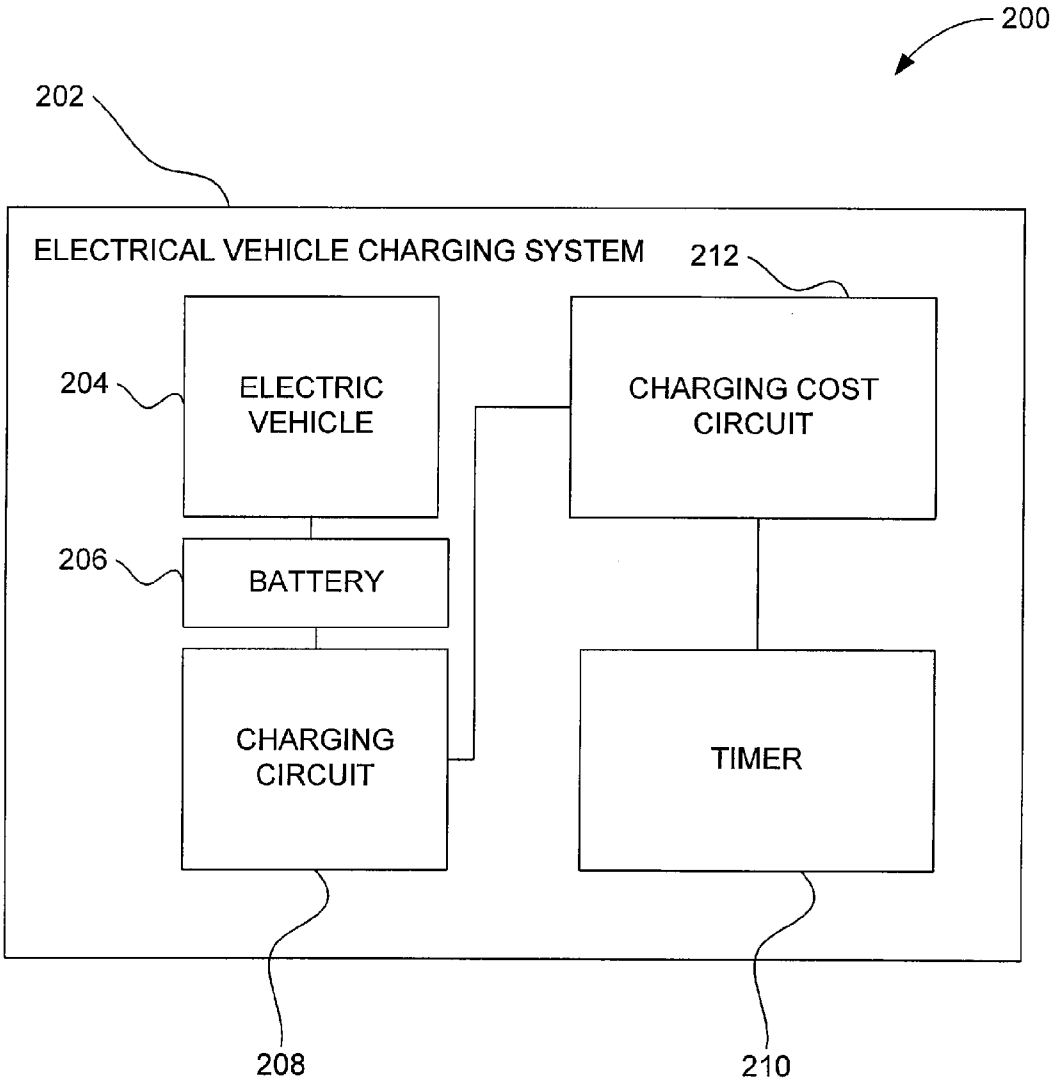

200
202
ELECTRICAL VEHICLE CHARGING SYSTEM
212
204
ELECTRIC VEHICLE
CHARGING COST CIRCUIT
206
BATTERY
CHARGING CIRCUIT
TIMER
208
210

FIG. 2

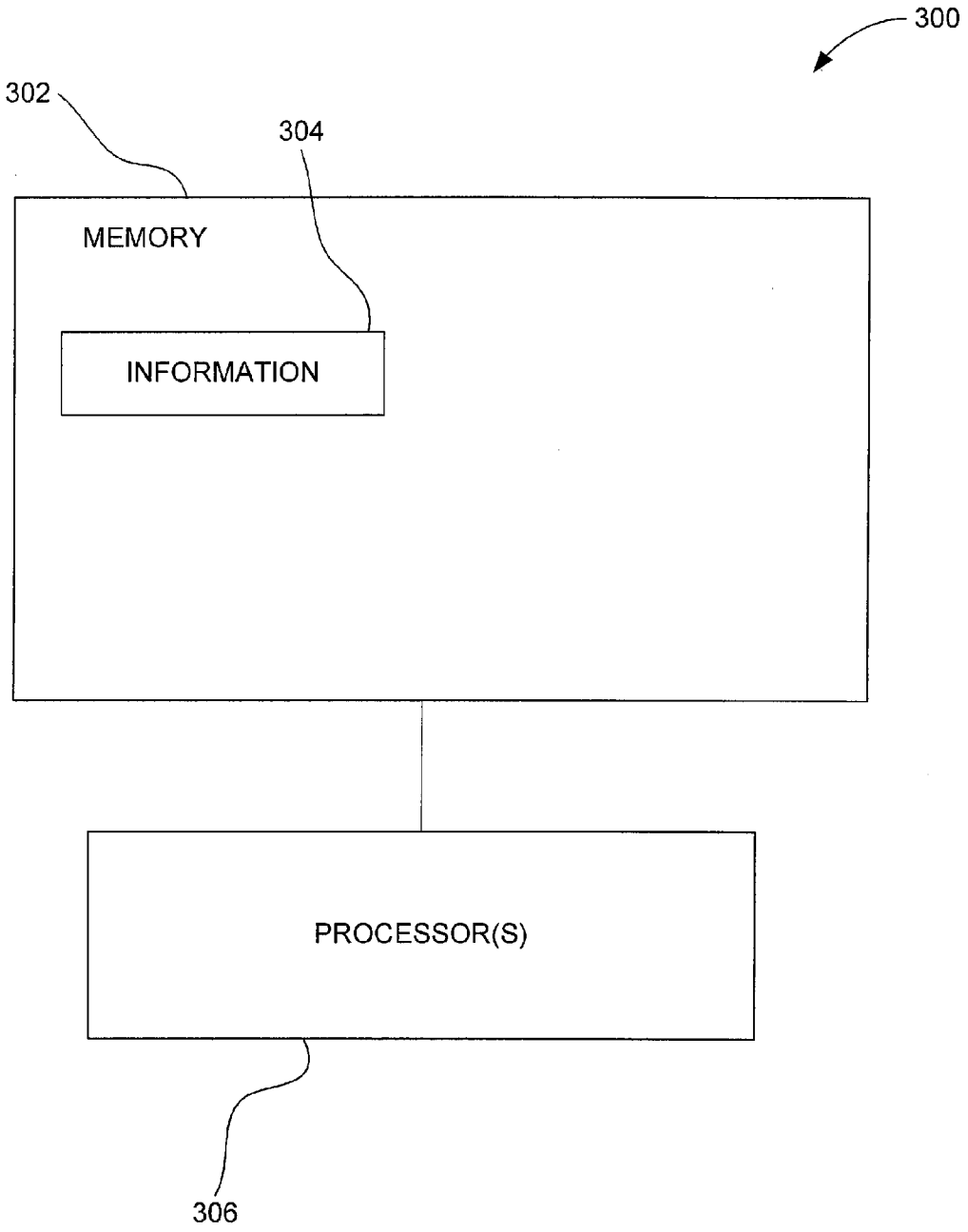


FIG. 3

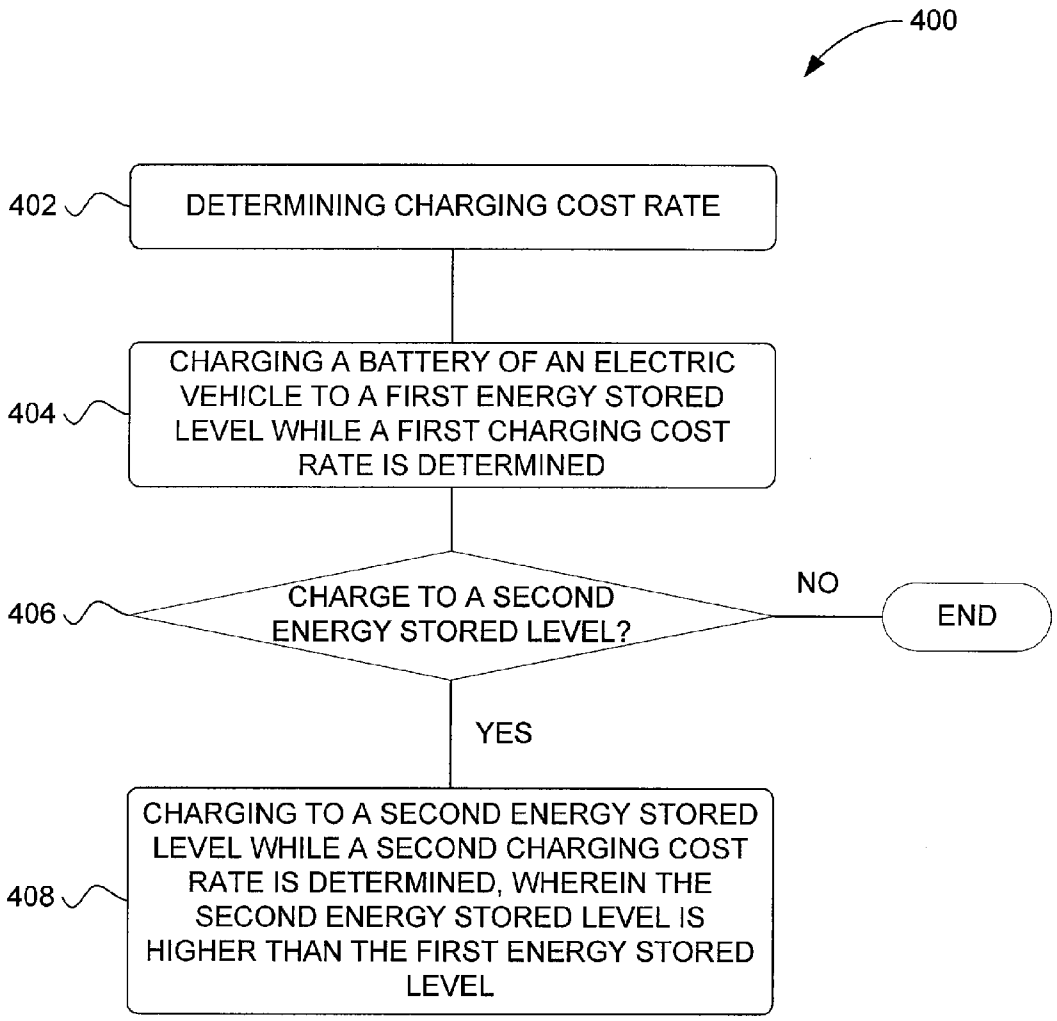

400
402
DETERMINING CHARGING COST RATE
404
CHARGING A BATTERY OF AN ELECTRIC VEHICLE TO A FIRST ENERGY STORED LEVEL WHILE A FIRST CHARGING COST RATE IS DETERMINED
406
CHARGE TO A SECOND ENERGY STORED LEVEL?
NO
END
YES
408
CHARGING TO A SECOND ENERGY STORED LEVEL WHILE A SECOND CHARGING COST RATE IS DETERMINED, WHEREIN THE SECOND ENERGY STORED LEVEL IS HIGHER THAN THE FIRST ENERGY STORED LEVEL

FIG. 4

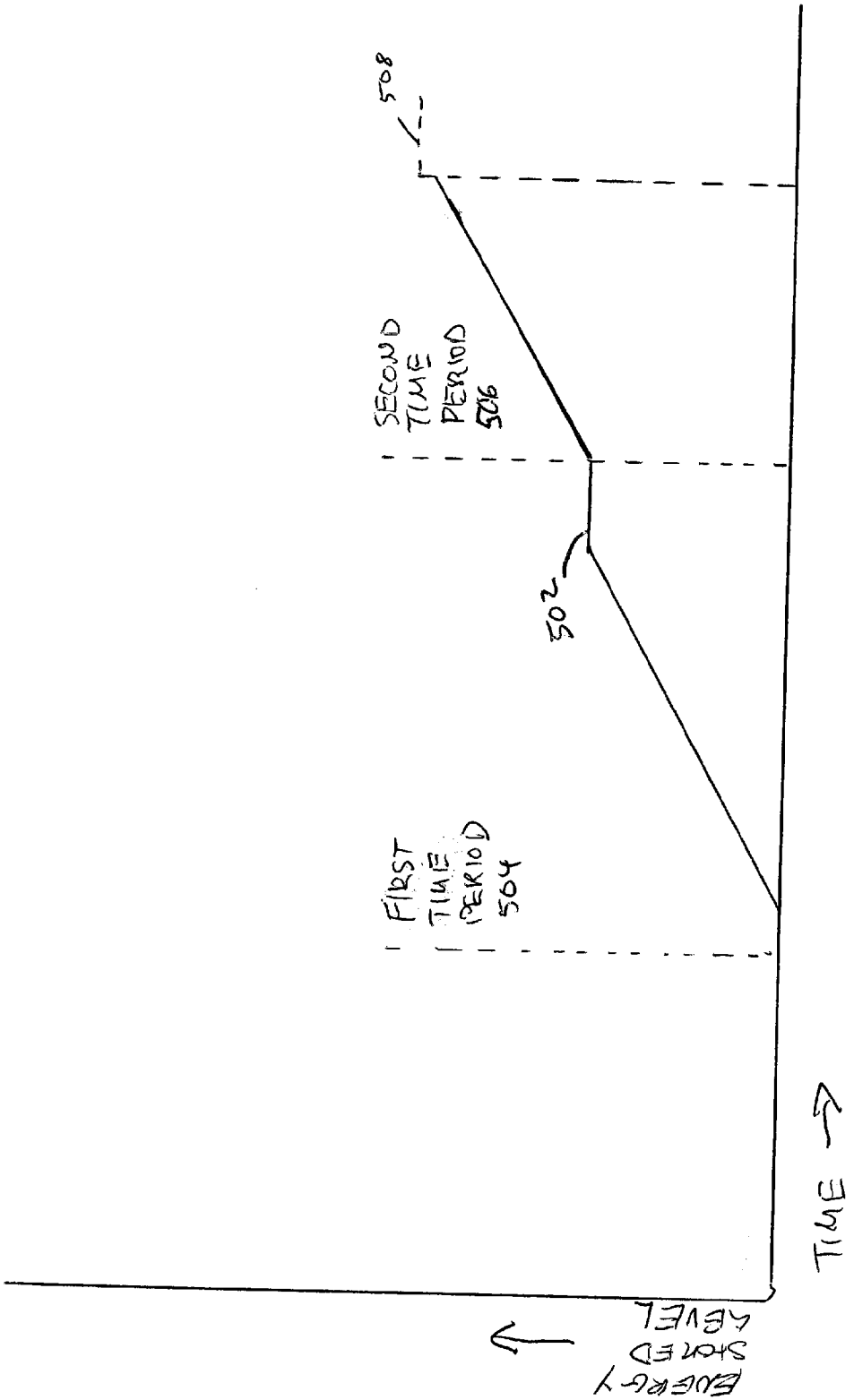

FIRST TIME PERIOD 504
502
SECOND TIME PERIOD 506
508
ENERGY STORED LEVEL
TIME

FIG. 5

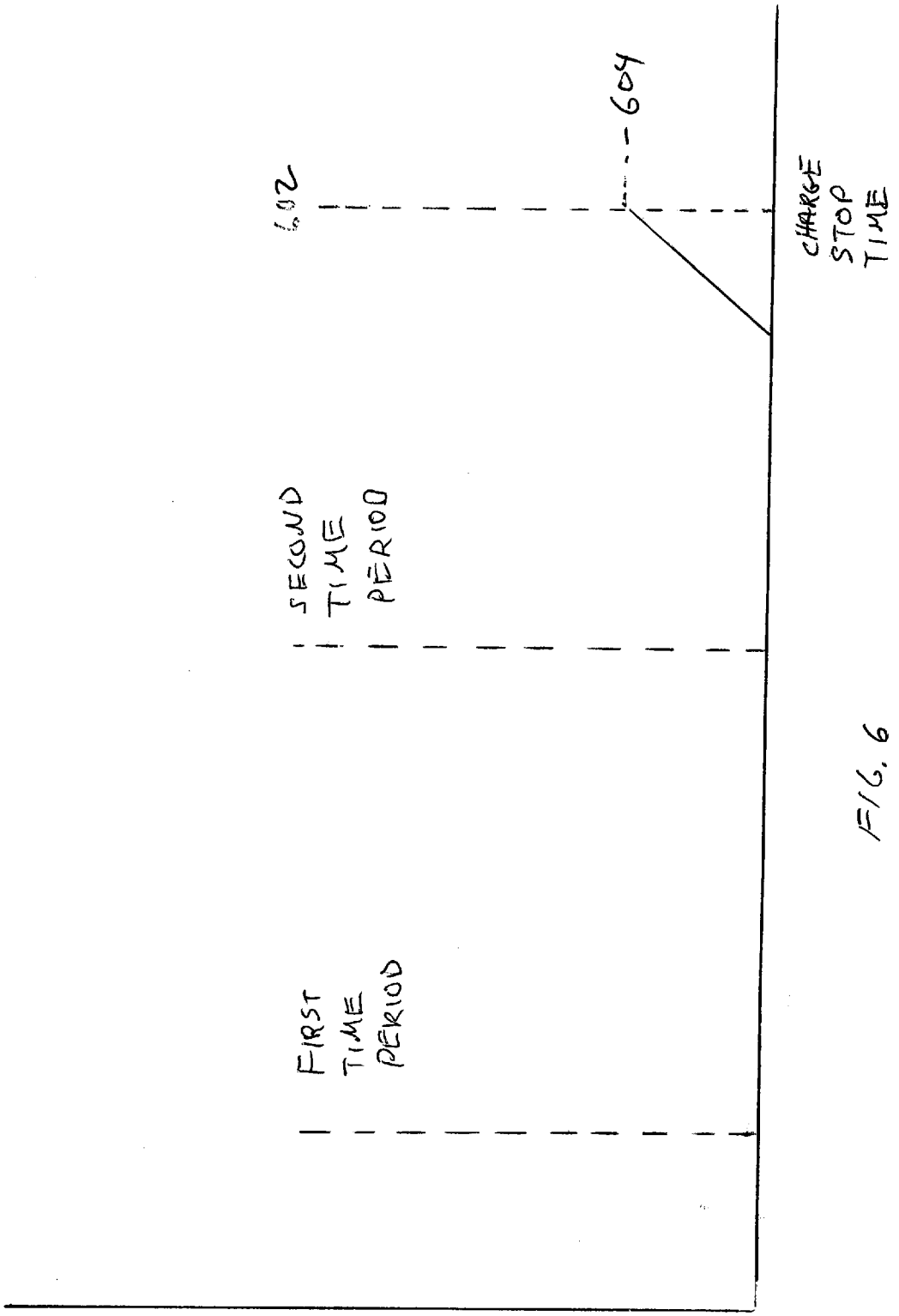

FIRST TIME PERIOD
SECOND TIME PERIOD
602
604
CHARGE STOP TIME

FIG. 6

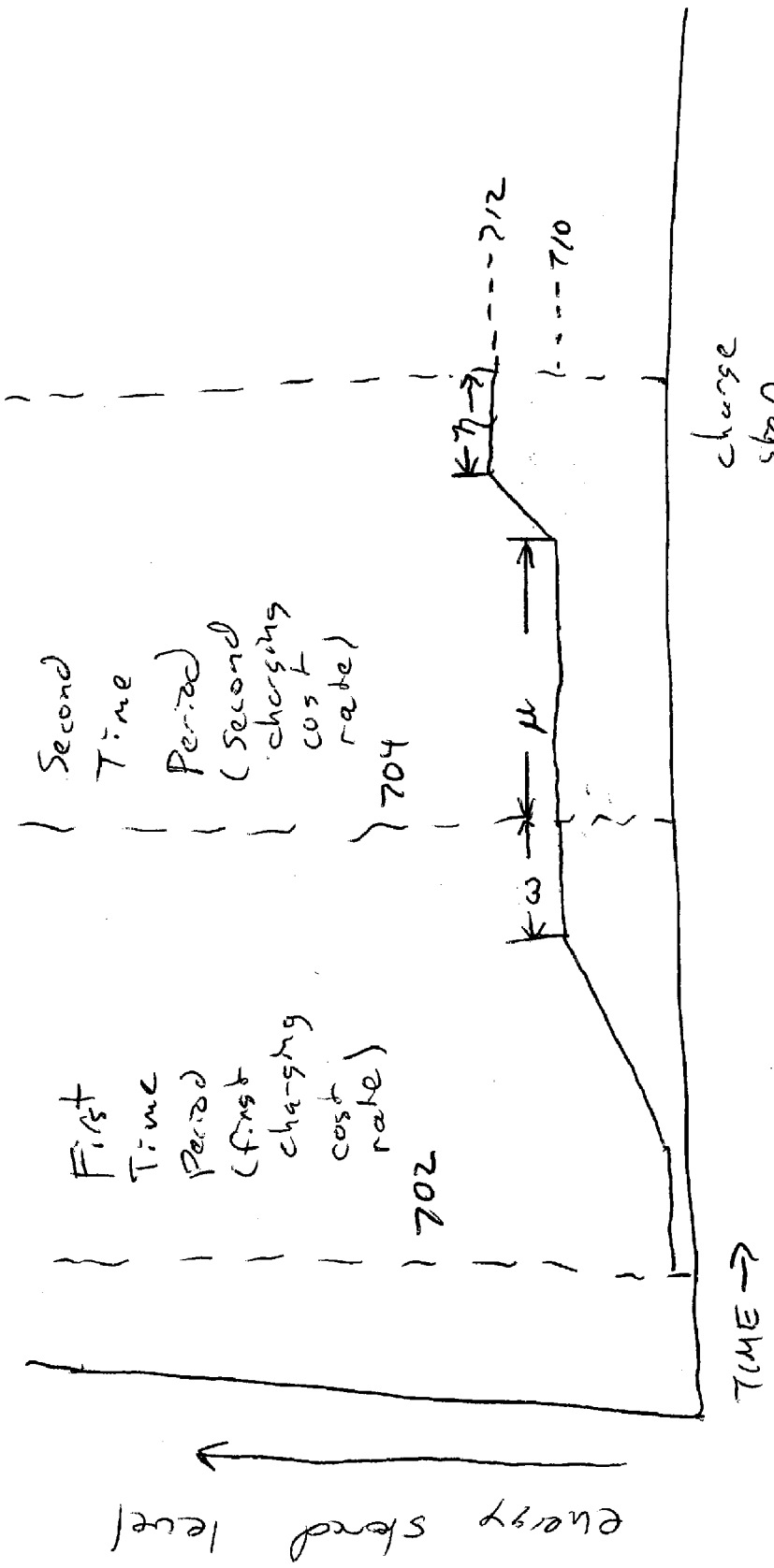

First Time Period (first charging cost rate)
702
Second Time Period (second charging cost rate)
704
3
μ
η
712
710
charge stop time
706
TIME →
energy stored level

FIG. 7

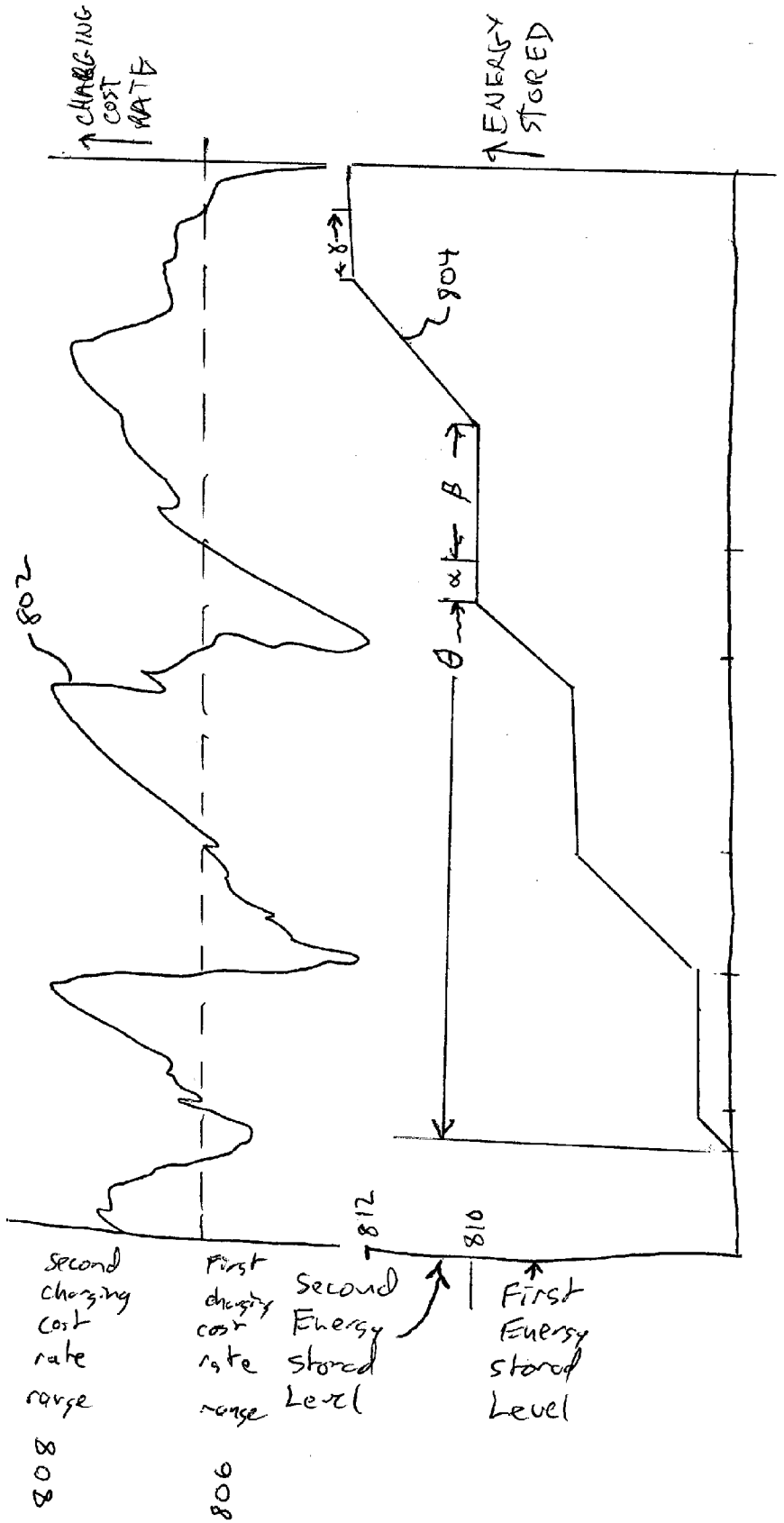

CHARGING COST RATE
ENERGY STORED
802
804
θ
α
β
γ
812
810
Second charging cost rate range
808
First charging cost rate range
806
Second Energy stored Level
First Energy stored Level

FIG. 8

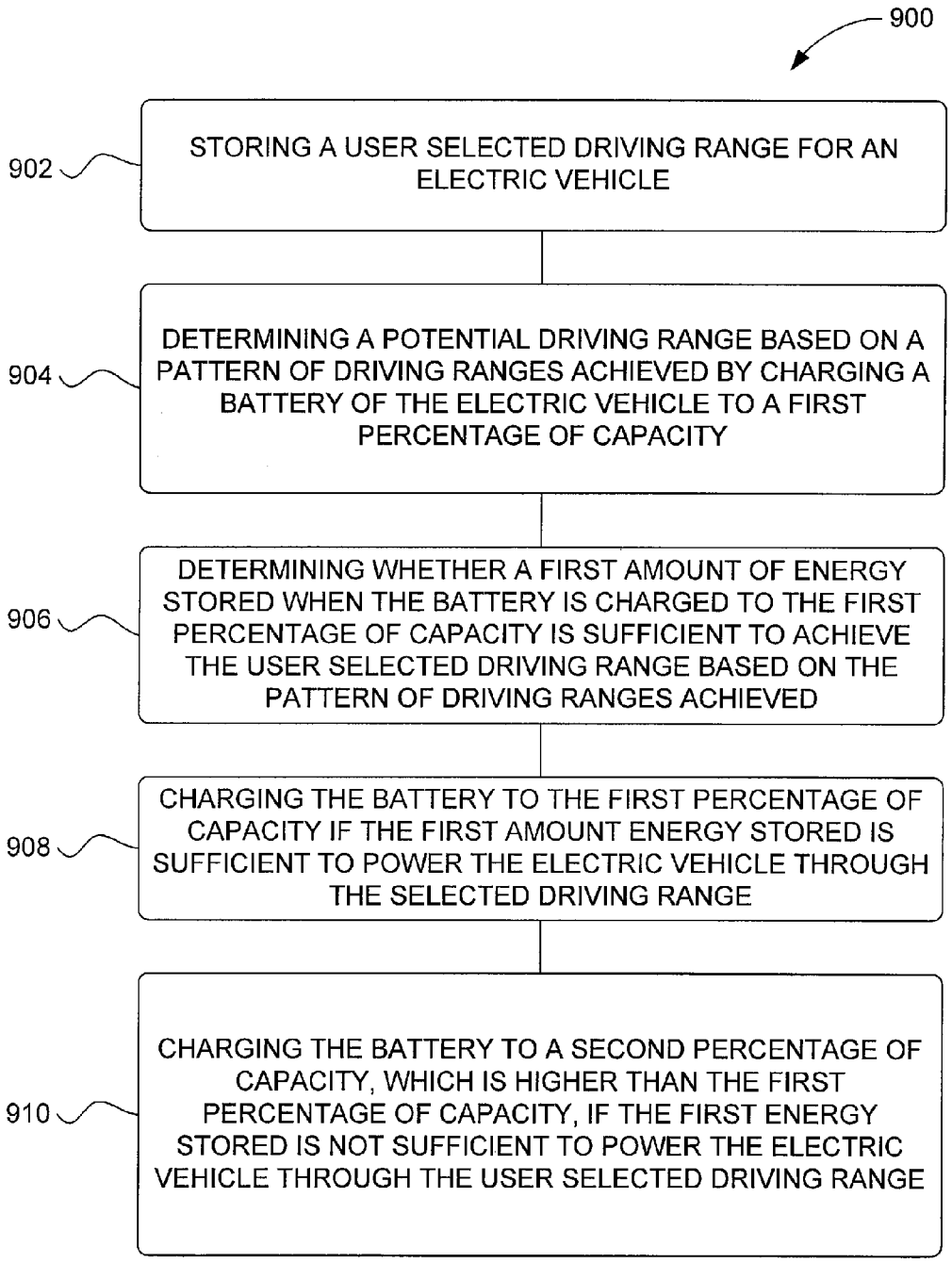

900
902
STORING A USER SELECTED DRIVING RANGE FOR AN ELECTRIC VEHICLE
904
DETERMINING A POTENTIAL DRIVING RANGE BASED ON A PATTERN OF DRIVING RANGES ACHIEVED BY CHARGING A BATTERY OF THE ELECTRIC VEHICLE TO A FIRST PERCENTAGE OF CAPACITY
906
DETERMINING WHETHER A FIRST AMOUNT OF ENERGY STORED WHEN THE BATTERY IS CHARGED TO THE FIRST PERCENTAGE OF CAPACITY IS SUFFICIENT TO ACHIEVE THE USER SELECTED DRIVING RANGE BASED ON THE PATTERN OF DRIVING RANGES ACHIEVED
908
CHARGING THE BATTERY TO THE FIRST PERCENTAGE OF CAPACITY IF THE FIRST AMOUNT ENERGY STORED IS SUFFICIENT TO POWER THE ELECTRIC VEHICLE THROUGH THE SELECTED DRIVING RANGE
910
CHARGING THE BATTERY TO A SECOND PERCENTAGE OF CAPACITY, WHICH IS HIGHER THAN THE FIRST PERCENTAGE OF CAPACITY, IF THE FIRST ENERGY STORED IS NOT SUFFICIENT TO POWER THE ELECTRIC VEHICLE THROUGH THE USER SELECTED DRIVING RANGE

FIG. 9

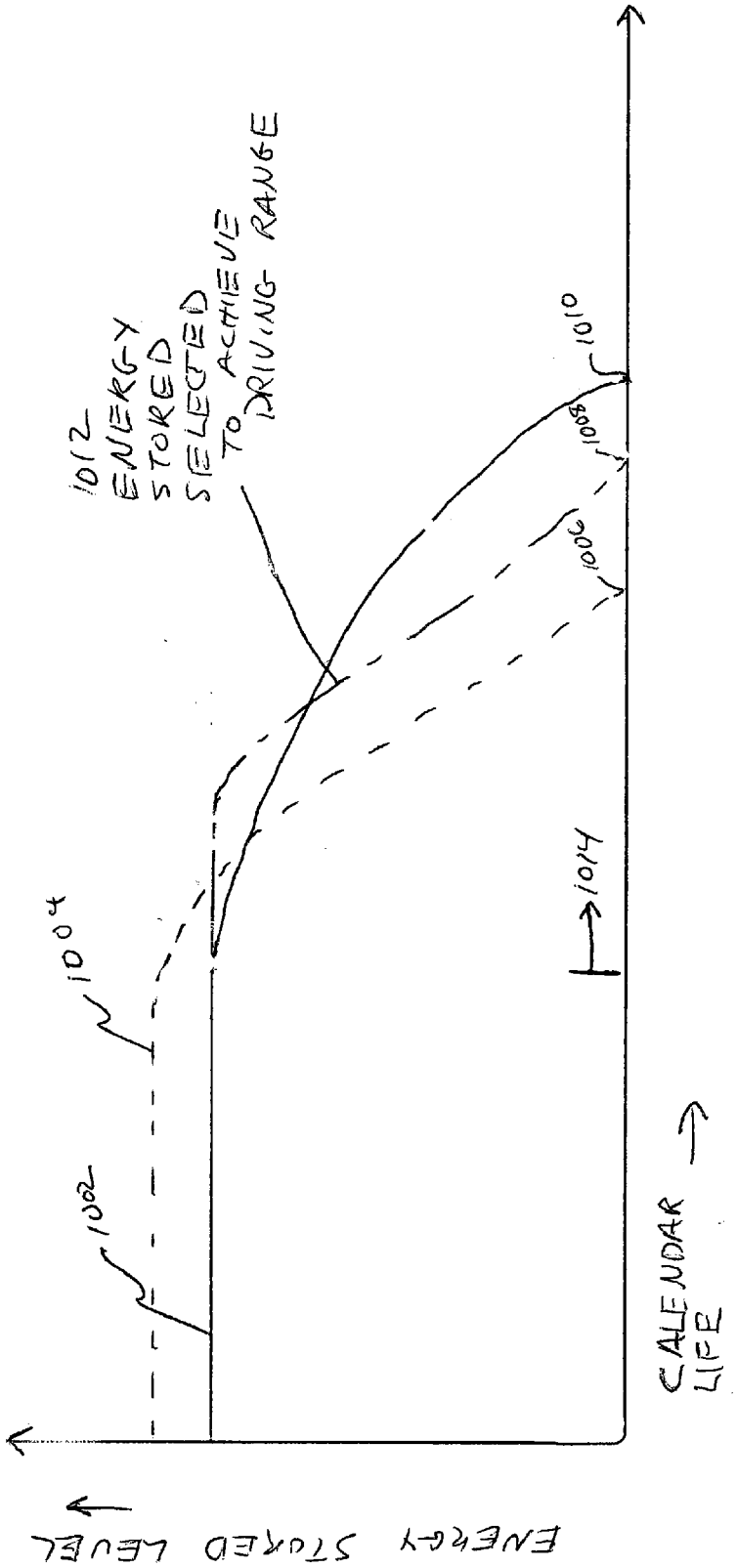

1012
ENERGY
STORED
SELECTED
TO ACHIEVE
DRIVING RANGE
1010
1008
1006
1004
1002
1014
CALENDAR
LIFE
ENERGY STORED LEVEL

FIG. 10

BATTERY CHARGING BASED ON COST AND LIFE

BACKGROUND

[0001] Charging the battery of an electric vehicle is expensive, and if it is done improperly, can damage the battery. Systems and methods are needed to reduce the cost of battery charging while reducing battery damage.

BRIEF DESCRIPTION OF THE DRAWINGS

[0002] FIG. **1** is a high level diagram of an electric vehicle, according to one embodiment.

[0003] FIG. **2** is a diagram of an electrical vehicle charging system, according to one embodiment.

[0004] FIG. **3** is a block diagram of an article according to various embodiments of the invention.

[0005] FIG. **4** is a method of charging a battery, according to one embodiment of the present subject matter.

[0006] FIG. **5** is a method of charging a battery to a first energy stored level during a first time period and charging the battery during a second time period, according to one embodiment of the present subject matter.

[0007] FIG. **6** is a method of charging a battery during a second time period, according to one embodiment of the present subject matter.

[0008] FIG. **7** is a method of charging to a first energy stored level during a first time period, and to a second energy stored level during a second time period, according to one embodiment of the present subject matter.

[0009] FIG. **8** is a method of charging a battery in the context of a charging rate that varies up and down throughout the day, according to one embodiment of the present subject matter.

[0010] FIG. **9** is a method according to one embodiment of the present subject matter.

[0011] FIG. **10** is a method of charging a battery to achieve a selected range, according to one embodiment of the present subject matter.

DETAILED DESCRIPTION

[0012] In the following description, reference is made to the accompanying drawings that form a part hereof, and in which is shown by way of illustration specific embodiments which may be practiced. These embodiments are described in sufficient detail to enable those skilled in the art to practice the invention, and it is to be understood that other embodiments may be utilized and that structural, logical and electrical changes may be made without departing from the scope of the present invention. The following description of example embodiments is, therefore, not to be taken in a limited sense, and the scope of the present invention is defined by the appended claims.

[0013] The present subject matter provides systems and methods to charge a battery of a vehicle in a way that is adaptive to context. For example, in some parts of the world, electricity is less expensive during certain time periods. For example, electricity can be less expensive during nighttime, when less energy is being consumed due to lower air conditioning rates. This is an example time period, and others are possible.

[0014] The present subject matter provides users with the ability to select schedules to charge their vehicle in light of such varying rates. For examples, a user can charge their car to a regular capacity (e.g., 80% of capacity) or a regular energy stored rate (percent of capacity needed to store a set amount of energy increases over time) during times when it is less expensive to purchase electricity. Users can optionally select to charge the car in excess of the regular amount, perhaps to augment available driving range, in certain examples. In some instances, a user can select to charge to a regular rate before they sleep, and can wake up and select to charge in addition to the regular range as they prepare for their day. These and other embodiments are discussed herein.

[0015] FIG. **1** shows a vehicle system **100**, according to one embodiment of the present subject matter. In various embodiments, the vehicle **102** is an electric vehicle and includes a vehicle propulsion battery **104** and at least one propulsion motor **106** for converting battery energy into mechanical motion, such as rotary motion. The present subject matter includes examples in which the vehicle propulsion battery **104** is a subcomponent of an energy storage system ("ESS"). An ESS includes various components associated with transmitting energy to and from the vehicle propulsion battery **104** in various examples, including safety components, cooling components, heating components, rectifiers, etc. The inventors have contemplated several examples of ESSs and the present subject matter should not be construed to be limited to the configurations disclosed herein, as other configurations of a vehicle propulsion battery **104** and ancillary components are possible.

[0016] The battery includes one or more lithium ion cells in various examples. In some examples, the battery **104** includes a plurality of lithium ion cells coupled in parallel and/or series. Some examples include cylindrical lithium ion cells. In certain examples, the battery **104** includes one or more cells compatible with the 18650 battery standard, but the present subject matter is not so limited. Some examples include a first plurality of cells connected in parallel to define a first brick of cells, with a second plurality of cells connected in parallel to define a second brick of cells, with the first brick and the second brick connected in series. Some examples connect 69 cells in parallel to define a brick. Battery voltage, and as such, brick voltage, often ranges from around 3.6 volts to about 4.2 volts in use. In part because the voltage of batteries ranges from cell to cell, some instances include voltage management systems to maintain a steady voltage. Some embodiments connect 9 bricks in series to define a sheet. Such a sheet has around 35 volts. Some instances connect 11 sheets in series to define the battery of the ESS. The ESS will demonstrate around 385 volts in various examples. As such, some examples include approximately 6,831 cells which are interconnected.

[0017] Additionally illustrated is an energy converter **108**. The energy converter **108** is part of a system which converts energy from the vehicle propulsion battery **104** into energy useable by the at least one propulsion motor **106**. In certain instances, the energy flow is from the at least one propulsion motor **106** to the vehicle propulsion battery **104**. As such, in some examples, the vehicle propulsion battery **104** transmits energy to the energy converter **108**, which converts the energy into energy usable by the at least one propulsion motor **106** to propel the electric vehicle. In additional examples, the at least one propulsion motor **106** generates energy that is transmitted to the energy converter **108**. In these examples, the energy converter **108** converts the energy into energy which can be stored in the vehicle propulsion battery **104**. In certain examples, the energy converter **108** includes transistors.

Some examples include one or more field effect transistors. Some examples include metal oxide semiconductor field effect transistors. Some examples include one more insulated gate bipolar transistors. As such, in various examples, the energy converter **108** includes a switch bank which is configured to receive a direct current ("DC") power signal from the vehicle propulsion battery **104** and to output a three-phase alternating current ("AC") signal to power the vehicle propulsion motor **106**. In some examples, the energy converter **108** is configured to convert a three phase signal from the vehicle propulsion motor **106** to DC power to be stored in the vehicle propulsion battery **104**. Some examples of the energy converter **108** convert energy from the vehicle propulsion battery **104** into energy usable by electrical loads other than the vehicle propulsion motor **106**. Some of these examples switch energy from approximately 390 Volts to 14 Volts.

[0018] The propulsion motor **106** is a three phase alternating current ("AC") propulsion motor, in various examples. Some examples include a plurality of such motors. The present subject matter can optionally include a transmission or gearbox **110** in certain examples. While some examples include a 1-speed transmission, other examples are contemplated. Manually clutched transmissions are contemplated, as are those with hydraulic, electric, or electrohydraulic clutch actuation. Some examples employ a dual-clutch system that, during shifting, phases from one clutch coupled to a first gear to another coupled to a second gear. Rotary motion is transmitted from the transmission **110** to wheels **112** via one or more axles **114**, in various examples.

[0019] A vehicle management system **116** is optionally provided which provides control for one or more of the vehicle propulsion battery **104** and the energy converter **108**. In certain examples, the vehicle management system **116** is coupled to vehicle system which monitors a safety system (such as a crash sensor). In some examples the vehicle management system **116** is coupled to one or more driver inputs (e.g., an accelerator). The vehicle management system **116** is configured to control power to one or more of the vehicle propulsion battery **104** and the energy converter **108**, in various embodiments.

[0020] External power **118** is provided to communicate energy with the vehicle propulsion battery **104**, in various examples. In various embodiments, external power **118** includes a charging station that is coupled to a municipal power grid. In certain examples, the charging station converts power from a 110V AC power source into power storable by the vehicle propulsion battery **104**. In additional examples, the charging station converts power from a 120V AC power source into power storable by the vehicle propulsion battery **104**. Some embodiments include converting energy from the battery **104** into power usable by a municipal grid. The present subject matter is not limited to examples in which a converter for converting energy from an external source to energy usable by the vehicle **100** is located outside the vehicle **100**, and other examples are contemplated.

[0021] Some examples include a vehicle display system **126**. The vehicle display system **126** includes a visual indicator of system **100** information in some examples. In some embodiments, the vehicle display system **126** includes a monitor that includes information related to system **100**. Some instances include one or more lights. Some examples include one or more lights, and the vehicle display system **126** in these embodiments includes the illumination and brightness of these lights. The vehicle management system, in certain embodiments, coordinates the function of a charge state circuit **106**, and the charging coupler port **108**, as pictured in FIG. **1**. In certain instances, the charge state circuit **106**, and the charging coupler port **108** are part of the vehicle management system **116**. In some of these instances, the lighting circuit **114** is part of the vehicle display system **126**. In certain examples, the illuminated indicator **116** of FIG. **1** is part of the vehicle display system **126**.

[0022] FIG. **2** is a diagram of an electrical vehicle charging system **202**, according to one embodiment. In various embodiments, the system includes an electric vehicle **204** and a battery **206** coupled to the electric vehicle to the electric vehicle **204** to propel the electric vehicle **204**. Electric vehicles contemplated by the present subject matter include ground based vehicles, as well as aircraft and aquatic vehicles.

[0023] The illustration includes a charging circuit **208** to charge the battery **206**. This can include an external charging station that converts power from a municipal power grid to power that can be stored in battery **206**. This can additionally include charging converter onboard the electric vehicle that can take energy from a generally available outlet of a municipal power grid (such as a National Electrical Manufacturers Association 5-15 outlet) and convert it to power storable in the battery **206**. Other configurations are possible.

[0024] Various examples include a charging cost circuit **212** to estimate a charging cost rate. In various embodiments, a charging cost rate is the instantaneous cost of energy transfer. Cost rate is in cost per energy transferred over time (e.g., $0.06 United States Dollars per kilowatt hour). The present subject matter is compatible with various ways of measuring how much energy is consumed and how quickly it is being consumed.

[0025] In various examples, the charging cost circuit **212** can control the charging circuit **208** and turn it on or off. In various embodiments, this includes interrupting a conductive path to the charging circuit **208**, such as by opening a switch. In additional instances, this includes communicating a charging state signal indicative of whether the charging circuit **208** should be active or inactive. For example, in certain examples, a field effect transistor switches activation power to the charging circuit **208**, and the charging cost circuit **212** controls the gate for the field effect transistor.

[0026] In some embodiments, the charging cost circuit **212** is part of a computer onboard a vehicle (e.g., the vehicle management system **116** of FIG. **1**). In additional examples, the charging cost circuit **212** is part of a computer in a home or workplace that at least partially controls how the electric vehicle **204** is charged. Various embodiments include a timer circuit to provide a time signal to the charging cost circuit. The timer **210** can be integrated with an electronics module, such as an assembly including a printed circuit board, the timer, and the charging cost circuit.

[0027] In various examples, the charging cost circuit **212** is to turn on the charging circuit **208** during a first time period in which the charging cost rate is below a first threshold. In certain instances, the charging circuit **208** is turned on until the battery reaches a first energy stored level (e.g., a specified amp-hours amount, coulomb amount, etc.). In some optional embodiments, the charging cost circuit **212** turns on the charging circuit **208** during a second time period in which the charging cost rate is above the first threshold. This might be

during the morning, after a power supplier has switched to a higher cost rate, but before a user begins to drive their electric vehicle.

[0028] In various examples, the system includes a cost estimator circuit to calculate total charging cost during the first period and the second period. For example, this circuit can estimate that it will cost $5.00 to charge an electric vehicle based on measured conditions and optionally learned conditions. In certain examples, an electric vehicle charging system monitors energy use patters to estimate total charging cost. In additional embodiments, an electric vehicle charging system cross references measured variables (such as voltage, temperature, and the like) with known values to estimate total charging cost. Some of these examples include a trend circuit to record a plurality of charging stop times over a period of days, and to predict a predicted charging stop time based on the plurality of charging stop times. A charging stop time, in various embodiments, is the time of day when a user usually unplugs their electric vehicle. In many cases, this is right before the user engages their electric vehicle for a drive.

[0029] In some examples, the charging cost circuit **212** automatically selects the length of the second time period to achieve a reduced charging cost that is less than a total charging cost. For example, if an electric vehicle charging system estimates a total charging cost as set out above, it can monitor charging cost rates and adjust time spent charging during a less expensive rate and time spend charging during a more expensive rate, such that the day's predicted cost of charging is less than the total charging cost that was estimated.

[0030] If desired, certain embodiments include a user controllable interface connected to the charging cost circuit **212** such that the user can input a threshold for what is a less expensive charging cost rate and what is a more expensive charging cost rate. For example, in certain embodiments, a user could specify to charge only when below a certain threshold by interacting with a computer (e.g., a vehicle computer or a home computer).

[0031] In some examples, the present system is also aware of how calendar life is being impacted by charging behaviors. This can be studied using monitored variables (e.g., by performing a load test) or by monitoring charging behavior over time (e.g., counting the number of cycles and monitoring cycle parameters such as current rate and time duration). The system can prioritize whether charging is selected to improve calendar life or reduce cost. For example, some instance charge a battery to a regular energy stored level, such as 80% of full stored energy, preferentially to improve calendar life, as certain battery chemistries, such as lithium ion, last longer if they are charged as such. Some examples will not charge above a regular energy stored level unless instructed to. Instruction can be in the form of an indicator, such as a signal from a computer that automatically provides the signal based on an analysis, or it can be provided based on a manual interaction with a user. For example, an electric vehicle can be adjusted so that it is always in "regular mode" in which it charges to 80% of full stored energy for most of its life, and is only charged to "boost mode" (e.g., 90% of full stored energy level) when a user or other source instructs it to do so.

[0032] As such, in certain examples, the charging cost circuit **212** is to turn on the charging circuit until the battery reaches a second energy stored level. The second energy stored level can be between a first energy stored level and a full energy stored level, or it can be at a full energy stored level. The present subject matter includes embodiments in that a charge is held at the second energy stored level for a period of time. For instance, if a first time period is specified in which a first energy stored level can be reached, and a second time period is specified in which a second energy stored level can be reached, the present system can reach the first energy stored level and pause until it enters the second time period, and then charge until the second energy stored level is reached. If the second energy stored level is reached before expiration of the second time period, the present system can maintain the second energy stored level. A user controllable interface is included in some examples and is connected to the charging cost circuit **212** such that the user can input length of the second period during which charging takes place.

Hardware and Operating Environment

[0033] This section provides an overview of example hardware and the operating environments in conjunction with which embodiments of the inventive subject matter can be implemented.

[0034] A software program may be launched from a computer-readable medium in a computer-based system to execute functions defined in the software program. Various programming languages may be employed to create software programs designed to implement and perform the methods disclosed herein. The programs may be structured in an object-orientated format using an object-oriented language such as Java or C++. Alternatively, the programs may be structured in a procedure-orientated format using a procedural language, such as assembly or C. The software components may communicate using a number of mechanisms well known to those skilled in the art, such as application program interfaces or inter-process communication techniques, including remote procedure calls. The teachings of various embodiments are not limited to any particular programming language or environment. Thus, other embodiments may be realized, as discussed regarding FIG. **3** below.

[0035] FIG. **3** is a block diagram of an article **300** according to various embodiments of the present subject matter. Such embodiments may comprise a computer, a memory system, a magnetic or optical disk, certain other storage device, or any type of electronic device or system. The article **300** may include one or more processor(s) **306** coupled to a machine-accessible medium such as a memory **302** (e.g., a memory including electrical, optical, or electromagnetic elements). The medium may contain associated information **304** (e.g., computer program instructions, data, or both) which, when accessed, results in a machine (e.g., the processor(s) **306**) performing the activities described herein.

Methods

[0036] Various methods disclosed herein provide for battery charging based on cost and life. As mentioned above, certain examples charge batteries with electricity derived from a municipal power grid. In some instances, this electricity is less expensive during certain times of the day. In particular, many parts of the world offer less expensive energy during evening times. The present subject matter provides methods that can automatically charge a vehicle in consideration of such less expensive charging cost rates. The present subject matter, however, is also functional under a manual operation scheme, in which a person is able to select an amount of energy to receive during a first period of time (e.g.,

a period of time when electricity is less expensive), and during a first period of time (e.g., a period of time when electricity is more expensive).

[0037] FIG. **4** is a method of charging a battery, according to one embodiment of the present subject matter. At **402**, the method includes determining charging cost rate. At **404**, the method includes charging a battery of an electric vehicle to a first energy stored level while a first charging cost rate is determined. At **406**, a decision is made: should the system charge to a second energy stored level? If yes, at **408**, the system charges the battery to a second energy stored level while a second charging cost rate is determined that is higher than the first energy stored level. If no, the method ends. Various optional features are combinable with the present methods. For example, in certain optional methods, the first charging cost rate is lower than the second charging cost rate. But some methods are contemplated in which the first charging cost rate is higher than the second charging cost rate.

[0038] Various options are contemplated. As stated elsewhere, examples in which a system does not charge fully, but will charge more fully when instructed to, are contemplated. In certain embodiments, if a user plugs in their electric vehicle at night, it will charge to a first energy stored level and pause at that level. In some embodiments that level is 80% of capacity, but the present subject matter is not so limited. In certain examples, unless the user instructs the electric vehicle to charge even more, the vehicle will not charge more. In certain instances, a push button is provided in an electric vehicle charging system that enables a user to instruct the system to add more charge. Such a push button could be operated in the morning, in some instances, shortly before a user realizes they should use their car to drive longer distances before recharging than normal.

[0039] In some embodiments, a system is provided that is able to store a battery at a energy stored level that improves calendar life. In certain examples, this energy stored level is 50% of capacity. This energy stored level can be monitored over time and maintained. The stored energy level maintenance mode is entered into upon a user input, in some examples. In additional embodiments, a vehicle realizes that it has been dormant for a period of time that exceeds a threshold, and enters a storage mode. Various examples recognize dormancy in other ways, such as by monitoring the odometer or reading other instruments. Storage mode can be indicated by a horn sound or with another indicator, such as a flashing light.

[0040] FIG. **5** is a method of charging a battery to a first energy stored level during a first time period **504** and charging the battery during a second time period **506**, according to one embodiment of the present subject matter. Illustrated is an example in which a battery is charged until the first energy stored level **502** is reached. In various embodiments, this charging is limited to a first time period **504**. In various examples, the first time period is coincident with the time of day in that a first charging cost rate is within in a first cost range.

[0041] Additional embodiments charge the battery until the second energy stored level **508** is reached. In various examples, this occurs during a second time period **506**. In certain instances, the second time period **506** is user selected. In some embodiments, the second time period **506** is coincident with a period of time in which a charging cost rate fits into a second cost range that is different from a first cost range. In certain examples, the second energy stored level **508** is less than a full energy stored level. The illustrated embodiment shows that the electric vehicle was unplugged shortly before it reached the second energy stored level **508**. This may be exhibited in examples in which a user decides to leave before the second time period ends.

[0042] FIG. **6** is a method of charging a battery during a second time period, according to one embodiment of the present subject matter. Embodiments of the present subject matter include charging the battery to the second energy stored level only if so instructed by a stored indicator, as discussed above.

[0043] Some examples include predicting a daily charge stop time **602** based on an energy usage pattern. Some instances prompt a user to select between improved calendar life and reduced cost. Embodiments that prompt a user for information include storing a user response as the stored indicator. In various examples, if the stored indicator indicates improved calendar life, the method charges to the second energy level by delaying charging to the second energy level until charging can occur constantly up to the predicted daily charge stop time such that the second energy stored level is reached. The present illustration shows that the battery of an electric vehicle was already charged near a regular stored charge, and elected to not charge the battery during the first time period. The electric vehicle charging system additionally recognized a charge stop time, and commenced charging such that it could reach the second energy stored level **604** at the charge stop time **602**. Such a system can improve calendar life of a battery. Various embodiments include electing to not charge to the second energy stored level.

[0044] FIG. **7** is a method of charging to a first energy stored **710** level during a first time period, and to a second energy stored **712** level during a second time period, according to one embodiment of the present subject matter. Various embodiments include charging the battery according to a charging schedule that includes a first time period **702** and a second time period **704**, the first energy stored level **710** reached (during the ω time period) within the first time period **702**, the second energy stored level **712** (during the η time period) reached during the second time period **704**.

[0045] Some examples include predicting a daily cost based on an energy usage pattern. Some instances adjust the length of the first time period and length of the second time period such that a total cost of charging to the second energy stored level is less than the predicted daily cost.

[0046] Some examples include predicting a daily charge stop time **706** based on an energy usage pattern. Some of these examples include delaying (during the p time period) charging to the second energy level until charging can occur constantly up to the predicted daily charge stop time **706**. In some instances, this occurs such that the second energy stored level **712** is reached. Embodiments are included in which no charging occurs during at least a portion of the second time period **704**.

[0047] FIG. **8** is a method of charging a battery in the context of a charging rate that varies up and down throughout the day, according to one embodiment of the present subject matter. A charge rate **802** is determined and varies. A battery energy stored level **804** is charted in the illustration. In various embodiments, if the charging rate is at a first charge cost rate **806**, the battery charges on its way to a first energy stored level **810**. If the system reaches this level, it stops charging if it is during the first time period. For example, a first time period, defined by the addition of time periods θ, α, and β is

illustrated. During this time, the system charges only when the charging cost rate is within the first charging cost rate range **806**. Starting after time period β, the illustration enters a second time period in which it is acceptable to charge as the second charging cost rate range **808**. The illustration reaches a second stored energy level **812**, and does not add more charge during the y time period, during that the second charging cost rate is realized, nor after that time period, during which the first charging cost rate is realized.

[0048] Such a system could be helpful in areas in which municipal power grid pricing fluctuates frequently, such as in areas where wind turbines produce excess power at windy times, and a shortage of power during times in which it is not windy. Various examples include receiving a cost signal and charging at one of the first charging cost rate and the second charging cost rate in response to that cost signal.

[0049] FIG. **9** is a method according to one embodiment of the present subject matter. At **902**, the method includes storing a user selected driving range for an electric vehicle. At **904**, the method includes determining a potential driving range based on a pattern of driving ranges achieved by charging a battery of the electric vehicle to a first percentage of capacity. At **906**, the method includes determining whether a first amount of energy stored when the battery is charged to the first percentage of capacity is sufficient to achieve the user selected driving range based on the pattern of driving ranges achieved. At **908**, the method includes charging the battery to the first percentage of capacity if the first amount energy stored is sufficient to power the electric vehicle through the selected driving range. At **910**, the method includes charging the battery to a second percentage of capacity, which is higher than the first percentage of capacity, if the first energy stored is not sufficient to power the electric vehicle through the user selected driving range. In certain examples, the second energy stored level is 100%.

[0050] FIG. **10** is a method of charging a battery to achieve a selected range, according to one embodiment of the present subject matter. A life cycle of a battery always charged to a regular capacity **1002** is illustrated, with a regular end of life **1010**. This is the energy stored when the battery is charged to a specific capacity, such as 80%, that is less than full capacity. Additionally illustrated is a life cycle of a battery always charged to a full capacity **1004**, with a full end of life **1006**. A hybrid curve **1012** is illustrated for a battery which is at first charged to a regular capacity, and then to a capacity that is more than the regular capacity, demonstrating a hybrid end of life **1008**. In the illustration, the hybrid begins to charge a battery at a capacity higher than a regular capacity starting at a certain time **1014**, although the present subject matter is not so limited. The time hybrid starts to charge to a capacity in excess of the regular capacity commences can coincide with the time that energy stored when charged to regular capacity starts to diminish. The penalty for charging the hybrid higher than the regular capacity is an earlier end of life **1008** than the end of life **1010** enjoyed by batteries always charged to regular capacity. Battery capacity has a linear relationship with voltage in some examples, and certain instances charge to respective voltages in certain examples.

[0051] The hybrid curve assists in a user to consistently maintain a usable driving range. For example, if energy stored for a certain capacity starts to diminish, as it does for the regular capacity curve **1002** after a certain time **1014**, driving range for that capacity also diminishes. But some users desire to avoid diminished range. As such, the present subject matter charges to a higher capacity, following the hybrid curve **1012**. This provides a compromise between enjoying some time during which a longer range is realized, and shortening the end of life of the battery.

[0052] Various examples of the present subject matter automatically track decreasing range based on an energy use pattern. Some of these embodiments switch to a hybrid curve automatically, so a user does not realize range is decreasing. In some embodiments, switching to the hybrid curve occurs only if the end of life is predicted to occur within the warranty period of an electric vehicle. Some embodiments provide an alert to a user than charging to a hybrid capacity has begun. In some instances the hybrid curve includes a series of incremental upward adjustments to capacity. In some embodiments, capacity is increased by 0.05% a day. Other increases are contemplated.

[0053] In some embodiments, a vehicle system drives a first range during some driving sessions and a second range during additional driving sessions, and a user selects which range to drive. In some of these embodiments, a vehicle charging system automatically selects which of the regular capacity and the hybrid capacity to use depending on the user selected range.

[0054] The Abstract is provided to comply with 37 C.F.R. §1.72(b) to allow the reader to quickly ascertain the nature and gist of the technical disclosure. The Abstract is submitted with the understanding that it will not be used to interpret or limit the scope or meaning of the claims.

What is claimed is:

1. A system, comprising:

a battery;

an electric vehicle, the battery coupled to the electric vehicle to propel the electric vehicle;

a charging circuit to charge the battery;

a charging cost circuit to estimate a charging cost rate and to turn on the charging circuit; and

a timer circuit to provide a time signal to the charging cost circuit,

wherein the charging cost circuit is to turn on the charging circuit during a first time period in which the charging cost rate is below a first threshold until the battery reaches a first energy stored level, and to turn on the charging circuit during a second time period in which the charging cost rate is above the first threshold.

2. The system of claim **1**, further comprising:

a cost estimator circuit to calculate total charging cost during the first period and the second period; and

a trend circuit to record a plurality of charging stop times over a period of days, and to predict a predicted charging stop time based on the plurality of charging stop times,

wherein the charging cost circuit automatically selects the length of the second time period to achieve a reduced charging cost that is less than the total charging cost.

3. The system of claim **1**, further comprising a user controllable interface connected to the charging cost circuit such that the user can input the first threshold.

4. The system of claim **1**, wherein the charging cost circuit is to turn on the charging circuit until the battery reaches a second energy stored level, the second energy stored level being higher than the first energy stored level.

5. The system of claim **4**, further comprising a user controllable interface connected to the charging cost circuit such that the user can input length of the second period.

6. Method, comprising:

determining charging cost rate; and

selectively charging a battery of an electric vehicle to a first energy stored level while a first charging cost rate is determined, and to a second energy stored level while a second charging cost rate is determined;

wherein the second energy stored level is higher than the first energy stored level.

7. The method of claim **6**, wherein the first charging cost rate is lower than the second charging cost rate.

8. The method of claim **6**, wherein the first charging cost rate is higher than the second charging cost rate.

9. The method of claim **6**, comprising charging the battery until the first energy stored level is reached while the charging cost rate is within in a first cost range, and until the second energy stored level is reached while the charging cost rate fits into a second cost range.

10. The method of claim **6**, wherein the second energy stored level is less than a full energy stored level.

11. The method of claim **6**, further comprising charging the battery to the second energy stored level only if so instructed by a stored indicator.

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

predicting a daily charge stop time based on an energy usage pattern;

prompting a user to select between improved calendar life and reduced cost;

storing a user response as the stored indicator; and

if the stored indicator indicates improved calendar life, charging to the second energy level by delaying charging to the second energy level until charging can occur constantly up to the predicted daily charge stop time such that the second energy stored level is reached.

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

predicting a daily charge stop time based on an energy usage pattern;

prompting a user to select between improved calendar life and reduced cost;

storing a user response as the stored indicator; and

if the stored indicator indicates improved calendar life, selecting to not charge to the second energy stored level.

14. The method of claim **6**, further comprising charging the battery according to a charging schedule that includes a first time period and a second time period, the first energy stored level reached within the first time period, the second energy stored level reached during the second time period.

15. The method of claim **14**, further comprising:

predicting a daily cost based on an energy usage pattern; and

adjusting the length of the first time period and length of the second time period such that a total cost of charging to the second energy stored level is less than the predicted daily cost.

16. The method of claim **14**, further comprising:

predicting a daily charge stop time based on an energy usage pattern; and

delaying charging to the second energy level until charging can occur constantly up to the predicted daily charge stop time such that the second energy stored level is reached.

17. The method of claim **16**, wherein no charging occurs during at least a portion of the second time period.

18. Method, comprising:

storing a user selected driving range for an electric vehicle;

determining a potential driving range based on a pattern of driving ranges achieved by charging a battery of the electric vehicle to a first percentage of capacity;

determining whether a first amount of energy stored when the battery is charged to the first percentage of capacity is sufficient to achieve the user selected driving range based on the pattern of driving ranges achieved;

charging the battery to the first percentage of capacity if the first amount energy stored is sufficient to power the electric vehicle through the selected driving range; and

charging the battery to a second percentage of capacity, which is higher than the first percentage of capacity, if the first energy stored is not sufficient to power the electric vehicle through the user selected driving range.

19. The method of claim **18**, wherein the second capacity is 100%.

20. The method of claim **18**, further comprising incrementally adding an increment to the magnitude of the first capacity to determine the second capacity.

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