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(54) **METHOD AND APPARATUS FOR PREVENTING EXCESSIVE HEAT GENERATION IN A ALTERNATOR OF A GENERATOR SET**

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(52) **U.S. Cl.** **700/286**; 700/22; 700/293; 290/40; 361/31; 361/68
(58) **Field of Search** 700/236, 293, 700/287, 292, 290; 361/319, 68, 31; 290/40

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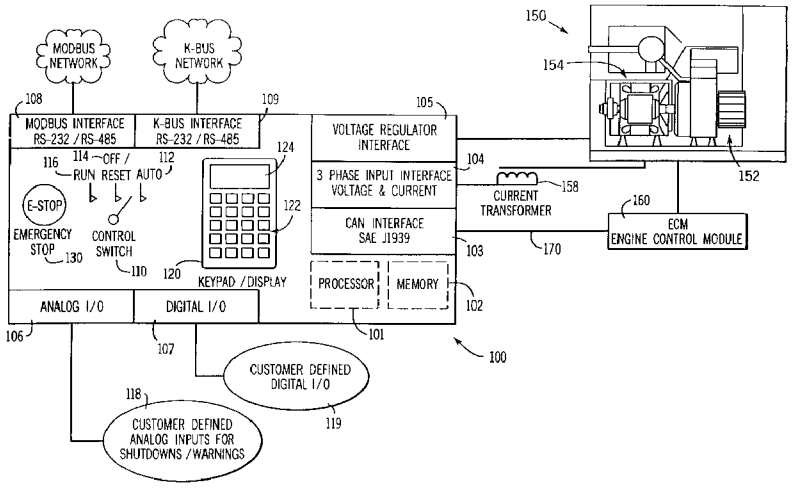
(57) **ABSTRACT**

A method and apparatus are disclosed for preventing damage to an alternator of a genset resulting from high currents within the alternator. The method includes calculating, at a processor, a first quantity related to a current flowing through the alternator during a first time period, and comparing, at the processor, the first quantity with a first threshold. The method further includes calculating, at the processor, a second quantity related to the current flowing through the alternator during at least one of the first time period and a second time period, and comparing, at the processor, the second quantity with a second threshold. The method additionally includes indicating a current overload condition if at least one of the first quantity exceeds the first threshold or the second quantity exceeds the second threshold.

19 Claims, 6 Drawing Sheets



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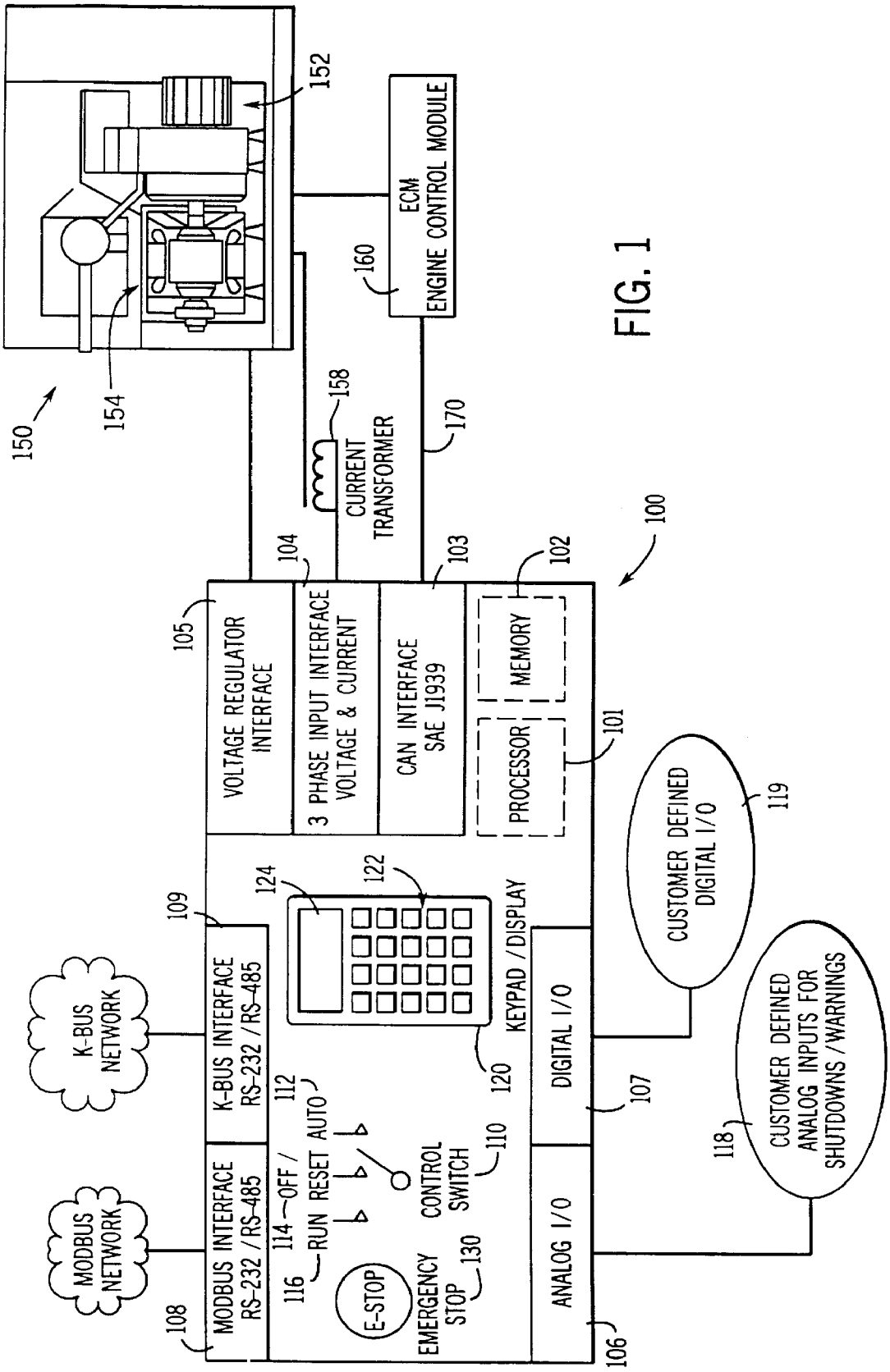
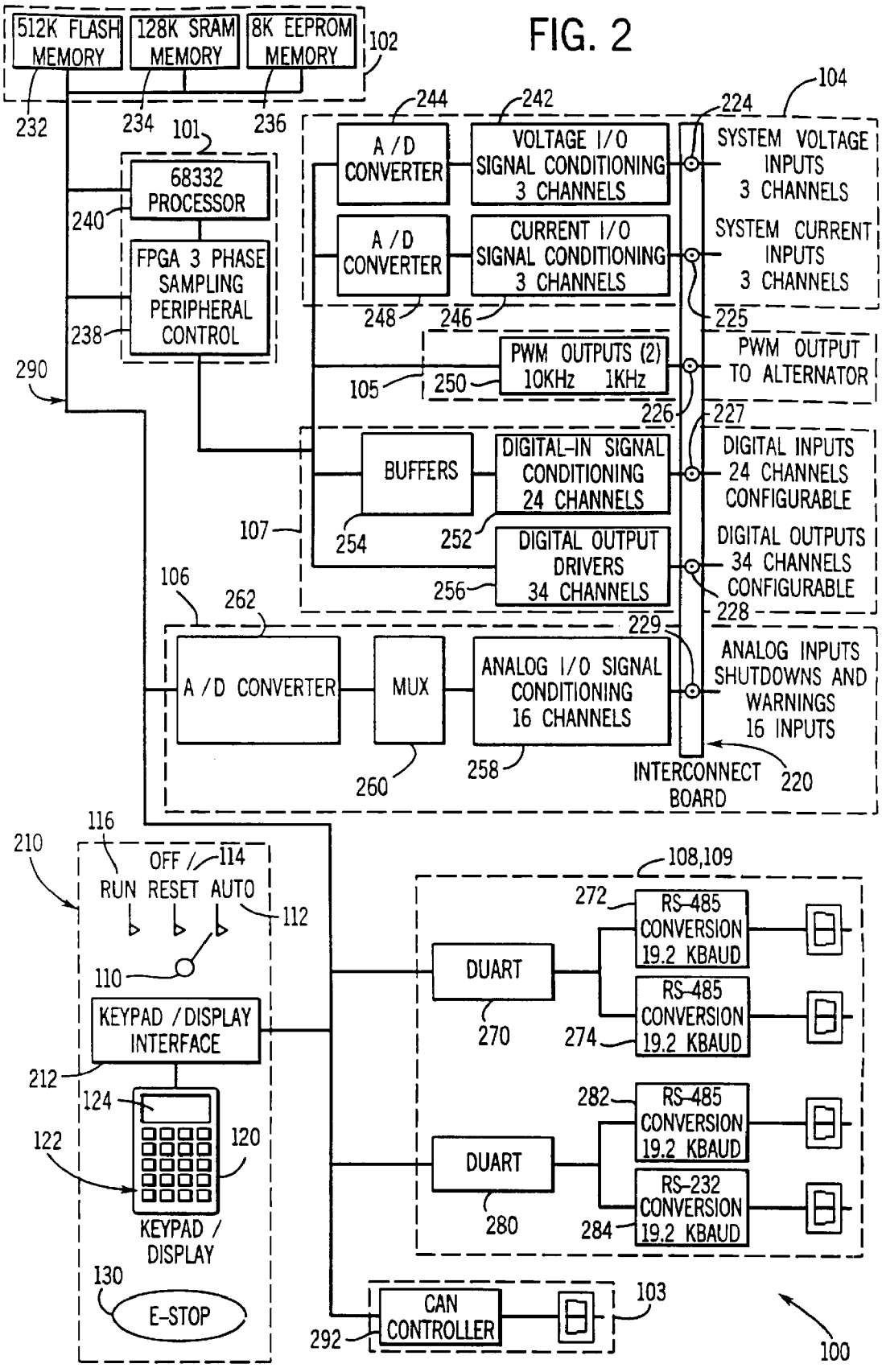

150
154
152
ECM
ENGINE CONTROL MODULE
160
158
CURRENT
TRANSFORMER
170
100
104
103
102
105
VOLTAGE REGULATOR
INTERFACE
3 PHASE INPUT INTERFACE
VOLTAGE & CURRENT
CAN INTERFACE
SAE J1939
PROCESSOR
MEMORY
101
109
124
122
K-BUS
NETWORK
K-BUS INTERFACE
RS-232 / RS-485
KEYPAD / DISPLAY
CUSTOMER DEFINED
DIGITAL I/O
119
112
MODBUS
NETWORK
MODBUS INTERFACE
RS-232 / RS-485
114
OFF /
RUN RESET AUTO
110
CONTROL
SWITCH
120
DIGITAL I/O
107
CUSTOMER DEFINED
ANALOG INPUTS FOR
SHUTDOWNS / WARNINGS
118
116
E-STOP
EMERGENCY
STOP
130
108
ANALOG I/O
106

FIG. 1

FIG. 2


512K FLASH MEMORY
128K SRAM MEMORY
8K EEPROM MEMORY
102
232
234
236
101
68332 PROCESSOR
240
FPGA 3 PHASE SAMPLING PERIPHERAL CONTROL
238
290
244
242
224
104
A/D CONVERTER
VOLTAGE I/O SIGNAL CONDITIONING 3 CHANNELS
SYSTEM VOLTAGE INPUTS 3 CHANNELS
A/D CONVERTER
CURRENT I/O SIGNAL CONDITIONING 3 CHANNELS
SYSTEM CURRENT INPUTS 3 CHANNELS
248
246
225
PWM OUTPUTS (2) 10KHz 1KHz
105
250
PWM OUTPUT TO ALTERNATOR
226
227
BUFFERS
DIGITAL-IN SIGNAL CONDITIONING 24 CHANNELS
DIGITAL INPUTS 24 CHANNELS CONFIGURABLE
107
254
252
DIGITAL OUTPUT DRIVERS 34 CHANNELS
DIGITAL OUTPUTS 34 CHANNELS CONFIGURABLE
256
228
106
262
229
A/D CONVERTER
MUX
ANALOG I/O SIGNAL CONDITIONING 16 CHANNELS
ANALOG INPUTS SHUTDOWNS AND WARNINGS 16 INPUTS
260
258
INTERCONNECT BOARD
220
116
210
OFF
114
RUN RESET AUTO
112
110
KEYPAD / DISPLAY INTERFACE
212
124
122
120
KEYPAD / DISPLAY
130
E-STOP
108,109
272
RS-485 CONVERSION 19.2 KBAUD
DUART
270
274
RS-485 CONVERSION 19.2 KBAUD
282
RS-485 CONVERSION 19.2 KBAUD
DUART
280
284
RS-232 CONVERSION 19.2 KBAUD
CAN CONTROLLER
292
103
100

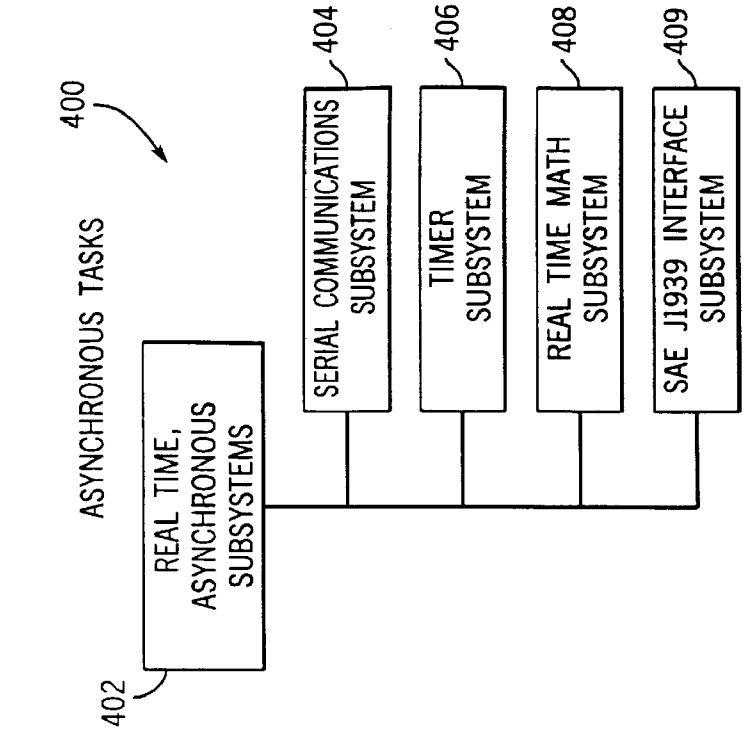

ASYNCHRONOUS TASKS
400
REAL TIME, ASYNCHRONOUS SUBSYSTEMS
402
SERIAL COMMUNICATIONS SUBSYSTEM
404
TIMER SUBSYSTEM
406
REAL TIME MATH SUBSYSTEM
408
SAE J1939 INTERFACE SUBSYSTEM
409

FIG. 4

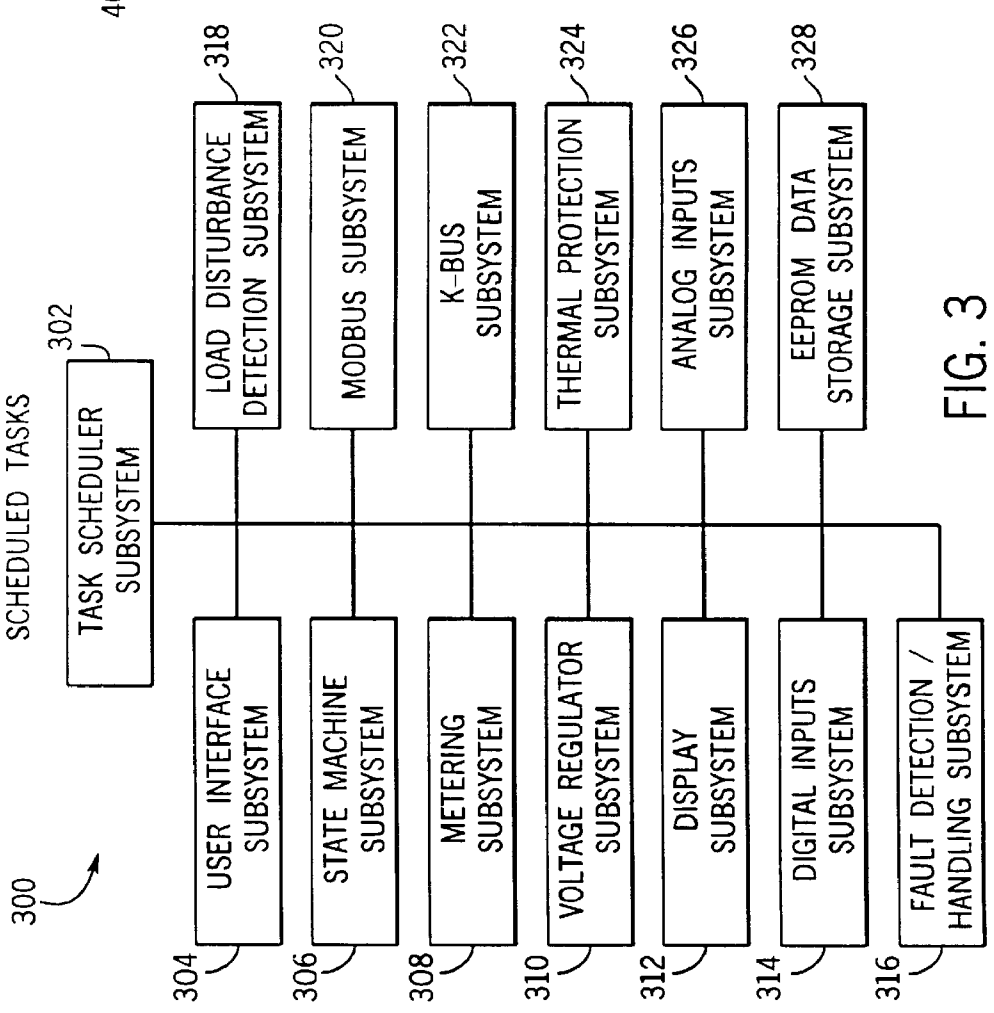

SCHEDULED TASKS
300
TASK SCHEDULER SUBSYSTEM
302
LOAD DISTURBANCE DETECTION SUBSYSTEM
318
MODBUS SUBSYSTEM
320
K-BUS SUBSYSTEM
322
THERMAL PROTECTION SUBSYSTEM
324
ANALOG INPUTS SUBSYSTEM
326
EEPROM DATA STORAGE SUBSYSTEM
328
USER INTERFACE SUBSYSTEM
304
STATE MACHINE SUBSYSTEM
306
METERING SUBSYSTEM
308
VOLTAGE REGULATOR SUBSYSTEM
310
DISPLAY SUBSYSTEM
312
DIGITAL INPUTS SUBSYSTEM
314
FAULT DETECTION / HANDLING SUBSYSTEM
316

FIG. 3

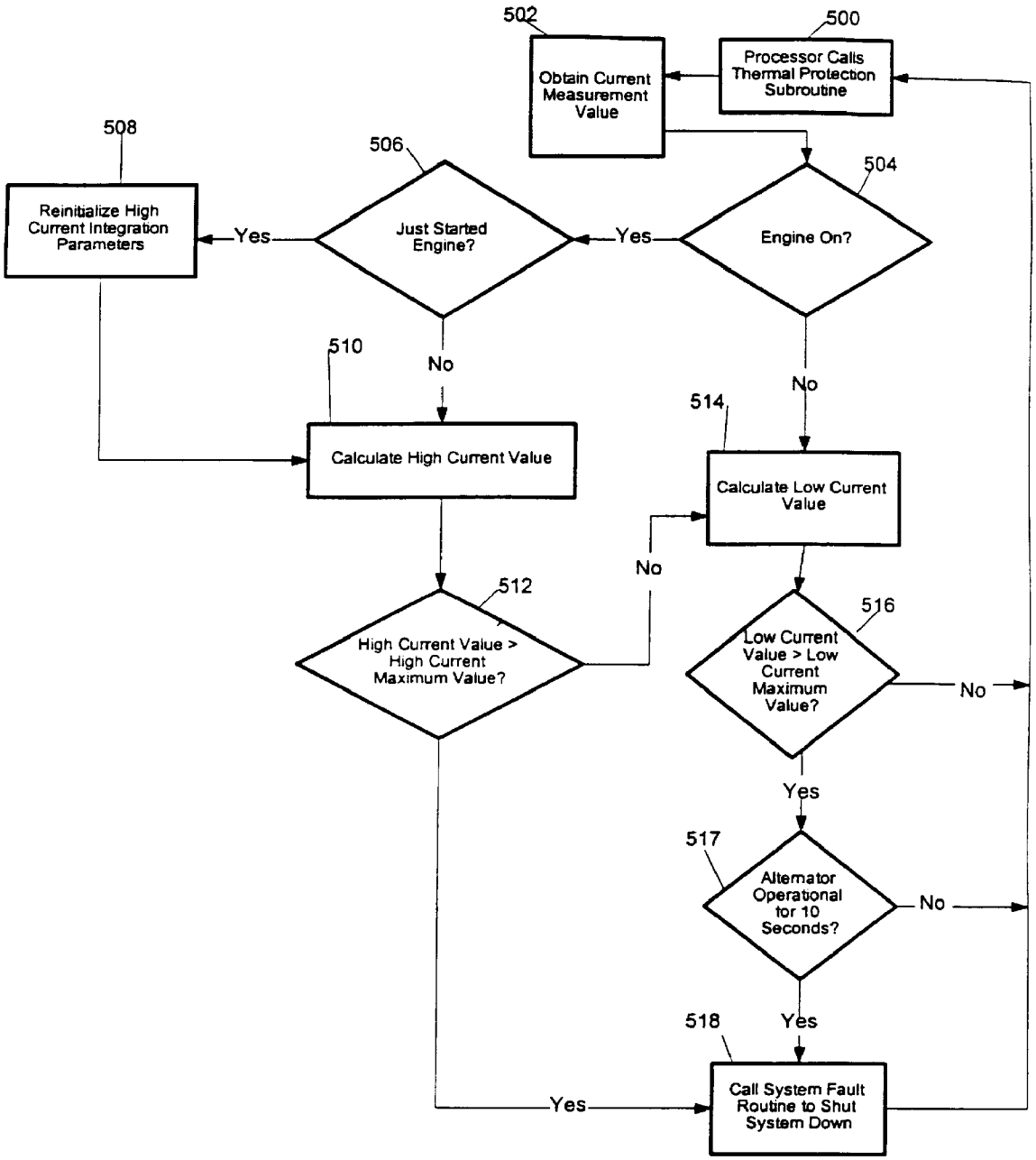

502
500
Obtain Current Measurement Value
Processor Calls Thermal Protection Subroutine
508
506
504
Reinitialize High Current Integration Parameters
Yes
Just Started Engine?
Yes
Engine On?
510
No
No
514
Calculate High Current Value
Calculate Low Current Value
No
512
516
High Current Value > High Current Maximum Value?
Low Current Value > Low Current Maximum Value?
No
Yes
517
Alternator Operational for 10 Seconds?
No
518
Yes
Yes
Call System Fault Routine to Shut System Down

Fig. 5

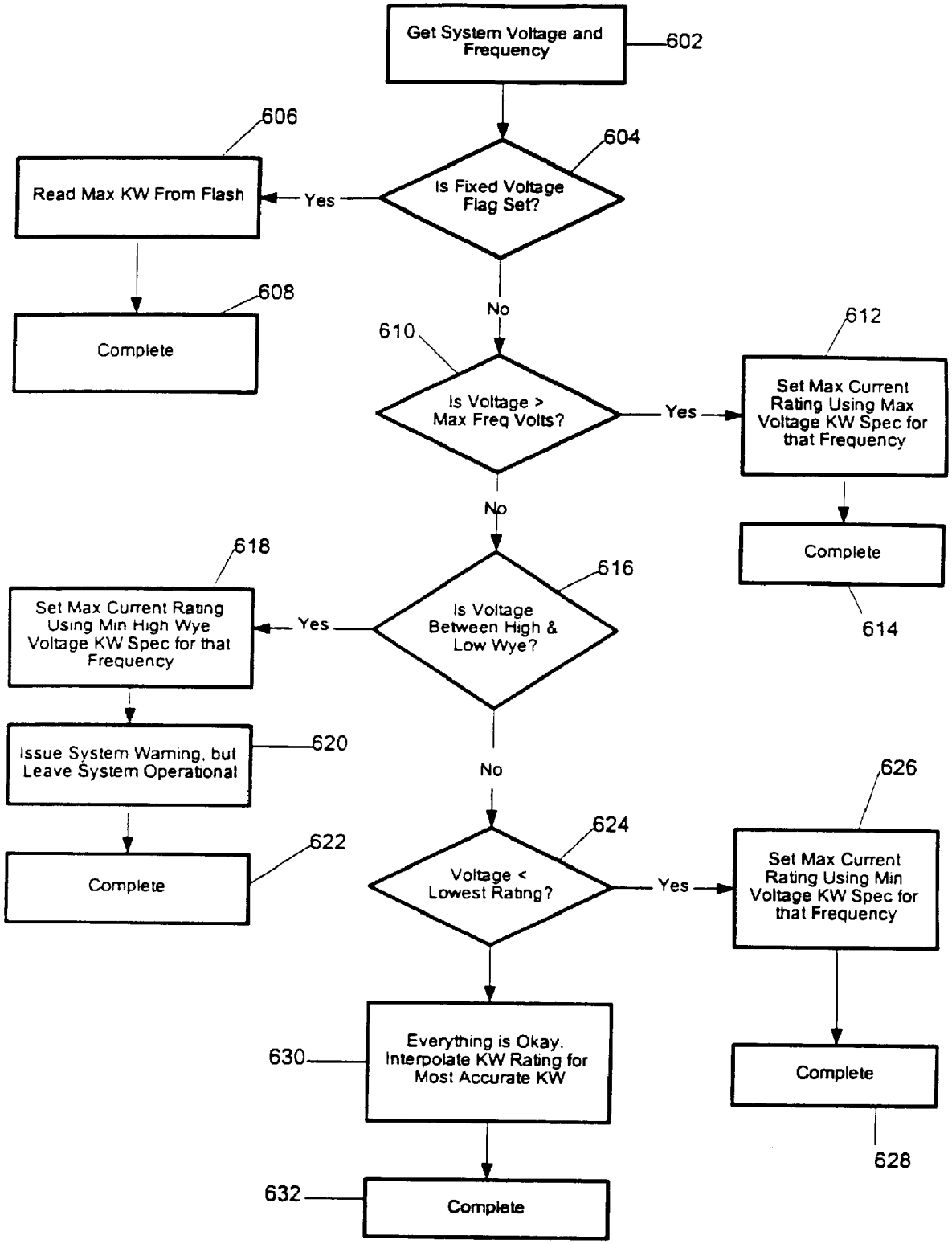

Get System Voltage and Frequency
602
Is Fixed Voltage Flag Set?
604
Yes
Read Max KW From Flash
606
Complete
608
No
Is Voltage > Max Freq Volts?
610
Yes
Set Max Current Rating Using Max Voltage KW Spec for that Frequency
612
Complete
614
No
Is Voltage Between High & Low Wye?
616
Yes
Set Max Current Rating Using Min High Wye Voltage KW Spec for that Frequency
618
Issue System Warning, but Leave System Operational
620
Complete
622
No
Voltage < Lowest Rating?
624
Yes
Set Max Current Rating Using Min Voltage KW Spec for that Frequency
626
Complete
628
Everything is Okay. Interpolate KW Rating for Most Accurate KW
630
Complete
632

Fig. 6

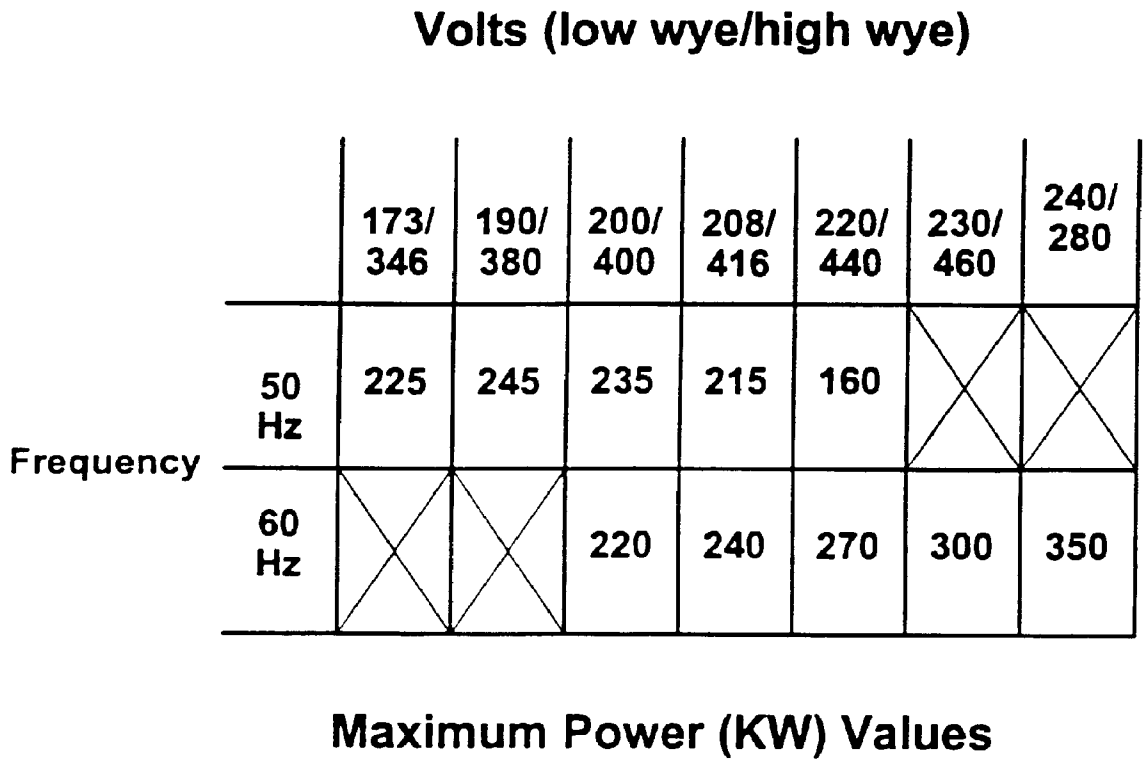

Volts (low wye/high wye)
173/ 346
190/ 380
200/ 400
208/ 416
220/ 440
230/ 460
240/ 280
Frequency
50 Hz
225
245
235
215
160
60 Hz
220
240
270
300
350
Maximum Power (KW) Values

Fig. 7

METHOD AND APPARATUS FOR PREVENTING EXCESSIVE HEAT GENERATION IN A ALTERNATOR OF A GENERATOR SET

FIELD OF THE INVENTION

The present invention relates to the control of an electric generator set including an engine and an alternator. In particular, the present invention relates to the control of an electric generator set to prevent the generation of excessive heat by the alternator.

BACKGROUND OF THE INVENTION

Electric generator sets (or "gensets") are widely used to provide electric power. A genset typically includes an engine coupled to an alternator, which converts the rotational energy from the engine into electrical energy. The terminal voltage of a genset is proportional to both the magnetic flux density within the alternator, and the speed of the engine. The magnetic flux density is typically determined by controlling an armature voltage or field current on the alternator, while the speed of the engine is typically determined by an engine governor.

During the operation of the genset, excessively high levels of current can be produced within the alternator depending upon the load, the engine speed, and other factors. Such excessively high levels of current can produce excessive heat within the alternator, which can damage the alternator and produce other undesirable effects. Consequently, it is known to include a mechanism with a genset that stops or otherwise limits the operation of the genset if excessively high levels of current occur.

Typically, an alternator does not suffer damage or other undesirable effects from excessive heat unless it is exposed to the heat for an extended period of time. Consequently, excessively high currents within the wire windings of an alternator do not immediately cause damage to the alternator. Rather, exposure to excessively high currents over an extended period of time is the cause of damage to an alternator. It is known to determine whether excessive exposure is occurring in an alternator by (a) measuring the RMS current I within the alternator during a given time period, (b) taking the square of these current measurements to obtain I^2 during the time period, (c) calculating an integral or summation of I^2 over the time period to obtain a value I^2t, (d) comparing the result of the integral or summation with a damage curve specifying the maximum allowable value for I^2t during the time period, and then (e) repeating this process during successive time periods.

While it is exposure to excessively high currents over an extended period of time that precipitates damage in an alternator, the levels of the currents to which the alternator can be exposed without sustaining damage vary significantly depending upon the amount of time the alternator is exposed to those currents. In particular, an alternator can be exposed to currents that are very high in magnitude when those currents are short-term transient currents, but can only be exposed to currents that are much lower in magnitude when the alternator is exposed to those currents over a long period of time.

Because the tolerance of an alternator with respect to excessive currents varies depending upon the time the alternator is exposed to those currents, the above-discussed process is not always an accurate indicator of whether the alternator is experiencing exposure to excessive currents. On the one hand, the above process may fail to indicate that the alternator is experiencing excessive exposure to a short burst of extremely high current because the average current level during the measured period of time is such that the overall value of I^2t is less than the maximum tolerance specified by the damage curve for that period of time.

On the other hand, the above process may incorrectly indicate that the alternator is experiencing excessive exposure when there is a short burst of extremely high current such that the overall value of I^2t exceeds the damage curve even though, over the long term, the current levels are actually tolerable. This may be the case where, for example, the current immediately decreases to a very low level following the short burst of high current. This is particularly problematic if the damage curve is conservative, namely, the allowed values of I^2t are set low. The damage curve may be set conservatively in order to avoid the problems discussed above, i.e., to minimize the inappropriate tolerance of short bursts of high current.

It would therefore be advantageous if a method and apparatus were developed for determining whether an alternator was being exposed to excessive currents and resultant heat, where the method and apparatus accounted for whether the currents were occurring for long periods of time or only for short periods of time. In particular, it would be advantageous if a method and apparatus were developed for determining excessive exposure of an alternator to currents during a given period of time in spite of the existence of significant short term variations of the currents within that period of time. It would additionally be advantageous if the method and apparatus were configured to cause a cessation or reduction in the operation of the genset upon a determination of the existence of excessive currents.

SUMMARY OF THE INVENTION

The present invention relates to a method of preventing damage to an alternator of a genset resulting from high currents within the alternator. The method includes calculating, at a processor, a first quantity related to a current flowing through the alternator during a first time period, and comparing, at the processor, the first quantity with a first threshold. The method further includes calculating, at the processor, a second quantity related to the current flowing through the alternator during at least one of the first time period and a second time period, and comparing, at the processor, the second quantity with a second threshold. The method additionally includes indicating a current overload condition if at least one of the first quantity exceeds the first threshold or the second quantity exceeds the second threshold.

The present inventors have discovered that it is possible to accurately determine whether an alternator is being exposed to excessive currents and resultant heat over a given period of time in spite of the existence of significant short term variations of the current by determining values of I^2t (or related to I^2t) over both short periods of time and over long or unending periods of time, and then comparing the determined values with respect to both a short term limit and a long term limit, respectively. With respect to determining the value of I^2t over the long term, it is necessary to increase the overall calculated value of I^2t to account for periods of time in which the current I is greater than a rated current, and to decrease the overall calculated value of I^2t to account for periods of time in which the current I is less than the rated current.

The present invention additionally relates to a method of preventing damage to an alternator of a genset resulting

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from high currents within the alternator. The method includes (a) calculating a first quantity equaling a first sum of n squares of n type-A normalized currents determined based upon n most recent current measurements obtained during n most recent successive short time periods; (b) determining whether the first quantity exceeds a first threshold; and (c) providing a first command to limit an operation of the genset when it is determined that the first quantity exceeds the first threshold. The method further includes (d) calculating a second quantity equaling a second sum of x values functionally dependent upon x squares of x type-B normalized currents determined based upon x current measurements obtained during x successive short time periods, wherein x is the total number of short time periods that have occurred since at least one of a first time at which a performance of the method began and a second time occurring after the first time. The method additionally includes (e) determining whether the second quantity exceeds a second threshold; and (f) providing a second command to limit an operation of the genset when it is determined that the second quantity exceeds the second threshold.

The present invention further relates to an apparatus for preventing damage to an alternator of a genset resulting from high currents within the alternator. The apparatus includes a means for measuring a current flowing within the alternator during successive time periods, and a processor coupled to the means for measuring. The processor is operable to calculate a first parameter that is related to a first set of measured current values that were obtained by the means for measuring during a first time period, and to calculate a second parameter that is related to a second set of measured current values that were obtained by the means for measuring during a second time period. The processor is further operable to compare the first parameter with a first threshold and the second parameter with a second threshold, and to provide a command to cause at least a portion of the genset to be limited in its operation when either the first parameter exceeds the first threshold or the second parameter exceeds the second threshold. The apparatus further includes a means responsive to the command to alter the operation of the genset.

The present invention additionally relates to an apparatus for preventing damage to an alternator of a genset resulting from high currents within the alternator. The apparatus includes a means for determining whether a current flowing through the alternator during a recent time period has been excessive; and a means for determining whether a current flowing through the alternator during an extended time period has been excessive. The apparatus further includes a means for halting the operation of the genset if at least one of the two determining means determines that the current has been excessive.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a block diagram showing a genset including an alternator, an engine control module, and an exemplary apparatus that is capable of determining whether the alternator is being exposed to excessive current and resultant heat;

FIG. **2** is a detailed block diagram of the apparatus of FIG. **1**;

FIG. **3** is a detailed block diagram of synchronous software tasks that are performable by the apparatus of FIG. **1**;

FIG. **4** is a detailed block diagram of asynchronous software tasks that are performable by the apparatus of FIG. **1**;

FIG. **5** is a flow chart with exemplary method steps that are performable by the apparatus of FIG. **1** in accordance with one embodiment of the invention;

FIG. **6** is a flow chart with exemplary method steps for determining a maximum power value used in the performance of the method steps of FIG. **5**; and

FIG. **7** is an exemplary voltage/frequency table for use in connection with the performance of the steps of FIG. **6**.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring to FIG. **1**, a generator set controller (or genset controller) **100** is shown coupled to a generator set (genset) **150**. Genset controller **100** can be located remotely from genset **150** (up to 40 feet) or attached to the genset directly by way of an engine harness. Genset **150** includes an engine **152** and an alternator (or synchronous generator) **154**, and has a typical power rating of between 20 kW and 2000 kW or more. Engine **152** is typically an internal combustion engine that is powered by gasoline, diesel fuel, methane gas or other fuels, for example, the Series 60, Series 2000 or Series 4000 engines manufactured by Detroit Diesel Company of Detroit, Mich. Engine **152** rotates a rotor (not shown) of alternator **154**, which outputs electrical power. Alternator **154** is typically a three-phase machine, such as the Model 5M4027 alternator manufactured by Marathon Electric Company.

Genset controller **100** operates to control and monitor the operation of genset **150**. As shown in FIGS. **1** and **2**, genset controller **100** is a microprocessor-based (or otherwise computer-driven) system having a processor **101** and a memory **102**. Referring to FIG. **2**, memory **102** includes a 512K FLASH memory **232**, a 128K SRAM memory **234**, and an 8K EEPROM memory **236**. Processor **101** includes a microcontroller or microprocessor **240** (e.g., a MC68332 processor manufactured by Motorola, Inc. of Schaumburg, Ill.), and also a field-programmable gate array (FPGA) **238**. FPGA **238** allows for memory allocation among memories **232–236**. Processor **101** and memory **102** are coupled to one another and other elements of the genset controller **100** by an internal bus structure **290**.

Genset controller **100** employs several interfaces to provide control and monitoring of genset **150**, including a CAN interface **103**, a three-phase input interface **104**, a voltage regulator interface **105**, an analog input/output interface (analog I/O) **106** and a digital input/output interface (digital I/O) **107**. Three-phase input interface **104**, voltage regulator interface **105** and digital I/O **107** each are coupled directly to FPGA **238** of processor **101**, which allows for signal sampling, signal multiplexing, and control of peripheral devices (such as operator interface devices, discussed below). CAN interface **103** and analog I/O **106** are coupled to processor **101** by way of internal bus **290**. Input and output ports for each of interfaces **104–107** are provided on an interconnect board **220** of genset controller **100**.

The processor **240** operates under the direction of stored program instructions to read in information through the three-phase input interface **104** regarding the operation of the alternator **154** in the genset **150**. Referring to FIGS. **1** and **2**, the three-phase alternator output voltages are applied to system voltage inputs **224**, and the three-phase alternator output currents are coupled through a current transformer **158** to system current inputs **225**. These six analog input signals are filtered by respective voltage and current conditioning circuits **242** and **246** and are digitized by respective voltage and current analog-to-digital converters **244** and

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248. These digitized indications of alternator output voltages and currents are read by the processor **240** and used to monitor genset performance. This information may be displayed and it may be used to calculate other genset operating parameters, such as output power, reactive power, power factor and alternator duty level and frequency.

The digitized alternator output signals are also used as the basis for controlling the operation of the alternator **154**. As will be described below, the processor **101** is programmed to provide command signals to the voltage regulator interface **105**. These commands operate a pulse width modulation (PWM) unit **250** which outputs pulse-width modulated signals to PWM output **226** of interconnect board **220**. These PWM signals are applied to alternator **154** to control the voltage, current, and power output levels of the alternator. In particular, voltage regulator interface **105** provides an approximately 10 KHz PWM signal to adjust the field current on alternator **154** to control the armature voltage and maintain the output voltage at a particular level. The voltage regulator interface **105** may also provide a 1 KHz PWM signal for governing engine speed **152**, if an ECM is not employed.

In addition to providing control and monitoring of alternator **154**, genset controller **100** also provides control and monitoring of engine **152**. Although in certain embodiments genset controller **100** directly controls engine **152**, in the preferred embodiment genset controller **100** does not directly control the engine. Rather, the operation of engine **152** is directly controlled by an engine control module (ECM) **160**, which typically is physically attached to the engine. ECM **160** can control engine speed (and other engine operating parameters), and thereby control the output power of alternator **154**. ECM **160** also monitors a variety of engine characteristics, for example, fuel consumption, oil pressure, emissions levels, coolant temperature, time delay engine cool down information, and time delay engine start information.

The genset controller **100** controls and monitors the ECM **160** through CAN interface **103** which connects to the CAN serial link **170**. CAN serial link **170**, employs the SAE J1939 protocol which is an industry standard protocol for serial communications. By way of CAN databus **170**, genset controller **100** receives the information about the operation of engine **152** that has been collected by ECM **160**, and provides commands to the ECM **160** to influence the operation of the engine. Further, upon determining the occurrence of system faults, genset controller **100** provides commands to engine **152** via ECM **160** causing the engine to shutdown, by turning off both the ignition and the cranking of the engine. In particular, genset controller **100** can provide a command to slow down or entirely shut down the engine **152** if it is determined that one or more currents flowing through alternator **154** are excessive and may potentially produce excessive heat in the alternator.

The genset controller **100** includes analog I/O **106** and digital I/O **107** which enable it to communicate with a variety of devices. The analog I/O **106** receives up to sixteen separate analog input signals at inputs **229** on interconnect board **220**. These analog signals are filtered by conditioning circuit **258**, and applied to an A/D converter **262** through a multiplexer **260**. The processor **101** can thus sequentially scan the analog inputs and read in digitized signals indicative of engine parameters such as engine temperature, gas emissions and engine battery charge.

The digital I/O **107** receives 24 single-bit TTL signals at digital inputs **227**, and produces 34 single-bit TTL signals at digital outputs **228** on interconnect board **220**. Digital inputs **227** are coupled to a digital input signal conditioning unit **252**, which conditions the input signals and provides the signals to FPGA **238** via buffers **254**. Three of the inputs **227** are dedicated to signals relating to emergency stopping, remote starting, and low coolant level of genset **150**. The remaining inputs are definable inputs, which can be enabled or disabled, and are coupled to a variety of discrete sensors. The discrete sensors are capable of indicating various types of engine characteristics, warning conditions, and system faults relating to low fuel, or high oil temperature, as well as switchgear conditions concerning the synchronization of the power output of genset **150** with power lines to which the genset is being connected.

Genset controller **100** is capable of performing a variety of functions in response to the signals received at analog inputs **229** and digital inputs **227**. In particular, genset controller **100** is capable of scaling the signals, monitoring genset parameters through the use of the signals, detecting system faults, and providing system warnings or system shutdowns in response to the signals. As will be discussed in more detail below, genset controller **100** is also capable of displaying (in real-time) information obtained from the signals, providing relay driver outputs (RDOs)in response to the signals, and relaying information in the signals to remote control and monitoring stations.

The 34 digital outputs **228** are driven by digital output drivers **256**. The digital outputs **228** are controlled by the processor acting through FPGA **238**. Three digital outputs are dedicated to a Controller Panel Lamp Relay, a Controller Engine Crank Relay, and a Controller Engine Fuel Relay. The remaining digital outputs are definable, and typically are RDOs that determine the on/off status of a variety of indication/warning lamps within a remote control station. The definitions of these digital outputs typically correspond to particular system warnings, shutdowns or other conditions. For example, the definable digital outputs can be RDOs corresponding to "NFPA-110" functions such as overspeed, overcranking, low oil pressure, or high coolant temperature of engine **152**. The definable digital outputs can also be RDOs corresponding to loss of signal functions, including a loss of communications with ECM **160**. Additionally, the definable digital outputs can be RDOs corresponding to one of many system fault conditions concerning the genset **150** or the genset controller **100** itself.

As shown in FIGS. **1** and **2**, genset controller **100** also includes a number of operator interface devices, by which an operator can both provide commands to the genset controller and receive information from the genset controller. The operator interface devices are included on a front panel Man Machine Interface (MMI) **210**, which is situated on a controller box. One of the operator interface devices is an emergency stop button **130**. Emergency stop button **130** allows an operator to immediately stop the genset **150** by pressing a pushbutton.

A second operator interface device is a keypad/display **120**, which includes 16 individual keypads **122** and a vacuum flourescent display (VFD) **124**. Keypad/display **120** is coupled to a keypad/display interface **212** in front panel MMI **210**, which in turn is coupled to internal databus **290**. Keypads **122** allow an operator to enter a variety of information and commands to genset controller **100**. VFD **124** is an alphanumeric display, and allows genset controller **100** to display various information concerning system operation and system faults to an operator. A VFD is employed because it provides good visibility over a large range of temperatures and from a wide range of viewing angles.

The operator interface devices further include a control switch **110**, which can be rotatably set to one of three positions: an Automatic (Auto) position **112**; an Off/Reset position **114**; and a Run position **116**. Setting the control switch to Run position **116** causes genset controller **100** to send a signal via ECM **160** to start and run the genset **150**. Setting control switch **110** to Auto position **112** allows the genset **150** to be started and controlled from a remote location. This mode of operation also allows for time-delayed engine starting and cool-down. Setting control switch **110** to Off/Reset position **114** initiates the immediate shutdown of genset **150** and also results in a resetting of the software of genset controller **100**. If a fault occurs that precipitates a system shutdown, an operator must move control switch **110** to Off/Reset position **114** to clear the fault before genset **150** can be started again.

Genset controller **100** also includes other devices which provide information to an operator, including several light-emitting diodes (LEDs) and an alarm horn (not shown). These devices are used to provide system status information to an operator, as well as to alert the operator to the existence of system faults. During the occurrence of some faults, a message concerning the fault or related warning/shutdown condition is displayed on VFD **124**, an appropriate warning LED on front panel MMI **210** is turned on, the alarm horn is activated, and a corresponding RDO is produced at a digital output **228**.

As shown in FIG. **1**, genset controller **100** is capable of communication with other remote control and monitoring devices via both a K-BUS interface **109** and a second serial interface **108**. K-BUS interface **109** provides serial communications using the proprietary K-BUS serial communications protocol. Second serial interface **108** provides serial communications using any of a variety of other "open" serial communications protocols, including the Modbus™ protocol. Each of K-BUS interface **109** and second serial interface **108** is configurable to use either the RS-232 or RS-485 standards.

In the preferred embodiment shown in FIG. **2**, the structures associated with K-BUS interface **109** and second serial interface **108** include a first dual universal asynchronous receiver/transmitter (DUART) 270 that is coupled to two RS-485 conversion units **272** and **274**, and a second DUART 280 that is coupled to an RS-485 conversion unit **282** and an RS-232 conversion unit **284**. Each of DUARTs 270, 280 is coupled to internal databus **290** and is controlled in response to program instructions executed by microcomputer **240**.

The microprocessor **240** operates the genset under the direction of programs illustrated in FIGS. **3** and **4**. The programs include scheduled tasks which, as illustrated in FIG. **3**, are performed one at a time under the direction of a task scheduler program **302**. The programs also include asynchronous tasks as illustrated in FIG. **4**. The asynchronous tasks are performed in response to interrupts that are managed by a real time, asynchronous program **402**.

Referring to FIGS. **3** and **4**, two block diagrams **300**, **400** are provided showing software based subsystems (or tasks) that are performed by microprocessor **240** of genset controller **100**. Through the operation of these subsystems, microprocessor **240** is capable of monitoring genset **150** (as well as capable of monitoring the operation of genset controller **100**), receiving operator commands, detecting system faults, providing system warnings and shutdowns when necessary, displaying information at keypad/interface **120** (and at other operator interface devices), and conducting communications with genset **150**, ECM **160** and other devices via K-BUS interface **109** and second serial interface **108**. The subsystems of block diagrams **300**, **400** are self-contained routines that control specific aspects of genset controller **100**. Each subsystem is an independent, modular unit with well-defined input/output protocols to communicate with other subsystems.

Block diagram **300** shows scheduled tasks or subsystems, which are scheduled according to a task scheduler subsystem **302**. The task scheduler subsystem **302** is capable of invoking any scheduled subsystem at a rate of up to 100 times a second, and is able to handle transitions between scheduled subsystems and to monitor the execution times of scheduled subsystems to make sure that the subsystems do not exceed their time allotments. As shown, other scheduled subsystems (which are scheduled by task scheduler subsystem **302**) include a user interface subsystem **304**, a state machine subsystem **306**, a metering subsystem **308**, a voltage regulator subsystem **310**, a display subsystem **312**, a digital inputs subsystem **314**, and a fault detection/handling subsystem **316**. Further, the scheduled subsystems include a load disturbance detection subsystem **318**, a Modbus™ (or other serial communications) subsystem **320**, a K-BUS subsystem **322**, a thermal protection subsystem **324**, an analog inputs subsystem **326**, and an EEPROM data storage subsystem **328**.

Block diagram **400** shows asynchronous tasks or subsystems. As shown in block **402**, these subsystems operate in real time, asynchronously, with respect to the scheduled subsystems (i.e., operate in the "background" of the scheduled subsystems). The asynchronous subsystems also provide data when the scheduled subsystems require such data. The asynchronous subsystems are interrupt-driven modules and can take advantage of special features of microprocessor **240** (such as the embedded time processing unit within the microprocessor). The asynchronous subsystems include a serial communications subsystem **404**, a timer subsystem **406**, a real time math subsystem **408** (which employs a time processing unit of microprocessor **240**), and a SAE J1939 interface subsystem **409**.

Turning to FIG. **5**, a flowchart is provided showing exemplary method steps that are performed by the genset controller **100** in accordance with one embodiment of the invention. The performance of the method begins at step **500**, in which the processor **101** of genset controller **100** calls a thermal protection subroutine. The thermal protection subroutine is executed as part of the thermal protection subsystem **324**. Upon the calling of the thermal protection subroutine, the genset controller **100** obtains a current measurement value concerning one or more currents of the alternator **154** of genset **150**. As discussed, current information is provided via current transformer **158** to the three-phase input interface **104**. The current measurement value typically is in a root mean squared format. Typically, each current measurement value is based upon actual measured current values associated with all of the three windings of the alternator **154**; however, the current measurement value can also be based upon information concerning fewer or only one of the windings. The obtaining of current measurement values can occur independently of the execution of the thermal protection subroutine. However, current measurement values must be obtained for the thermal protection subroutine to proceed, and thus the flow chart of FIG. **5** includes step **502**. In the preferred embodiment of the invention, new current measurement values are obtained every one second, and the thermal protection subroutine is repeated every one second.

Following step **502**, the thermal protection subroutine proceeds to step **504**, at which it is determined whether the

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engine **152** of the genset **150** is currently on. If the engine is not on, the subroutine proceeds to step **514**, at which a low current value is calculated, as further discussed below. If the engine is on, the subroutine proceeds from step **504** to step **506**, at which the processor **101** determines whether the engine just started operating. The determinations of whether the engine **152** is on or has just started operating can be made by way of signals from ECM **160** that are provided to CAN interface **103**.

If the engine **152** just started operating, the subroutine proceeds from step **506** to step **508**, at which the processor **101** reinitializes the high current integration parameters. Otherwise, the subroutine proceeds directly to step **510**, at which the processor **101** calculates a high current value, as further discussed below. During the reinitialization at step **508**, the processor **101** eliminates various recorded data from the memory. In particular, data corresponding to the high current value calculations, including recent current measurement values utilized in those calculations, is eliminated from memory. The currently-stored high current value is also set to zero. Upon completion of step **508**, the subroutine proceeds to step **510**.

At step **510**, a high current value is calculated by the processor **101**. The high current value that is calculated is indicative of the strength of the measured currents within the alternator **154** during a most recent time period. In the preferred embodiment, the recent time period of interest is ten seconds. The high current value is calculated as the sum of the squares of ten normalized currents corresponding to the current measurement values taken during the ten most recent seconds of operation of the engine **152**. Each normalized current is a per unit value calculated by dividing the respective current measurement value by a rated standby or maximum current value (RMS). The maximum current value is determined as discussed with respect to FIG. **6**. Typically, to calculate the high current value, a rotating buffer of the last ten current measurement values is maintained.

Once the high current value is calculated in step **510**, the subroutine proceeds to step **512**, at which the high current value is compared with a high current maximum value H_{MAX}. The comparison determines whether the following inequality is true:

$$\sum_{1}^{10} I^2 > H_{\max} \tag{1}$$

where the left hand side of the inequality is the definition of the high current value as discussed with respect to step **510**. In the preferred embodiment, the high current maximum value H_{MAX} is 90. The value of 90 is chosen based upon the NEMA MG 1-16.45 standards. Thus, if the normalized current value (**I**) is continuously greater than 3 for any 10-second window of operation of the engine **152**, the inequality of equation (1) is true and therefore it is determined that the current within the alternator **154** is excessive. If the current is determined to be excessive at step **512**, the subroutine proceeds to step **518**, in which the processor **101** provides a command to shut down the operation of genset **150**.

The command provided at step **518** normally involves calling a system fault routine to shut the genset **150** down. In other embodiments, only a portion of the genset **150** is commanded to be shut down, such as the engine **152** or the alternator **154**. In further embodiments, the processor **101** does not provide a command to completely shut down the genset **150** or a portion thereof, but rather provides a command to reduce some operational parameter of the genset or a portion thereof, e.g., a command to slow down the speed of engine **152**. The system fault routine of step **518** in one embodiment is performed by way of fault detection/handling subsystem **316**. The command provided by processor **101** typically results in a signal being transmitted from CAN interface **103** to ECM **160**, which then effects the appropriate response from the genset **150**. In certain embodiments, the commands of the processor **101** are effected by way of voltage regulator interface **105** or another interface. In additional embodiments, elements of the genset controller **100** or other elements are also shut down, or other events are triggered, upon the determination of excessive current at step **512**.

If the inequality of equation (1) is found to be untrue at step **512**, the subroutine proceeds to step **514**, at which a low current value is calculated. The low current value is an indicator of the overall current experienced by the alternator **154** throughout its operation. Specifically, the low current value is a summation of the squares of normalized currents corresponding to each of the current measurement values taken with respect to the alternator **154** over its entire period of operation, or at least the entire period since the thermal protection subroutine began operating. The normalized currents used to determine the low current value are calculated in a different manner than the normalized currents used to calculate the high current value. In this case, each normalized current is calculated by dividing a respective current measurement value by the maximum current value (RMS) to obtain a per unit value and then subtracting 1 from the result.

Further unlike the summation performed to obtain the high current value at step **510**, the summation performed at step **514** adds the squared normalized currents when the normalized currents are positive, but subtracts the squared normalized currents when the normalized currents are negative. For example, if the result of taking a current measurement value and dividing it by the maximum current is less than 1, the resulting normalized current is negative, and so the squared normalized current is subtracted from the overall summation. Consequently, the low current value not only increases when the current measurement values are high, but also decreases when the current measurement values are low.

Upon calculating the low current value in step **514**, the processor **101** determines whether the low current value exceeds a low current maximum value L_{MAX} in accordance with equation (2):

$$\Sigma(I-1)^2 > L_{MAX} \tag{2}$$

In the preferred embodiment, the low current maximum value L_{MAX} is 40. The value of 40 is chosen based upon the NEMA MG 1-1998-32.7, MG 1-1998-32.8, and MG 1-1998-32.13 standards. If the low current maximum value is not exceeded, the processor **101** repeats the subroutine by returning to step **500**. If the low current maximum value is exceeded, the processor **101** proceeds to step **517**, at which it is determined whether the alternator **154** (or, in alternate embodiments, the engine **152** or the thermal protection subroutine) has been operational for 10 seconds.

If the alternator **154** has not been operational for seconds, the fact that the low current value is determined to exceed the low current maximum value is not indicative of an excessive alternator current. The low current maximum value is chosen as a maximum level that can be sustained nearly indefinitely, and consequently is a much lower level than that which can be sustained for less than 10 seconds.

Consequently, if less than 10 seconds have passed, the processor **101** returns to step **500** to repeat the subroutine. If the thermal protection subroutine has been operational for 10 seconds, and the low current value has been determined to exceed the low current maximum value, then the alternator current is excessive. In such case, the processor **101** proceeds to step **518** and provides a command to shut down or otherwise limit the operation of the genset **150** or a portion thereof. Although in FIG. **5**, the thermal protection subroutine is shown to be repeated upon completion of step **518**, this need not be the case.

In the case where the thermal protection subroutine has already been operating for more than ten seconds but the engine **152** is off, e.g., the genset **150** was operating but has been turned off temporarily, the thermal protection subroutine can keep operating. In such case, the calculated high current value is not updated while the engine **152** is off, since the thermal protection subroutine skips steps **506–512**. The calculated low current value decreases while the engine **152** is off, since during this time a negative value (representative of zero actual current) is added to the summation for calculating the low current value during each cycle of the subroutine.

Alternate embodiments of the thermal protection subroutine shown in FIG. **5** are also possible. In one alternate embodiment, the order of the steps performed by the subroutine is changed such that an evaluation of the low current value is made prior to an evaluation of the high current value. In one such embodiment, the reversal in the order of steps relating to the evaluations of the low current and high current values only occurs while the alternator has not yet been operational for ten seconds. In a second alternate embodiment, upon commencement of the operation of the thermal protection subroutine, the sampling of the current measurement values used to calculate the low current value is delayed by one sample, e.g., one cycle through the thermal protection subroutine, relative to the sampling of the current measurement values used to calculate the high current value. That is, the calculated low current value (which is not allowed to fall below zero) is maintained at zero following the first cycle through the subroutine even though the calculated high current value may have been calculated to be greater than zero. Such delaying of the sampling of the current measurement values used to calculate the low current value assures that a false determination of excessive current is not made as a result of a particularly high transient current during the startup of the genset **150**.

As discussed, to calculate the high current value and the low current value, the current measurement values must be normalized with respect to a rated standby or maximum current value. Under normal operating circumstances, in one embodiment, the maximum current value I_{MAX} is calculated as follows:

$$I_{MAX} = \frac{KW \times 1000}{System\ Voltage \times .8 \times \sqrt{3}} \quad (3)$$

where KW is a maximum power value for the alternator **154**. Thus, the maximum current value depends upon a maximum power value and the system or output voltage. The maximum power value can be determined in accordance with a second subroutine as showed in the flow chart of FIG. **6** and a corresponding voltage/frequency table as shown in FIG. **7**. Referring to FIG. **6**, to determine the maximum power value, the genset controller **100** begins the execution of the second subroutine by determining the system voltage and frequency at step **602**. At step **604**, the genset controller **100** determines whether a fixed voltage flag has been set. This can occur if the genset **150** includes a specialty or high voltage alternator. If the genset controller **100** determines that a fixed voltage flag has been set, it proceeds to step **606**, at which a maximum power value is read directly from the flash memory **232**, and then proceeds to step **608**, at which the second subroutine is completed. In alternate embodiments, a maximum current value is directly read from the flash memory such that, in this case, equation (3) need not be employed to calculate the maximum current value.

If the fixed voltage flag is not set, which is normally the case, the genset controller **100** proceeds to step **610**. Because the fixed voltage flag is not set, the genset controller **100** determines the maximum power value by way of the voltage/frequency table shown in FIG. **7**. The table of FIG. **7** displays various maximum power values corresponding to different system voltages and frequencies. In step **610**, the genset controller **100** determines whether the system voltage is greater than the maximum voltage allowed on the table of FIG. **7** for the particular frequency of operation. If the system voltage is determined to be greater than the maximum voltage in step **610**, the genset controller **100** selects the maximum power value shown on the voltage/frequency table for the appropriate frequency and then the second subroutine is completed at step **614**. For example, since the table only provides maximum power values for system voltages up to 440 volts (high wye) for a 50 Hz frequency of operation, the genset controller **100** will select the maximum power value corresponding to the 440 volt level (e.g., 160 kW) if the system voltage is above 440 volts and the system is operating at 50 Hz.

If the system voltage is not greater than the maximum voltage allowed on the voltage/frequency table of FIG. **7**, the genset controller **100** proceeds to step **616**, at which the genset controller determines whether the system voltage is between the high wye and low wye voltages. If the genset controller **100** determines that the voltage is between the high wye and low wye voltages, the genset controller selects the maximum power value corresponding to the minimum high wye voltage for the particular frequency of operation from the table of FIG. **7**. The genset controller then proceeds to step **620**, at which a system warning is issued without affecting system operability, and then the second subroutine is completed at step **622**. If the system voltage is not determined to be between the high wye and low wye voltages, the genset controller **100** proceeds to step **624**, at which the genset controller compares the system voltage to the lowest voltage rating (or minimum voltage) on the voltage/frequency table. If the system voltage is determined to be less than the lowest rating, the genset controller **100** proceeds to step **626**, at which the genset controller selects the maximum power value corresponding to the minimum voltage allowed on the voltage/frequency table for the particular frequency of operation. The second subroutine is then completed at step **628**.

If the system voltage is determined to be greater than the lowest voltage rating allowed on the voltage/frequency table, then the genset controller **100** proceeds to step **630**, in which the genset controller interpolates the appropriate maximum power value based upon the information in the voltage/frequency table. For example, if the system frequency is 60 Hz and the system voltage is 225 volts (low wye), then the appropriate maximum power value determined using linear interpolation is 285 kW. In alternate embodiments, various forms of non-linear interpolation are employed. Upon calculation of the maximum power value, the second subroutine is completed at step **632**. However, in

certain alternate embodiments, the maximum current value determined by way of equation (3) is compared with a predetermined level, and a command is issued to the fault subsystem if the current is calculated to be too high.

The maximum power values of the voltage/frequency table of FIG. **7** are stored within a section of the flash memory **232** of the genset controller **100** along with other default system parameters. Because of their nature, the values are alternator specific, and are downloaded into the flash memory **232** at the time the genset controller **100** is placed onto the genset **150**. The information is meant to be unalterable by the end user of the device.

While the foregoing specification illustrates and describes the preferred embodiments of this invention, it is to be understood that the invention is not limited to the precise construction herein disclosed. The invention can be embodied in other specific forms without departing from the spirit or essential attributes of the invention.

For example, the maximum current value I_{MAX} can be determined in a manner other than through the use of equation (3) and the voltage/frequency table of FIG. **7**, e.g., through the use of a formula. Also, for example, the exact low current and high current maximum values used in equations (1) and (2) can vary greatly depending upon the application, as can the exact manner in which the current measurement values are normalized for use in those equations. Additionally, in other embodiments, the calculations of the low current and high current values can vary. For example, in different embodiments the calculations of these values will vary in terms of the number of normalized currents that are summed together, to account for current variation within the alternator **154** during other time periods then those specified herein. Accordingly, reference should be made to the following claims, rather than to the foregoing specification, as indicating the scope of the invention.

What is claimed is:

1. A method of preventing damage to an alternator of a genset resulting from high currents within the alternator, the method comprising:

calculating, at a processor, a first quantity related to a current flowing through the alternator during a first time period;

comparing, at the processor, the first quantity with a first threshold;

calculating, at the processor, a second quantity related to the current flowing through the alternator during a second time period, wherein one of the first and second time periods is of greater length than the other of the first and second time periods;

comparing, at the processor, the second quantity with a second threshold; and

indicating a current overload condition if at least one of the first quantity exceeds the first threshold or the second quantity exceeds the second threshold.

2. A method of preventing damage to an alternator of a genset resulting from high currents within the alternator, the method comprising:

calculating, at a processor, a first quantity related to a current flowing through the alternator during a first time period;

comparing, at the processor, the first quantity with a first threshold;

calculating, at the processor, a second quantity related to the current flowing through the alternator during at least one of the first time period and a second time period;

comparing, at the processor, the second quantity with a second threshold; and

indicating a current overload condition if at least one of the first quantity exceeds the first threshold or the second quantity exceeds the second threshold,

wherein the calculating includes

(a) obtaining a first measured current value indicative of the current during a first short time period;

(b) taking the square of a first related value that is functionally dependent upon the first measured current value to obtain a first comparison value;

(c) repeating (a) and (b) to obtain at least one additional measured current value indicative of the current during at least one additional short time period, and to take the square of at least one additional related value that is functionally dependent upon the at least one additional measured current value to obtain at least one additional comparison value; and

(d) adding the first comparison value and the at least one additional comparison value to obtain at least one of the first quantity and the second quantity.

3. The method of claim **2**, wherein the first time period and the second time period each include at least one time period equivalent in length to the first short time period.

4. The method of claim **2**,

wherein the first related value is a first normalized current value, and

wherein the first normalized current value is calculated based upon the first measured current value by dividing the first measured current value by a maximum current value.

5. The method of claim **4**, wherein the maximum current value is calculated based upon the following equation:

$$I_{MAX} = \frac{KW \times 1000}{System\ Voltage \times .8 \times \sqrt{3}};$$

and wherein the KW value is obtained by way of a maximum power subroutine and a voltage/frequency lookup table.

6. The method of claim **2**,

wherein the first related value is a first normalized current value, and

wherein the first normalized current value is calculated based upon the first measured current value by dividing the first measured current value by a maximum current value and then subtracting unity.

7. The method of claim **2**,

wherein the at least one additional measured current value includes nine measured current values, each of the nine measured current values being obtained based upon nine respective measurements taken during nine respective short time periods;

wherein the at least one additional comparison value includes nine comparison values, each of the nine comparison values being obtained by taking the squares of nine respective related values that are functionally dependent upon the nine respective measured current values; and

wherein the first quantity is obtained by adding the first comparison value and each of the nine comparison values.

8. The method of claim 7,

wherein the first short time period and each of the nine short time periods are successive single-second time periods, which together form a ten second window; and

wherein the first threshold is equal to 90.

9. The method of claim 2,

wherein (a) and (b) are continually repeated for additional short time periods while the genset is operational, so that a respective additional measured current value is obtained during each respective additional short time period, a respective additional related value is obtained that is functionally dependent upon each respective additional measured current value, and a respective comparison value is obtained by taking the square of each respective additional related value.

10. The method of claim 9,

wherein the first quantity is obtained by adding the first comparison value and each of the additional comparison values.

11. The method of claim 9,

wherein the second quantity is obtained by:

(i) adding the first comparison value when the first related value is a positive number;

(ii) subtracting the first comparison value when the first related value is a negative number;

(iii)adding each respective additional comparison value when the respective related value is a positive number; and

(iv) subtracting each respective additional comparison value when the respective related value is a negative number.

12. The method of claim 11, wherein the first short time period and each of the additional short time periods are successive single-second time periods; and

wherein the second threshold is equal to 40.

13. The method of claim 11, wherein the first quantity includes the first comparison value based upon the first measured current value, but the second quantity does not include the first comparison value, and does not include any comparison value based upon the first measured current value.

14. A method of preventing damage to an alternator of a genset resulting from high currents within the alternator, the method comprising:

(a) calculating a first quantity equaling a first sum of n squares of n type-A normalized currents determined based upon n most recent current measurements obtained during n most recent successive short time periods;

(b) determining whether the first quantity exceeds a first threshold;

(c) providing a first command to limit an operation of the genset when it is determined that the first quantity exceeds the first threshold;

(d) calculating a second quantity equaling a second sum of x values functionally dependent upon x squares of x type-B normalized currents determined based upon x current measurements obtained during x successive short time periods, wherein x is the total number of short time periods that have occurred since at least one of a first time at which a performance of the method began and a second time occurring after the first time;

(e) determining whether the second quantity exceeds a second threshold; and

(f) providing a second command to limit an operation of the genset when it is determined that the second quantity exceeds the second threshold.

15. The method of claim 14, further comprising:

(g) obtaining a new current measurement with respect to a new short time period; and

(h) repeating (a)–(g).

16. The method of claim 14, wherein n is equal to 10, and each short time period lasts one second.

17. The method of claim 14, wherein (a)–(c) are performed only when an engine of the genset is operating, and (f) is performed only when x exceeds 9.

18. An apparatus for preventing damage to an alternator of a genset resulting from high currents within the alternator, the apparatus comprising:

a means for measuring a current flowing within the alternator during successive time periods;

a processor coupled to the means for measuring, wherein the processor is operable to:

calculate a first parameter that is related to a first set of measured current values that were obtained at respective different times by the means for measuring during a first time period,

calculate a second parameter that is related to a second set of measured current values that were obtained at respective different times by the means for measuring during a second time period,

compare the first parameter with a first threshold and the second parameter with a second threshold, and

provide a command to cause at least a portion of the genset to be limited in its operation when either the first parameter exceeds the first threshold or the second parameter exceeds the second threshold; and

a means responsive to the command to alter the operation of the genset.

19. An apparatus for preventing damage to an alternator of a genset resulting from high currents within the alternator, the apparatus comprising:

a means for determining whether a current flowing through the alternator during a recent time period has been excessive;

a means for determining whether a current flowing through the alternator during an extended time period different in length than the recent time period has been excessive; and

a means for halting the operation of the genset if at least one of the two determining means determines that the current has been excessive.

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