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(54) **Title**: ELECTRIC VEHICLE SUPPLY EQUIPMENT WITH TEMPERATURE-CONTROLLED CURRENT

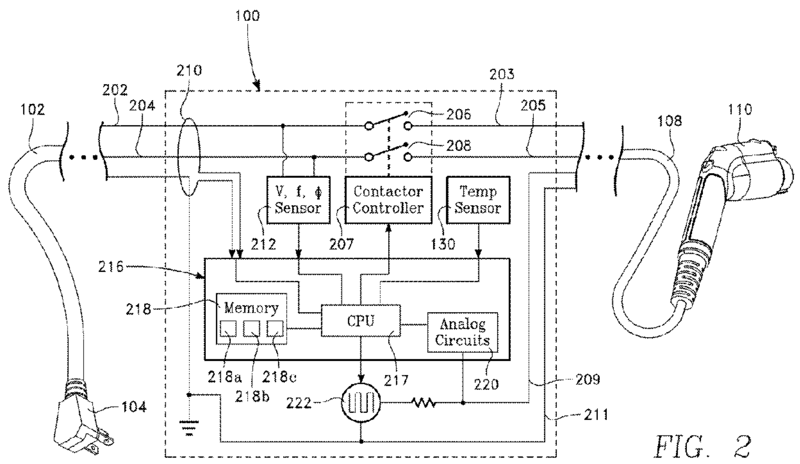


FIG. 2

(57) **Abstract**: In electric vehicle supply equipment (EVSE), interruption of charging due to overheating is prevented by adjusting the pulse duty cycle on the control pilot conductor communicating the maximum allowed current level to the electric vehicle, the adjustment being performed whenever the EVSE temperature exceeds a predetermined threshold temperature below the maximum operating temperature as a function of the approach of the temperature to the maximum operating temperature.

WO 2012/129104 A1

ELECTRIC VEHICLE SUPPLY EQUIPMENT WITH TEMPERATURE-CONTROLLED CURRENT

Inventor: Albert Joseph Flack

CROSS-REFERENCE TO RELATED APPLICATIONS

[1] This application claims priority of U.S. Provisional Application Serial No. 61/454,316 filed March 18, 2011 entitled ELECTRIC VEHICLE SUPPLY EQUIPMENT WITH TEMPERATURE-CONTROLLED CURRENT, by Albert J. Flack.

TECHNICAL FIELD

[2] The invention pertains to electric vehicle supply equipment (EVSE) for charging the on-board battery pack of an electric vehicle.

BACKGROUND

[3] Electric vehicles in the form of passenger cars have recently come into production by certain automobile manufacturers. Each electric vehicle (EV) carries an on-board battery pack which is charged while the vehicle is parked at home for the night and, in some cases, at other locations where the EV may be parked during the day. The charging is provided by electric vehicle supply equipment (EVSE). The EVSE may be a unit for residential use mounted on the wall of a household garage or car port, and is powered by electricity from a household electrical utility outlet. The EVSE includes a multi-conductor docking cable having a multi-conductor docking connector at its far end that is received in the charging port of the EV. The electrical interface between the EVSE and

the EV is defined by Specification SAE J1772 of the Society of Automotive Engineers. This specification also defines a protocol performed by the EV and the EVSE when the EVSE's docking connector is inserted into the EV charging port. The protocol is performed by the EV and EVSE changing voltage levels on a control pilot conductor of the docking connector in a prescribed handshaking sequence. The handshaking sequence is facilitated by a microprocessor in the EVSE and another microprocessor of the on-board battery management system in the EV. Both microprocessors contain firmware enabling them to perform this function. The handshaking sequence or protocol enables either the EV or the EVSE to suspend operation if either one detects a fault or unacceptable condition in the other.

[4] The time required to fully charge the EV on-board battery pack is determined by the voltage and current level of the power supplied by the EVSE. It is desirable to minimize this charging time, and for that reason the charging current is maintained at the highest practical level. This level may be in accordance with Table 1 of SAE J1772, which defines allowable current levels for different nominal supply voltages of the utility. For example, for a nominal supply voltage of single phase 120 VAC, the maximum allowable charging current that can be drawn from the EVSE by the EV is 12 A using a 15 A circuit breaker or 16 A using a 20 A circuit breaker. For a nominal supply voltage of 240 VAC, the maximum allowable current may be as high as 80 A, depending upon the current ratings of the components employed.

[5] At such high current levels, the charging may be quite rapid. However, the risk of overheating the microprocessor in the EVSE increases as the current level increases. In hot weather or at locations exposed to a hot sun, overheating is a risk. It is important to avoid overheating so that the microprocessor temperature is maintained below its specified temperature limit (e.g., 85 degrees C), to avoid microprocessor failure. The problem is that the user is greatly inconvenienced because no charging may be performed as long as the EVSE processor is overheated. Charging will not be restarted until the microprocessor has cooled down sufficiently for system restart. Such cooling may take an unacceptably long time. There is a need to solve this problem in an economical and reliable way.

SUMMARY OF THE INVENTION

[6] In one aspect, the invention is embodied in a method of charging an electric vehicle, comprising: providing in an electric vehicle supply equipment (EVSE) a utility cable for receiving electrical power and containing a first pair of power conductors, a docking cable containing a second pair of power conductors and terminated at a docking connector that is engagable with a charging port of an electric vehicle, and a pair of contactors between said first and second pairs of power conductors; providing a control pilot conductor extending through said docking cable to a control pilot pin of said docking connector; setting a pulse duty cycle on said control pilot conductor to a nominal pulse duty cycle corresponding to a maximum allowable charging current; sensing a present temperature in said EVSE; and whenever

said present temperature exceeds a predetermined threshold temperature, reducing said pulse duty cycle from said nominal pulse duty cycle to an adjusted pulse duty cycle by a reduction factor that is a function of an increase of said present temperature above said predetermined threshold temperature.

[7] The function may be a proportional function. The reduction factor may be proportional to the nearness of said present temperature to a maximum operating temperature.

[8] The method predetermined threshold temperature may be in a range of 10% to 30% of said maximum operating temperature.

[9] In another aspect, the invention is embodied in an apparatus or EVSE system, comprising a utility cable for receiving electrical power and containing a first pair of power conductors, a docking cable containing a second pair of power conductors and terminated at a docking connector that is engagable with a charging port of an electric vehicle; a pair of contactors providing an interruptable connection between said first and second pairs of power conductors; a microprocessor and a memory coupled to said microprocessor, said pair of contactors being controlled by said microprocessor; a control pilot conductor extending through said docking cable to a control pilot pin of said docking connector, said microprocessor being capable of controlling voltage on said control pilot conductor; a pulse generator coupled to said control pilot conductor and having a pulse duty

cycle controlled by said microprocessor; a temperature sensor having an output representative of a present temperature, said output coupled to said microprocessor. The memory contains: (a) a nominal pulse duty cycle corresponding to a nominal value of maximum allowable current, (b) a predetermined threshold temperature, and (c) set of program instructions executable by said microprocessor whenever said present temperature exceeds said predetermined threshold temperature to reduce the pulse duty cycle of said pulse generator from said nominal pulse duty cycle to an adjusted pulse duty cycle by a reduction factor that is a function of an increase of said present temperature above said predetermined threshold temperature.

[10] The memory may further contain a maximum operating temperature, and the reduction factor may be a function of the closeness of said present temperature to said maximum operating temperature.

BRIEF DESCRIPTION OF THE DRAWINGS

[11] So that the manner in which the exemplary embodiments of the present invention are attained and can be understood in detail, a more particular description of the invention, briefly summarized above, may be had by reference to the embodiments thereof which are illustrated in the appended drawings. It is to be appreciated that certain well known processes are not discussed herein in order to not obscure the invention.

[12] FIG. 1 depicts an EV connected to an EVSE embodying an aspect of the invention.

[13] FIG. 2 is a simplified schematic diagram of the EVSE in accordance with one embodiment.

[14] FIG. 3 is a block flow diagram depicting a method of operating in accordance with an embodiment of the invention.

[15] FIGS. 4 and 5 are correlated graphs depicting, respectively, control pilot pulse signal duty cycle and charging current as functions of EVSE temperature.

[16] FIG. 6 is a graph depicting EVSE temperature as a function of time in accordance with a tutorial example, and charging current as a function of time.

[17] To facilitate understanding, identical reference numerals have been used, where possible, to designate identical elements that are common to the figures. It is contemplated that elements and features of one embodiment may be beneficially incorporated in other embodiments without further recitation. It is to be noted, however, that the appended drawings illustrate only exemplary embodiments of this invention and are therefore not to be considered limiting of its scope, for the invention may admit to other equally effective embodiments.

DETAILED DESCRIPTION

[18] The problem of interruption of charging of the EV due to overheating of the EVSE microprocessor is solved in a preferred embodiment by prevention of such overheating. The charging current drawn from the EVSE is

reduced whenever the EVSE temperature exceeds a predetermined threshold well below the maximum allowed temperature of the EVSE microprocessor, thereby preventing it from reaching the maximum temperature limit (e.g., 85 degrees C). The predetermined threshold temperature may be in a range of 10% to 30% below the maximum temperature. For example, if the maximum operating temperature of the EVSE microprocessor is 85 degrees C, then the predetermined threshold temperature may be about 70 degrees C. As a result, necessity for shutting down the charging operation is avoided. The reduction in charging current is proportional to the rise in temperature above the predetermined threshold (e.g., above 70 degrees C). In a preferred embodiment, the reduction in charging current is proportional to the approach of the measured EVSE temperature to the maximum temperature limit (e.g., 85 degrees C). One problem is how to accomplish all this without requiring any additional hardware.

[19] A preferred embodiment exploits the feature of a standard EVSE in which the maximum current drawn by the EV battery management system is set by the pulse duty cycle of the voltage on the control pilot conductor transmitted to the EV. The pulse duty cycle is controlled by the EVSE microprocessor. Conventionally, the maximum current drawn by the EV is proportional to the duty cycle in accordance with a function defined by SAE J1772. The system designer determines the maximum allowed current draw based upon current ratings of the components of the EVSE, and sets the control pilot pulse to a nominal duty cycle corresponding to the maximum allowed current draw by programming the EVSE microprocessor. In a preferred embodiment of the invention, the EVSE microprocessor is further programmed to override the nominal setting of the pulse duty cycle by reducing the pulse duty cycle whenever the EVSE temperature exceeds the predetermined threshold. In a preferred embodiment, the reduction in the control pilot pulse duty cycle is proportional to the approach of the EVSE temperature to the maximum operating temperature.

[20] Referring now to FIG. 1, an EVSE 100 receives electrical power through a utility cable 102 terminated in a standard electrical socket 104 (which may be a 120 VAC or 240 VAC socket) plugged into a standard electrical outlet 106. The outlet 106 may be powered through a household utility panel (not shown) from the municipal utility grid and/or from local renewable sources, such as a local wind turbine or a local solar cell array and/or a local rechargeable battery. The EVSE 100 further has a docking cable 108 terminated in a docking connector 110. An EV 120 has an EV charging port or receptacle 122 into which the EVSE docking connector 110 may be inserted to connect the EV 120 to the EVSE 100.

[21] During charging of the EV 120, current flows from the EVSE utility cable 102 through the EVSE 100 to the EVSE docking cable 108. The EVSE 100 controls this current by enabling current flow when certain conditions specified in SAE J1772 are met. The conditions include the voltage being within a specified range (e.g., 120 VAC ± 10%), the frequency being within a specified range, an absence of any detectable ground faults, EVSE temperature being below the maximum limit, and a completion of the EV-EVSE handshake sequence or protocol specified in SAE J1772. A temperature sensor 130 and a current limiter 134 are provided in the EVSE 100 to implement the present invention. In the preferred embodiment that will be described below with reference to FIG. 2, the current limiter 134 operates by communicating a reduction in maximum allowable current draw to the EV on-board battery management system.

[22] Referring now to FIG. 2, the EVSE 100 connects conductors 202, 204 of the utility cable 102 with conductors 203, 205 of the docking cable 108 through respective contactors 206, 208 controlled by a contactor controller 207. A grounded neutral conductor 211 passes through the utility cable 102 and through the docking cable 108. The EVSE 100 includes a computer or processor 216 consisting of a microprocessor or central processing unit 217 and a memory 218. The temperature sensor 130 is coupled to the microprocessor 217. A voltage/frequency/phase sensor 212 is connected to both conductors 202, 204 and has an output coupled to the microprocessor 217. A ground fault sensor or loop 210 is wrapped around the conductors 202, 204 and 211, and has an output coupled to the microprocessor 217.

[23] A control pilot conductor 209 passes from the EVSE 100 and through the docking cable 108 to the docking connector 110, through which it is connected to an EV control pilot conductor (not shown) in the EV charging port 122 of the EV 120. The EV's on-board computer (not shown) and the EVSE's microprocessor 217 are programmed to perform the handshake protocol and other functions defined in SAE J1772. They do this by imposing a prescribed sequence of voltage changes on the control pilot conductor 209, thus communicating with each other. In addition, the EVSE 100 pulse modulates the voltage on the control pilot conductor and controls the pulse duty cycle. The pulse duty cycle informs the EV's battery management system of the maximum allowable current that may be drawn from the EVSE 100 during charging. In one embodiment, the maximum allowable current may be determined from the pulse duty cycle in the manner defined in SAE J1772 at section 5.3.5.5. The EVSE microprocessor 217 creates the prescribed sequence of voltage changes on the control pilot conductor 209 through analog circuitry 220 controlled by the EVSE microprocessor 217. The analog circuitry 220 acts as a voltage control circuit that enables the microprocessor 217 to impose changes in voltage on the control pilot conductor 209. Functionality of the analog circuitry 220 is defined in SAE J1772, and the analog circuitry 220 may be implemented as a suitable buffer, or digital-to-analog converter or as an analog circuit. The analog circuitry 220 is connected to the control pilot conductor 209. Pulse modulation of the voltage on the control pilot conductor 209 is performed by a pulse generator 222 having an output connected to the control pilot conductor 209. The EVSE microprocessor 217 controls the duty cycle of the pulse generator 222. A ground terminal of the pulse generator 222 may be connected to the neutral conductor 211.

[24] The microprocessor 217 may be programmed to set the duty cycle of the pulse generator 222 in accordance with a duty cycle value stored in a prescribed location in the memory 218. The system designer loads the correct (nominal) duty cycle value into that memory location as a part of the manufacturing process. This nominal duty cycle corresponds to the maximum charging current determined by the system designer.

[25] In the preferred embodiment of the invention, the microprocessor 217 is further programmed to prevent shutdown of the charging operation due to overheating of the EVSE. Specifically, the EVSE microprocessor 217 is programmed to override the nominal pulse duty cycle and reduce the duty cycle, in response to the output of the temperature sensor 130 exceeding the predetermined threshold temperature mentioned previously herein (e.g., 70 degrees C). It does this so as to reduce the charging current (set by the pulse duty cycle) by an amount proportional to the approach of the measured temperature to the maximum operating temperature of the microprocessor 217 (e.g., 85 degrees C). The nominal pulse duty cycle is stored in the memory 218 at location 218a, the predetermined threshold temperature is stored in the memory 218 at location 218b and the maximum operating temperature is stored at location 218c of the memory 218, as indicated in FIG. 2. The reduction in charging current may be by an amount proportional to the rise of the measured temperature above the predetermined threshold temperature. The operation is represented as a series of program instructions stored in the memory 218

and executed by the microprocessor 217, and is illustrated in FIG. 3.

[26] Referring now to FIG. 3, the EVSE 100 and the EV 120 perform the prescribed handshake protocol via the control pilot conductor 209 after the docking connector 110 has been inserted into the EV charging port 122 (block 310 of FIG. 3). The duty cycle of the pulse generator 222 is set to the maximum allowable current draw that was previously determined by the system designer (block 315). The output of the temperature sensor 130 is sampled to obtain a present temperature of inside the EVSE 100 (block 320). A comparison of the present temperature to the predetermined threshold temperature (e.g., 70 degrees C) is performed (block 325). If the present temperature is below the predetermined threshold temperature (YES branch of block 325), then the operation returns to the step of block 315. Otherwise (NO branch of block 325), the present temperature is compared with the maximum operating temperature (e.g., 85 degrees C) in block 330. If the present temperature is less than the maximum operating temperature -- e.g., 85 degrees C-- (YES branch of block 330), then the microprocessor 217 overrides the previously set nominal duty cycle value and reduces the duty cycle from the nominal value by a factor proportional to either the ratio between the measured present temperature and the maximum operating temperature or the difference between them (block 335). In the unlikely event that the measured temperature exceeds the maximum operating temperature (NO branch of block 330), charging is halted (block 340), and the operation returns to the step of block 320. The occurrence of such an event is unlikely because the onset of charging current reduction (block 335) occurs at the predetermined threshold temperature, which is 10% to 30% below the maximum operating temperature. Thus, in the examples provided herein, the predetermined threshold temperature may be 70 degrees C for a maximum operating temperature of 85 degrees C.

[27] In an exemplary embodiment, the step of block 335 may be performed by reducing the control pilot pulse duty cycle by a factor F, so that the duty cycle is changed from the current duty cycle D by multiplying D by (1-F), so that the new duty cycle is (1-F)D. F depends upon the present temperature sensed by the sensor 130. One example of how to define F is as follows:

F = (present temp - 70 deg C)/(85 deg C - 70 deg C),

where "present temp" is the measured temperature from the sensor 130 in degrees C, 85 deg C is the maximum operating temperature, and 70 deg C is the predetermined threshold temperature. The skilled worker may use suitable definitions of F other than the foregoing.

[28] It should be noted that the maximum possible decrease in duty cycle may be limited to avoid a reduction in duty cycle below 5%, at which a communication failure would be indicated to the EV.

[29] FIG. 4 is a graph depicting the factor by which the duty cycle is reduced as a function of measured temperature. There is no reduction for temperatures below the predetermined threshold (70 degrees C). From the predetermined threshold (70 degrees C) to the maximum operating temperature (85 degrees C), the reduction increases from 0% to 100% in a linear fashion, although a different function may be implemented in alternative embodiments. For example, since the power, and therefore heat, created by current through a fixed impedance follows the square of the current [$P = I^2R$], the function may be a second order function rather than a linear function. FIG. 5 is a graph corresponding to FIG. 4 depicting the reduction in charging current as a function of measured temperature.

[30] FIG. 6 is a graph depicting a hypothetical case in which the EVSE measured temperature (smooth curve) peaks at a time Tp, so that the charging current (stepped curve) dips at time Tp. The time between steps in the stepped curve of FIG. 6 reflects the sampling rate of the temperature in the operation of FIG. 3.

[31] While the foregoing is directed to embodiments of the present invention, other and further embodiments of the invention may be devised without departing from the basic scope thereof, and the scope thereof is determined by the claims that follow.

What is claimed is:

1. An electric vehicle supply equipment (EVSE) system for charging an electric vehicle, comprising:

a utility cable for receiving electrical power and containing a first pair of power conductors;

a docking cable containing a second pair of power conductors and terminated at a docking connector that is engagable with a charging port of an electric vehicle;

a pair of contactors providing an interruptable connection between said first and second pairs of power conductors;

a microprocessor and a memory coupled to said microprocessor, said pair of contactors being controlled by said microprocessor;

a control pilot conductor extending through said docking cable to a control pilot pin of said docking connector, said microprocessor being capable of controlling voltage on said control pilot conductor;

a pulse generator coupled to said control pilot conductor and having a pulse duty cycle controlled by said microprocessor;

a temperature sensor having an output representative of a present temperature, said output coupled to said microprocessor;

said memory containing: (a) a nominal pulse duty cycle corresponding to a nominal value of maximum allowable current, (b) a predetermined threshold temperature, and (c) set of program instructions executable by said microprocessor whenever said present temperature exceeds said predetermined threshold temperature to reduce the pulse duty cycle of said pulse generator from said nominal pulse duty cycle to an adjusted pulse duty cycle by a reduction factor that is a function of an increase of said present temperature above said predetermined threshold temperature.

2. The EVSE system of Claim 1 wherein said function is a proportional function.

3. The EVSE system of Claim 1 wherein said memory further contains a maximum operating temperature.

4. The EVSE system of Claim 3 wherein said reduction factor is a function of the closeness of said present temperature to said maximum operating temperature.

5. The EVSE system of Claim 3 wherein said predetermined threshold temperature is in a range of 10% to 30% of said maximum operating temperature.

6. An electric vehicle supply equipment (EVSE) system, comprising:

a utility cable for receiving electrical power and containing a first pair of power conductors;

a docking cable containing a second pair of power conductors and terminated at a docking connector that is engagable with a charging port of an electric vehicle;

a pair of contactors providing an interruptable connection between said first and second pairs of power conductors;

a microprocessor and a memory coupled to said microprocessor, said pair of contactors being controlled by said microprocessor;

a control pilot conductor extending through said docking cable to a control pilot pin of said docking connector, said microprocessor being capable of controlling voltage on said control pilot conductor;

a pulse generator coupled to said control pilot conductor and having a pulse duty cycle controlled by said microprocessor;

a temperature sensor having an output representative of a present temperature, said output coupled to said microprocessor;

said memory storing: (a) a nominal pulse duty cycle corresponding to a nominal value of maximum allowable current, (b) a maximum operating temperature, and a (c) set of program instructions executable by said microprocessor to reduce the pulse duty cycle of said pulse generator from said nominal pulse duty cycle to an adjusted pulse duty cycle by a reduction factor that is a function of the closeness of said present temperature to said maximum operating temperature.

7. The EVSE system of Claim 6 wherein said function is a proportional function.

8. The EVSE system of Claim 6 wherein said predetermined threshold temperature is in a range of 10% to 30% of said maximum operating temperature.

9. A method of charging an electric vehicle, comprising:

providing in an electric vehicle supply equipment (EVSE) a utility cable for receiving electrical power and containing a first pair of power conductors, a docking cable containing a second pair of power conductors and terminated at a docking connector that is engagable with a charging port of an electric vehicle, and a pair of contactors between said first and second pairs of power conductors;

providing a control pilot conductor extending through said docking cable to a control pilot pin of said docking connector;

setting a pulse duty cycle on said control pilot conductor to a nominal pulse duty cycle corresponding to a maximum allowable charging current;

sensing a present temperature in said EVSE;

whenever said present temperature exceeds a predetermined threshold temperature, reducing said pulse duty cycle from said nominal pulse duty cycle to an adjusted pulse duty cycle by a reduction factor that is a function of an increase of said present temperature above said predetermined threshold temperature.

10. The method of Claim 9 wherein said function is a proportional function.

11. The method of Claim 9 wherein said reduction factor is proportional to the nearness of said present temperature to a maximum operating temperature.

12. The method of Claim 11 wherein said predetermined threshold temperature is in a range of 10% to 30% of said maximum operating temperature.

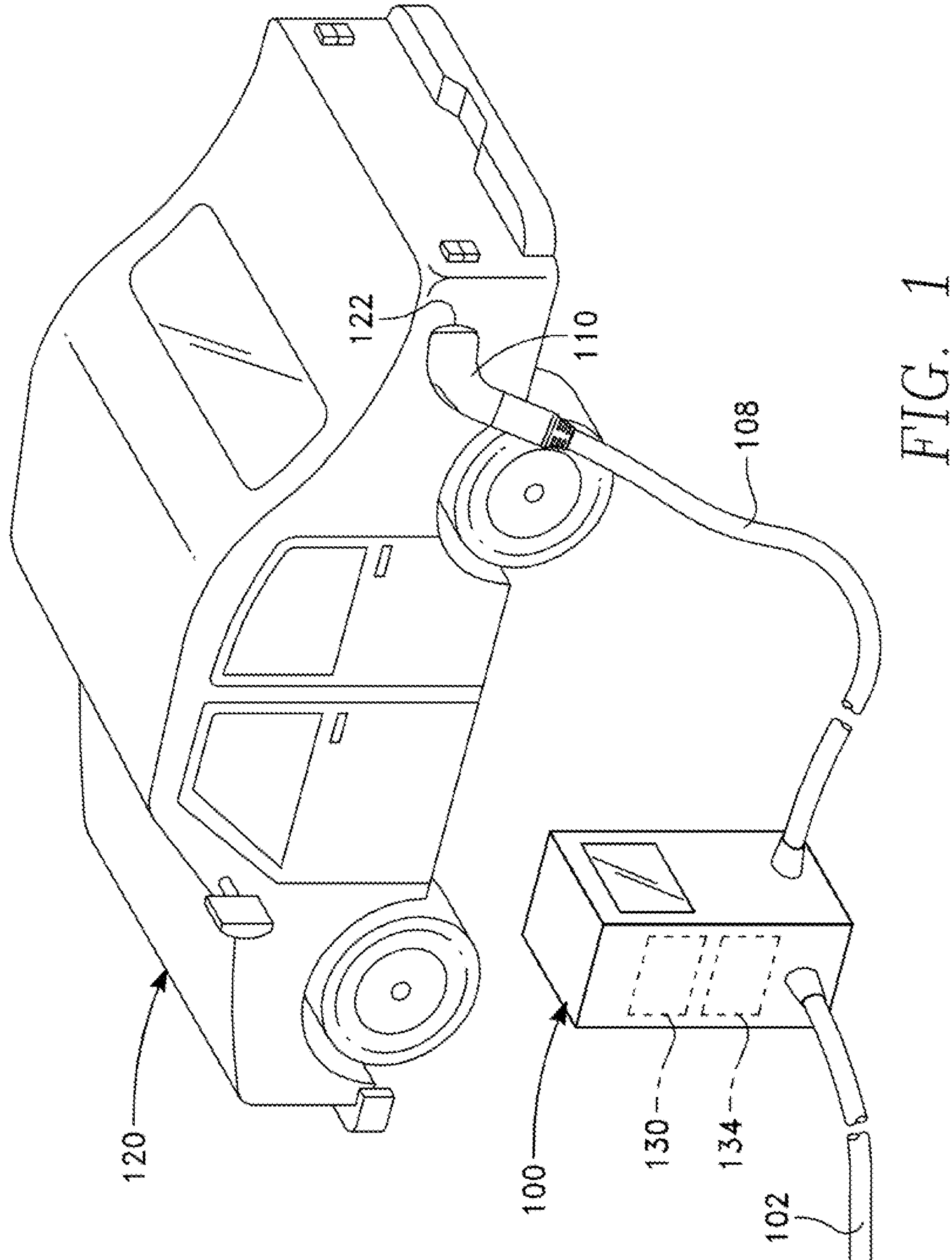
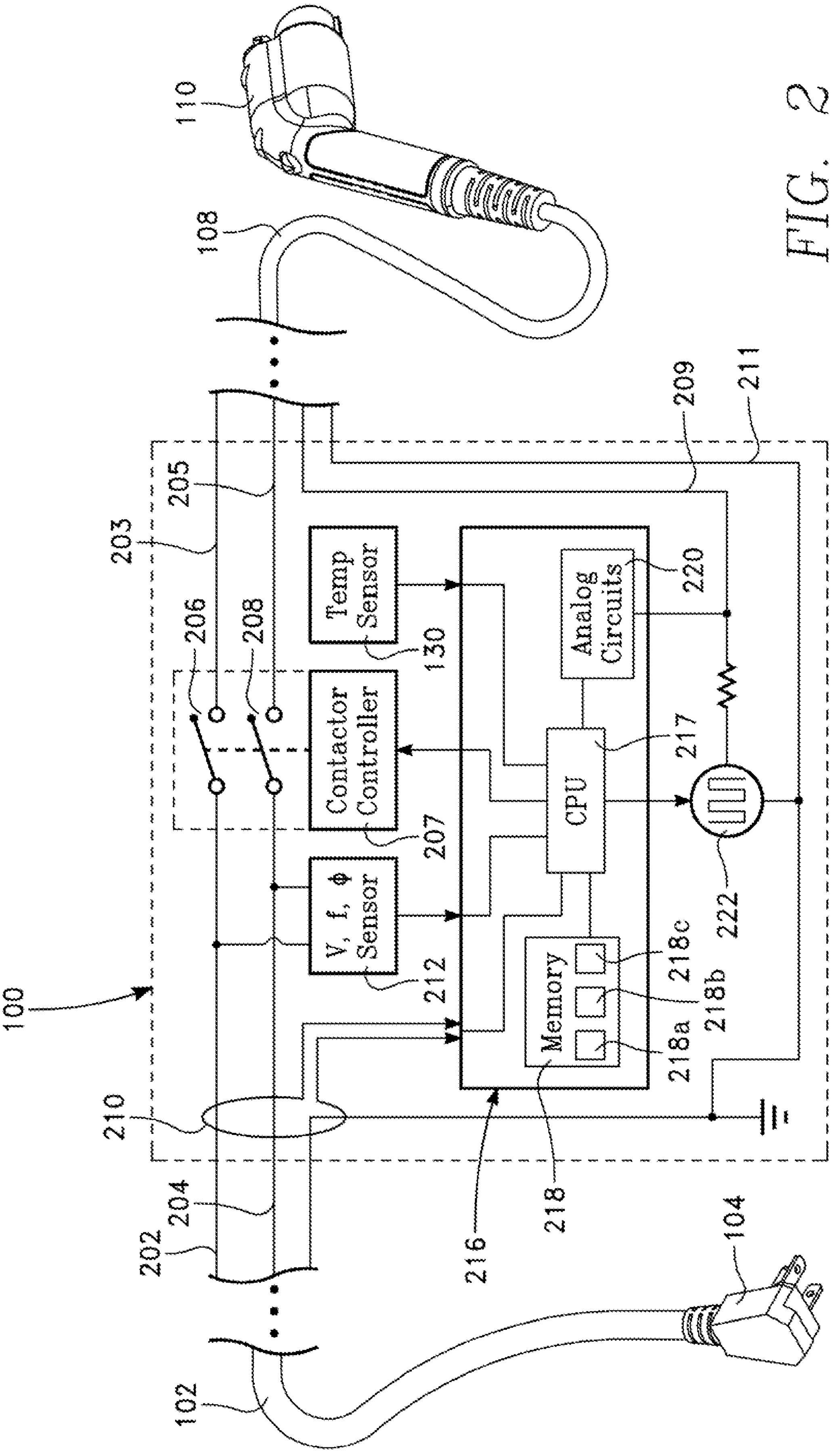


FIG. 1



100
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104
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V, f, ϕ
Sensor
212
Contactor
Controller
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Temp
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130
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CPU
217
Memory
218
218a
218b
218c
Analog
Circuits
220
222

FIG. 2

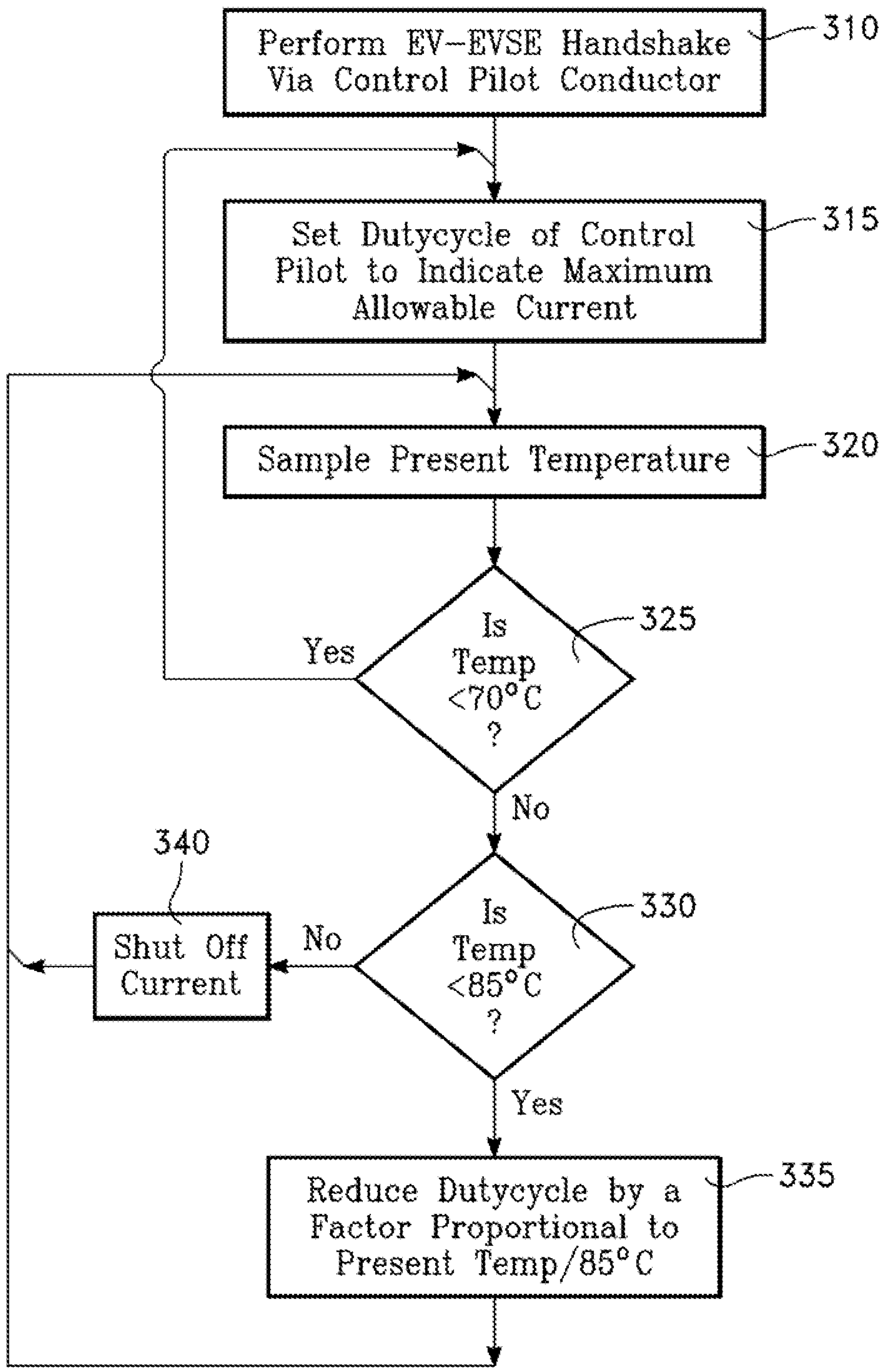
Perform EV-EVSE Handshake Via Control Pilot Conductor
310
Set Dutycycle of Control Pilot to Indicate Maximum Allowable Current
315
Sample Present Temperature
320
Is Temp <70°C ?
325
Yes
No
Is Temp <85°C ?
330
No
Shut Off Current
340
Yes
Reduce Dutycycle by a Factor Proportional to Present Temp/85°C
335

FIG. 3

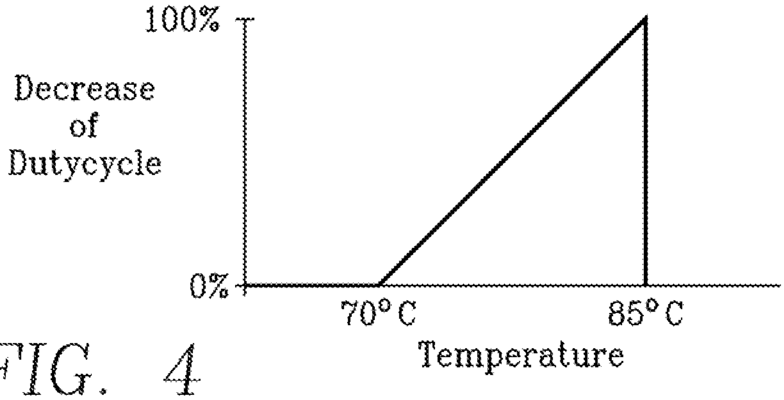

FIG. 4

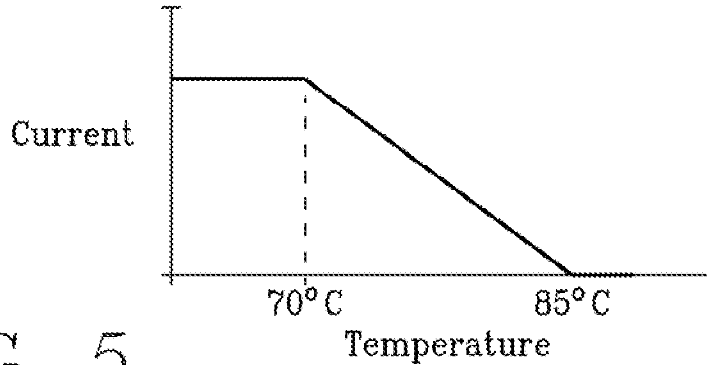

FIG. 5

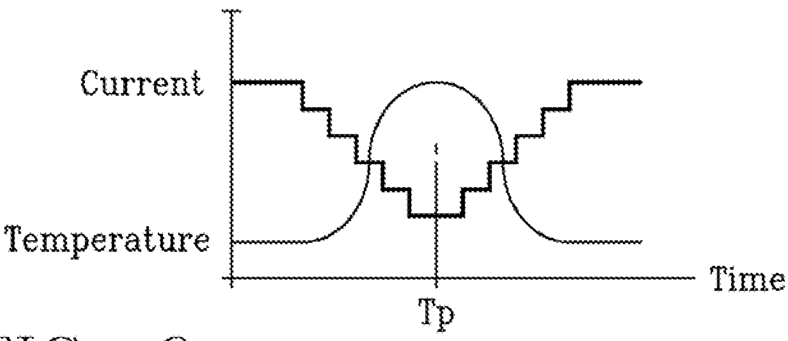

FIG. 6

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US 12/29485

A. CLASSIFICATION OF SUBJECT MATTER

IPC(8) - H02J 7/02 (2012.01)
USPC - 320/109

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC(8): H02J 7/02 (2012.01)
USPC: 320/109

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
IPC(8): H02J 7/02 (2012.01) (keyword limited, see terms below)
USPC: 320/107,109, 137 (keyword limited, see terms below)

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
PubWEST (PGPB, USPT, EPAB, JPAB), Google Scholar, Thomson Innovation. Search terms used: Current, temperature, pulse, duty, cycle, power, conductor, contactor, generator, regulate, control, modify, adjust, increase, decrease, slow, reduce, dock, processor, microprocessor, control, device, unit, apparatus, sensor, detect, measure, memory, threshold,

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2010/0207771 A1 (TRIGIANI) 19 August 2010 (19.08.2010) entire document, especially: Fig 1, Abstract, para [0010], [0015], [0024]-[0028], [0035], [0039], [0042], [0045], [0053], [0054]	1-12
Y	US 2009/0015209 A1 (MORINA et al.) 15 January 2009 (15.01.2009) [0048]-[0053], [0086]-[0088], [0093]	1-12
A	US 2011/0006731 A1 (WANG et al.) 13 January 2011 (13.01.2011) entire document	1-12

☐ Further documents are listed in the continuation of Box C. ☐

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
29 June 2012 (29.06.2012)	13 JUL 2012

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Authorized officer:
Lee W. Young
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