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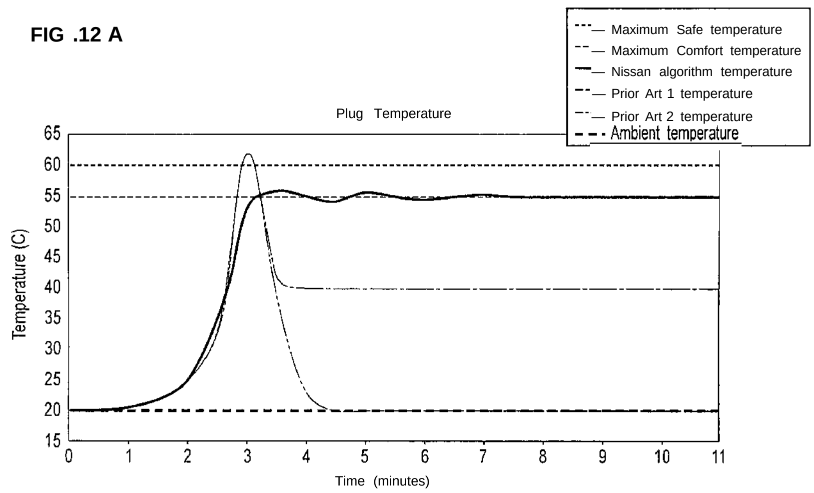
FIG .12 A



(57) Abstract: A method of charging an electric vehicle battery using the following electrical connections: a first plug (3, Fig. 8) mating with a first socket (3, Fig. 8) on the vehicle (200, Fig. 8); a second plug (400, Fig. 8) mating with a second "mains power" socket (44, Fig. 8); and a cable (7, Fig. 8) connecting the plugs; the charging system also comprising a control means comprising an electronic memory device. At least one electrical connection comprises temperature sensing means (412U, 412E, 412L, Fig. 7), mounted close to electrical conductors) within the plug or socket. The method comprises: measuring the temperature of the connection during charging; comparing said temperature with preset thresholds held in the electronic memory; and varying the current drawn by the battery from the electrical supply to maximize the charging rate without allowing the plug or socket to get too hot.

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IMPROVEMENTS IN ELECTRICAL CONNECTIONS

Field of the invention

The present invention relates to the charging and re-charging of electric vehicles and particularly to a method of charging an electric vehicle, enabled by improvements in the electrical connection or coupling, for example an electrical plug and/or socket, between the charging point and the vehicle being charged. Aspects of the invention relate to a method of charging an electric vehicle; to an electric vehicle charging system, and to an electric vehicle.

Background of the invention

Electrically powered domestic or commercial vehicles, such as automobiles, are becoming increasingly common. Most forms of electric vehicle (EV) or hybrid electric vehicle (HEV) are provided with an energy storage device, such as a battery, that supplies electric power to one or more motors for providing motive power to the vehicle. In some cases, the vehicle is provided with an electrical connection, such as a socket, to permit recharging of the battery by connection to a suitable external power supply, for example a domestic mains voltage consumer unit.

Such vehicles are commonly referred to as 'plug-in hybrid' or "plug-in electric" vehicles. The user of either a plug-in hybrid vehicle or an EV is required to electrically connect their vehicle to a dedicated charging station or a domestic power supply on a regular basis in order to recharge the vehicle after use.

The electrical infrastructure needed to electrically recharge such vehicles is still being developed in many countries where transport systems have, until recently, developed around the needs of vehicles powered by internal combustion engines. Some countries have started to provide dedicated recharging stations, able to supply the relatively high electrical current necessary to facilitate a rapid recharge of an electrically powered vehicle. However, the availability of these recharging stations will be limited, at least initially, until electrically powered vehicles become more popular and developing national electrical infrastructures have time to catch up with demand. Until such time as these dedicated vehicle recharging stations are commonplace, many early adopters of electrically powered vehicles will rely on recharging their vehicle via a domestic electrical outlet.

A known problem with using a domestic electrical outlet to recharge an electrically powered vehicle is the limited current capacity available to the vehicle. Typically a dedicated vehicle recharging station may provide up to 400V at around 60A, whereas a typical domestic electrical outlet may be limited to 220V at 13A or even less. Clearly, the rate of charge - and thus the time taken to recharge an electrically powered vehicle will be proportionally slower using a domestic electrical outlet, compared to using a dedicated vehicle recharging station. The infrastructure behind most domestic electrical outlets was never intended to supply such a high capacity electrical consumer as an electrically powered vehicle. As such, there are several challenges which the electricity providers and vehicle manufacturers alike must work to address.

A problem may arise if electrically powered vehicles become more commonplace, as there may be a significant increase in demand for recharging such vehicles at home. In this case, the vehicle may be parked in a domestic garage or carport or alternatively parked outside, for example on a private driveway. Typically, the most conveniently positioned domestic electrical outlet will be relatively distant from the main electrical supply to the residence. In this case, the distance from, for example, a fuse box or electrical meter tends to entail a relatively long electrical spur, resulting in electrical losses in the wiring between the residential supply and the outlet. Such losses affect the available rate of charge for the electrically powered vehicle, increasing recharge times. Due to the longer recharge times, the user is likely to leave the vehicle unattended for extended periods of time during the recharging cycle. However, if the user attempts to disconnect the vehicle from the domestic electrical outlet during, or shortly after recharging is completed, it is possible that the electrical plug and associated electrical outlet may have become warm, or even hot, to the touch due to the relatively high current drawn by the vehicle. This may lead to a perception that the recharging system is unsafe or that the electrical equipment in use is defective.

To minimise heating of the plug, it is possible to use thermal insulating materials in the region of the plug intended to be grasped by the user. However, such plugs are heavy, bulky, and more costly than a plug which is not thermally insulated.

It is against this background that the present invention has been conceived. It is an aim of the present invention to address one or more of the above problems. Embodiments of the invention may facilitate the recharging of electrically powered vehicles in a domestic environment whilst minimising the duration of the vehicle's recharge time and improving customer satisfaction. In addition, embodiments of the present invention may offer a reduction in plug mass and bulk compared to known systems. Such embodiments may improve user comfort and perceived quality when charging a power storage means such a battery for an electrically powered vehicle. Other aims and advantages of the invention will become apparent from the following description, claims and drawings.

Summary

Aspects of the invention therefore provide a method, a charging system, and a vehicle as claimed in the appended claims.

According to an aspect of the present invention for which protection is sought, there is provided a method of charging a power storage means of a vehicle using a charging system comprising the following electrical connections: a first plug arranged to cooperate with a corresponding first socket mounted on a vehicle; a second plug arranged to cooperate with a corresponding second socket of an electrical power supply; and a cable connecting the first and second plugs; the charging system also comprising at least one control means comprising an electronic memory device; wherein at least one of the electrical connections comprises temperature sensing means, and support means for supporting the temperature sensing means in close proximity to at least one electrical conductor within said electrical connection; the method comprising: measuring the temperature of the at least one electrical connection during the charging cycle; comparing the temperature of the electrical connection during the charging cycle with preset threshold data held in the electronic memory device; and in dependence on the temperature of the electrical connection during the charging cycle, varying the current drawn by the power storage means from the electrical power supply so as to maximize the rate of charge whilst not exceeding a pre-determined electrical connection temperature.

There may be one control means in an EVSE external to the vehicle, and a further control means within the vehicle. Each of these control means may be arranged to make measurements and to perform calculations.

In an example, the electrical connection comprising temperature sensing means is the second plug.

In an example, the pre-determined electrical connection temperature is a maximum safe temperature, which has been determined to be a maximum temperature at which unguarded human skin can touch an electrical connection without damage to said unguarded human skin.

In an example, the pre-determined electrical connection temperature is a maximum comfort temperature, which has been determined to be a maximum temperature at which unguarded human skin can comfortably touch an electrical connection without incurring an unacceptable level of pain.

In connection with the above examples, advantageously, the pre-determined electrical connection temperature is an intermediate maximum temperature between the maximum safe temperature and the maximum comfort temperature.

In connection with the above examples, advantageously, the current drawn by the power storage means from the electrical power supply is controlled by the control means so that the electrical connection temperature is allowed to oscillate between the intermediate maximum temperature and the maximum comfort temperature.

In connection with the above examples, advantageously, the current drawn by the power storage means from the electrical power supply is controlled by the control means so that the electrical connection temperature has a mean temperature corresponding to the maximum comfort temperature.

In connection with the above method, advantageously, the method further comprises: measuring the temperature of the at least one electrical connection before initiating a charging cycle; measuring a rate of change of the temperature of the electrical connection; comparing the rate of change of the temperature of the electrical connection during the charging cycle with preset threshold data held in an electronic memory device; and varying the current drawn by the power storage means from the electrical power supply in dependence on the rate of change of temperature of the electrical connection during the charging cycle so as to maximize the rate of charge whilst not exceeding a pre-determined electrical connection temperature.

In connection with the above method, advantageously, the method further comprises: measuring the voltage available from said electrical power supply; initiating said charging cycle appropriate to the voltage available from the electrical power supply; measuring the voltage supplied from the electrical power supply during the charging cycle; calculating the voltage drop, which is the reduction in voltage during the charging cycle; comparing the voltage drop at the electrical power supply during the charging cycle with preset threshold data held in an electronic memory device; and in dependence on the electrical voltage drop at the power supply during the charging cycle, varying the current drawn by the power storage means from the electrical power supply so as to optimise the rate of charge whist not exceeding a pre-determined electrical voltage drop at the power supply.

In connection with the above method, advantageously, the method further comprises: calculating the rate of change of the voltage drop at the electrical power supply during the charging cycle; comparing the rate of change of the voltage drop at the electrical power supply during the charging cycle with preset threshold held in an electronic memory device; and in dependence on the rate of change of the voltage drop at the power supply during the charging cycle, varying the current drawn by the power storage means from the electrical power supply so as to optimise the rate of charge whilst not exceeding a pre-determined rate of change of the electrical voltage drop at the power supply.

In connection with the above method, advantageously, the power storage means is charged according to the following schedule: i) where a measured characteristic comprising temperature, rate of change of temperature, voltage drop, rate of change of voltage, or rate of charge of the power storage means exceeds a first threshold held in an electronic memory device, the charging current is reduced to a value greater than zero; and ii) where the measured characteristic rate falls below a second threshold held in an electronic memory device, the charging current is increased.

In an example, the temperature sensing means comprises multiple temperature sensors in the second plug, and the method further comprises: sampling all of temperatures detected by the multiple temperature sensors; and establishing a highest one of the temperatures as the temperature of the electrical connection.

In an example, the method further comprises: calculating a maximum charging current to be drawn by the power storage means from the electrical power supply by a predetermined calculating expression; and if the calculated maximum charging current is more than a rated current for the electrical connection, changing the calculated maximum charging current to the rated current during the charging cycle so as to maximize the rate of charge whilst not exceeding a predetermined electrical connection temperature.

In an example, the method further comprises: measuring the degree of either ageing or dirtiness about the electrical connection; and in dependence on the degree of either ageing or dirtiness about the electrical connection, varying the current drawn by the power storage means from the electrical power supply so as to maximize the rate of charge whilst not exceeding a predetermined electrical connection temperature.
It should be noted that the term "dirtiness" includes corrosion within its scope.

In an example, the control means is arranged to provide an indication to a user of the temperature of at least one electrical connection in dependence on the temperature data from the temperature sensing means.

In an example, the method further comprises measuring the voltage available from said electrical power supply; and the control means is arranged to provide an indication to a user of the supply voltage of the electrical power supply in dependence on the voltage data generated by the control means.

In an example, the method further comprises calculating the power available from said electrical power supply; and the control means is arranged to provide an indication to a user of the power available from the electrical power supply in dependence on the voltage data and controlled current data generated by the control means.

In an example, the method further comprises calculating the remaining charge time according to the state of charge of the power storage means and the power available from the electrical power supply; and the control means is arranged to provide an indication to a user of the remaining charge time of the power storage means.

In an example, the method further comprises comparing the power available from the socket of the electrical power supply with the rated power output of said socket; and the control means is arranged to provide an indication to a user of the condition of the electrical power supply socket in dependence on the comparison of available power to rated power.

In an example, one or both of the first and second plugs comprise status indicator means disposed so as to be visible or audible to a user and arranged to indicate data comprising any one of: a state of charge of a power storage means of the vehicle; a temperature of at least one of the first and second plugs and the first and second sockets; a duration of electrical connection between the electrical power supply and the vehicle; a cost of electricity used by the power storage means; customer identification details; vehicle identification details; and a maximum current drawn from the electrical power supply. Some of this data may be input manually by the user.

According to a further aspect of the present invention for which protection is sought, there is provided an electric vehicle power storage means charging system adapted to use a charging method according to any preceding paragraph.

According to a yet further aspect of the present invention for which protection is sought, there is provided an electric vehicle adapted to use a power storage means charging method or system according to any preceding paragraph.

Within the scope of this application it is envisaged that the various aspects, embodiments, examples, features and alternatives set out in the preceding paragraphs, in the claims and/or in the following description and drawings may be taken independently or in any combination thereof. In particular, features described in connection with one embodiment are applicable to the other embodiment, except where there is an incompatibility of features.

Brief Description of the Drawings

The present invention will now be described, by way of example only, with reference to the accompanying drawings in which:

Figure 1 shows a side view of an electric vehicle known in the art, along with a known charging plug, positioned adjacent to a corresponding vehicle mounted charging socket;

Figure 2 shows a known charging lead for connecting an electric vehicle to a suitably configured power outlet, the charging lead comprising a pair of identically configured charging plugs connected by a coiled length of flexible cable;

Figure 3 shows a detailed view of the pin layout of a plurality of electrically conductive elements within the known charging plug shown in Figure 1 and in Figure 2;

Figure 4 shows an adapter of a known type, arranged to convert one type of electrical connection to another to facilitate charging from a domestic power outlet;

Figure 5A shows a schematic view of a device according to an aspect of the present invention;

Figures 5B and 6A to 6C show schematic views of devices integrated into electrical connections according to another aspect of the present invention;

Figure 7 shows a schematic view of another example of an electrical connection according to an aspect of the present invention;

Figure 8 shows a schematic view of a vehicle charging system according to a further aspect of the present invention;

Figure 9 shows an example of a logic table for use with a vehicle charging system according to an aspect of the present invention;

Figure 10 shows a block diagram of a vehicle charging system according to a further aspect of the present invention;

Figure 11 shows a flow chart explain the operation of an EVSE in the vehicle charging system of Figure 10;

Figure 12A shows a graph representing a comparison of temporal changes in plug temperature according to the present invention with those of the prior art; and

Figure 12B shows another graph representing a comparison of temporal changes in plug current according to the present invention with those of the prior art.

While the examples given for suitable applications for the present invention relate to equipment for charging electrically powered vehicles, it will be appreciated by one skilled in the art that there are potentially other uses for the present invention unrelated to vehicles, where electric current may be supplied via a disconnectable connection such as power generators, telecommunications devices, compressors or air handler units. The present invention is equally suitable for use with single-phase and multi-phase alternating current AC electrical supplies, and may also be used with direct current DC supplies as desired.

Figure 1 shows an example of an electric vehicle 100 of the prior art, showing the location of a vehicle mounted charging socket 5 behind a hinged cover in the side of the vehicle 100. Also shown in the Figure is a charge connection in the form of a vehicle charge plug 3 of a known type being held by a user adjacent to the vehicle mounted charging socket 5. The vehicle charge plug 3 is arranged to supply electrical power from a power outlet (not shown) to a power storage means such as a battery (also not shown) mounted within the vehicle 100 via a length of electrically conductive cable 7. The charging plug 3 and cable 7 are shown in greater detail in Figure 2.

Figure 2 shows a known vehicle charging lead 2 for connecting an electric vehicle 100 to a suitably configured power outlet or charging point (not shown). In the example shown, the charging lead 2 has a pair of charge connections in the form of a charge point plug 4 and an identically configured vehicle charge plug 3, connected together by a coiled length of flexible cable 7. Each charge connection comprises an exterior surface configured to facilitate gripping by the user. This gripping portion or hand grip 3a, 4a is arranged to facilitate operation of the plug by hand. Each charge connection further comprises an insertion portion 3b, 4b, arranged to cooperate with an associated socket (as shown in figure 1), and a plurality of conductors 3c, 4c. Each conductor 4c within the charge point plug 4 is connected via separate conductive cores in the cable 7 to the corresponding conductors 3c in the vehicle connection 3.

Figure 3 shows an example of a known charge plug with an appropriate layout of conductors. In Europe a consortium of energy providers, local Government and vehicle manufacturers have been working towards a standardised set of specifications for such a plug, an example of which is shown in Figure 3. This example of a vehicle charge plug has been developed by Mennekes ® of Germany as an answer to the demand in the European marketplace for a standardised electric vehicle charging plug.

It may be seen from the Figure that the hand grip 3a of the vehicle charge plug 3 extends downwardly from the insertion portion 3b, arranged to support and at least partly surround the plurality of electrical conductors 3c. The electrical conductors 3c are arranged around a centrally positioned earth pin 3E and are spaced therefrom. It will be appreciated that the body of the hand grip 3a, the insertion portion 3b and the insulating portions 3i between the conductors 3c are formed at least in part from a plastics moulding so as to insulate the user from the electricity conducted by the conductors 3c in use. The charge plug may be formed as an assembly of parts or as a unitary moulding. It will also be noted that there are two lead lines from numeral 31, as the immediate surroundings of each conductor 3c, and the flat end face of the plug, both serve as insulators.

The layout of conductors 3c of the charge plug 3 shown in Figure 3 provides for up to a three-phase electrical connection via three live conductors 3Li, $3L_2$ and $3L_3$. In addition, there are provided an Earth pin 3E, a Neutral connection 3N, and two communications connections 3pp, 3cp. The communication connections comprise a connector 3pp arranged to determine that the plug 3 has been correctly connected to the vehicle 100, known as a plug present connector; and a connector 3cp arranged to permit electrical communication between the vehicle 100 and the power outlet in use, known as a control pilot connector.

In the vehicle charge plug 3 shown in the Figure, the insertion portion 3b is formed from a substantially cylindrical section body containing the electrical conductors 3c.

The outer surface of this cylindrical section is substantially circular in section, but is provided with a keyed section or flattened portion 3f, arranged to guide the user to correctly orientate the plug 3 into a correspondingly shaped vehicle-mounted charging socket 5 as shown in Figure 1. It will be appreciated by one skilled in the art that this keyed section may be provided at any point around the outer circumference of the insertion portion 3b, so long at its position corresponds with the conductors 3c correctly aligning with the corresponding conductors in the socket 5. In the example shown, the keyed section or flattened portion 3f is located at the top of the insertion portion 3b so that it may be readily visible and is thus intuitive to the user, guiding them as to the correct insertion orientation of the plug into the socket. Distal from the conductors 3c and the insertion portion 3b is the cable 7, shown depending from a lower portion of the hand grip 3a of the charge plug 3.

A drawback of the vehicle charging lead 2 shown in Figure 2, is that its charge point plug 4 is incompatible with a standard domestic power outlet socket. As such, the user must reconfigure the charging lead 2 to charge from a domestic power outlet by connecting an adapter to the charge point plug 4 so that the charging lead 2 is terminated by a standard domestic power plug 9 at one end and a charging plug 3 at the other.

Such an adapter is shown in Figure 4. Adapter 8 is arranged to facilitate vehicle charging via a standard domestic electrical power outlet (not shown). The adapter comprises a domestic power plug 9 arranged to cooperate with the standard domestic electrical socket used in the market in which the vehicle is to be used. The adapter further comprises an EVSE (Electric Vehicle Safety Unit) 6, arranged to cooperate with the charge point plug 4 of the vehicle charging lead 2 of Figure 2. A length of electrical cable 7a electrically connects the EVSE 6 and the domestic power plug 9. The adapter is used when a dedicated vehicle charging point is not available, and the user must therefore charge the vehicle 100 by connecting it to a standard domestic power outlet. Although a British Standard 13 amp, 3-pin plug is shown, any national or international mains power plug could be used here.

In the adapter 8 shown in Figure 4, the EVSE 6 comprises a receiving section 6b and conductors 6c arranged to cooperate with a Live conductor 4Li, a Neutral connection 4N and an Earth connection 4E of the charge point plug 4. The conductors of the charge point plug 4 are not shown in detail in the Figures, but are arranged substantially identically to those of the vehicle charge plug 3 shown in Figure 3. The receiving portion 6b is arranged to accommodate the insertion portion 4b of the charge point plug 4. The receiving portion 6b is further provided with an alignment guide (not shown, but similar to flattened portion 3f in Fig. 3) to ensure that the user correctly aligns the conductors of the plug 4 and socket 6 before use. The EVSE 6 may further comprise a grippable portion or handle (not shown) to allow it to be held while plug 4 is inserted into receiving portion 6b.

In view of the size and shape of the EVSE - approximately equivalent to a shoe box - an alternative embodiment, not shown in the Figures, may be considered to be preferable. In this case, the EVSE 6 has a further fly lead at the end of the unit distal from cable 7a, which connects to a socket compatible with plug 4. The EVSE is thus allowed to lie on the ground, avoiding the need to handle its weight and bulk while making and maintaining an electrical connection.

It will be appreciated that the standard domestic power outlet and associated power plug 9 are primarily intended for use with general domestic appliances, and are therefore not optimised for the relatively high current demand typically associated with charging electric vehicles. If the distance between the power outlet and the consumer unit of the residence is relatively long, it will result in significant electrical losses in the wiring. Such losses adversely affect the available rate of charge for the electrically powered vehicle, increasing recharge times.

Plugs and sockets used in conjunction with domestic power outlets have a rated maximum continuous current related to the electrical resistance of the plug and socket components. The voltage supplied to these domestic outlets may vary from one market to another or even within a single market. Such variation is relatively simple to accommodate from the point of view of a vehicle designer by measuring the voltage available from the outlet upon initial connection with the vehicle.

However, one variable that will affect charging of an electrically powered vehicle is the available current.

Over time, electrical components within the plug and socket tend to oxidize, increasing their electrical resistance and potentially resulting in damage due to excess heating during the charge cycle even if the rated current is not exceeded.

Even if the heating of the outlet is not sufficient to cause permanent damage, the temperature of the outlet may exceed what is comfortable for the user to handle. In this case, it may become uncomfortable or difficult for the user to disconnect the electrical connection once the vehicle charge cycle has been completed. Uncomfortably high temperatures do not normally result in any change of appearance of the outlet which would indicate this to the user. In this case, the user may inadvertently grasp the electrical connection or outlet and, upon feeling the temperature of the part, become concerned that there was a malfunction in the equipment.

In some cases, manufacturers of electric vehicles and their associated charging equipment manage the problem of excess heat build-up in the connection and outlet by limiting the charge current to a fraction of the rated charge current of the outlet. Whilst this does tend to keep the heat build-up in the connection and outlet within acceptable limits, it adversely affects the charging cycle time, which might otherwise be shorter if the charging current was not limited in this way. Whilst some users may not experience excess heating of the electrical connection or outlet during charging, especially if the outlet or electrical connection is not corroded, an extended charge cycle time may be a problem to users wishing to charge their vehicle quickly.

In the example of the adapter 8 shown in Figure 4, the domestic power plug 9 is of a standard form configured for connection to a single phase electrical supply and thus comprises a body portion or casing 9b within which three electrical conductors 9c are mounted, and protrude outwardly therefrom. The three electrical conductors 9c are required to provide the power plug 9 with separate conductors for Live, Neutral and Earth connections, interfacing with the typical domestic power outlet socket. The body portion 9b is generally square in cross section and arranged to facilitate manual connection to and disconnection from the electrical outlet. It is known to produce power plugs 9 as an assembly, screwed or clipped together once the plug 9 has been fitted to the cable **7a.** It is also known to over-mould the plug 9 onto the cable to produce a sealed, unitary component.

In order to keep the duration of the charging cycle to a minimum, the current drawn by the vehicle must be held as close as possible to the maximum rated current capacity of the power outlet. Any ramping up to or down from this maximum current value must be done as quickly as possible to permit the electrical power storage means, such as a battery of the vehicle, to draw sufficient charge as quickly as possible. Dedicated vehicle charging outlets are specifically configured to meet these current demands and are often direct current (DC) voltage rather than alternating current (AC) voltage to gain further benefits in reducing the charge cycle time. However, when relying on existing domestic electrical infrastructure, the distance from the electrical supply into the building and the condition of the electrical cables are often not optimised for such a potentially high current electrical load.

Where the power outlet and plug being used to charge the vehicle are in good condition, the power outlet and associated domestic power plug 9 may only become warm to the touch during the charge cycle. However, if the condition of the power outlet or plug is poor, the temperature of the domestic power plug 9 may increase to a level which may be uncomfortable for the user to handle. This may lead to a false perception that some component within the vehicle, charging lead or power outlet is unsafe; or that the electrical equipment in question is defective.

The present invention seeks to address these issues, whilst at the same time facilitating charge cycle times which are optimised for the power outlet being used. The present invention provides the benefit of being compatible with a plurality of vehicles, power outlet configurations and voltage supplies, and does not rely on access to a dedicated vehicle charging station.

Figure 5 shows devices 10 and 410 embodying two forms of the present invention. Figure 5a shows an example of the device 10 arranged for use with a typical three-pin mains voltage plug used for domestic electrical appliances in the United Kingdom. Figure 5b shows an example of the device 410 adapted for integration within an electrical connection such as a vehicle charge plug 3 or charge point plug 4 as shown in Figure 1 and in Figure 2. It will be appreciated that the shape and size of the device 410 may be readily adjusted to be accommodated within electrical plugs for use in other markets.

In the example shown in Figure 5a, the device 10 takes the form of a generally U-shaped plate 16 arranged to be accommodated at least partially within the body portion of a standard three-pin plug. The first leg 16i and second leg 16ii form a planar and substantially continuous 'U' shape configured to rest against an inner surface of a front face of the power plug.

The legs 16i, 16ii of the U-shaped plate 16 include respective apertures 16Na and 16La, through which the neutral and live conductors (also known as pins) of the plug are arranged to extend. A third aperture 16Ea is provided at the intersection or apex of the legs 16i, 16ii to accommodate the earth conductor of the plug. The apertures 16Na, 16Ea, and 16La are preferably sized and shaped so as to remain in thermal contact with the relevant electrical conductor within the power plug. However, only one of these three apertures should be in electrical contact with a conductor, the other apertures being electrically isolated to avoid short circuits.

The first and second legs 16i, 16ii of the plate 16 are arranged to support at least one temperature sensing means 12, in the form of a thermistor, thermocouple or other suitable device, in close proximity to at least one of the electrical conductors within the power plug (not shown). Alternatively, in further embodiments not shown in the Figures, the temperature sensor may be bonded directly to the live pin, or clamped by a crimp joint or screw terminal provided to anchor the live wire.

Associated with the temperature sensing means 12 is a communication means 14 for communicating temperature data to a controller (not shown). The temperature sensing means 12 is arranged to determine the temperature of the electrical conductor, and to transmit this temperature data via the communication means 14 to at least one of an electrical power supply and/or electrical load (not shown). Alternatively, the temperature sensing means may be arranged to measure the temperature of a part of the removable electrical plug or socket in which the device 10 is installed.

In the illustrated embodiment, the plate 16 also comprises a third leg 16iii extending generally orthogonally from the intersection of the first and second legs 16i, 16ii, adjacent to the aperture 16Ea. The third leg 16iii is curved at its free end so as to extend in a substantially planar configuration, parallel with the first and second legs 16i, 16ii and spaced therefrom. The tip 16T of the third leg 16iii is arranged to lie in close proximity with an inner surface of a rear face of the body portion of the plug, being the portion gripped by the user during connection to and disconnection from the power outlet. The tip 16T of the third leg 16iii may support a second temperature sensing means (not shown) for detecting the temperature of the external surfaces of the body portion of the plug. In this arrangement, the device 10 is capable of measuring the temperature of both the electrical conductors and an exterior surface such as a hand grip in use.

The temperature sensing means 12 may be passive, or may be supplied with power from the conductors within the plug. Alternatively, the temperature sensing means 12 may be powered via a connection to a vehicle, connected to the power outlet via the removable electrical connection. It is also envisaged that the temperature sensing means 12 may be powered by a low voltage battery (not shown), accommodated within the plug. Preferably, the battery would be rechargeable and may be recharged whenever an electrical current passes through the electrical connection during the charging cycle. In this way, the battery provides a back-up source of power for the temperature sensing means 12 if the power supply is temporarily interrupted.

It will be appreciated that the device 10 may be readily adapted for use in electrical connections of a more specialist nature, such as those intended for dedicated charging stations.

Figure 5b shows an example of a device 410 adapted for integration into an electrical connection such as charge point plug 400, shown in Figure 7. The body of plug 400 comprises three distinct elements, being a main body 405M, arranged to fit between the electrical conductors, an upper body 405U and a lower body 405L.

The upper body 405U is arranged to support a temperature sensing means 412U close to the outer surface of an insertion portion 400b formed in the electrical connection 400 as shown in Figure 7. The lower body 405L is arranged to support a temperature sensing means 412L close to the outer surface of a hand grip feature (400a, Fig. 7) formed in the electrical connection 400. Arranged around a substantially centrally positioned aperture 410Ea, configured to fit around an Earth connection in the electrical connection 400, is a third temperature sensing means 412E. Temperature sensing means 412E is supported by the main body 410M, and is positioned to facilitate reliable measurement of the temperature not only of the conductors in the electrical connection 400 in which the device 410 is accommodated; but also of the temperature of the power outlet to which said electrical connection is connected. Similarly, temperature sensing means 412U and 412L are positioned so as to facilitate reliable measurement of the surface temperature of external surfaces of the electrical connection 400 which the user may handle in use.

The main body 410M is provided with a plurality of apertures 4 1Oca, each aperture being arranged to accommodate a portion of an electrical conductor. Two additional apertures 410ppa and 410cpa are provided in the main body 410M to accommodate a portion of the plug present (pp) connector and the control pilot (cp) connector respectively.

The temperature sensing means are each in communication with a communication circuit 414 arranged to process temperature data measured by the temperature sensing means; and to communicate that data via one or more of the conductors in the electrical connection 400. In the example shown, temperature data is communicated to a charge controller (not shown) via the plug present (pp) and the control pilot (cp) lines as required.

Figure 6a shows a view through an electrical connection in the form of a power plug 90 in which a device 110 similar to the device 10 of Figure 5a is installed. A different reference numeral is used because it is envisaged that device 110 will have additional features such as screw holes which are not shown in device 10 in Figure 5a. In this example, the power plug 90 is of a type suitable for connection to a standard 13A domestic power outlet in the United Kingdom. Preferably, the device 110 is integrated into the electrical connection as an over-moulded part. However, it is envisaged that the device 110 may be fitted into the electrical connection as part of an assembly, arranged to be held together by threaded fasteners, clips, heat staking and/or adhesives as may be appropriate.

In the example, the power plug 90 comprises a cover 90a arranged to enclose a body portion 90b extending from a connector portion 90c arranged to support a plurality of electrical conductors 90cc, of which the live conductor 90L and the earth conductor 90E can be seen in this view (the neutral connector 90N being concealed behind live conductor 90L). In the example, the power plug 90 is shown with a cable 70 entering the body 90b of the plug 90. The cable 70 is secured to the plug 90, either by means of a clamp (70CL, Fig. 6b) or by over-moulding the plug 90 to the end of the cable 70 during manufacture.

It may be seen from the Figure that the plate 116 (similar to plate 16 in Fig. 5a) is arranged to lie against the inner surface of the front face of the plug 90 so as to be in close proximity with an outer surface of the outlet (not shown) into which the power plug 90 is inserted in use. It may also be seen from the Figure that the third leg 116iii of plate 116 is arranged to abut the inner surface of the cover 90a of the plug 90.

It is envisaged that the temperature sensing means 112 (not shown in Figure 6a) may be located at any suitable position on any of the legs 116i to 116iii of the device 110. Indeed, the device 110 may be arranged to support a plurality of temperature sensors so as to measure temperature changes at various locations within the plug in use, or to measure the difference in temperature between different positions around the connection as desired. Figure 6b shows a rear view of the plug 90 of Figure 6a, and shows the device 110 in situ. Numeral 70CL denotes a cable clamp for cable 70. Numeral 90F denotes a fuse fitted to live terminal 90L.

Figure 6c shows another example 210 of a device according to an aspect of the present invention. The device 210 is shown accommodated within a power plug 290 having a form identical to that of plug 90 of Figures 6a and 6b. The device 210 is similar to the device 110 shown in Figure 6b in that it has a substantially 'U' shaped form. As with the device 110 of Figure 6b, the device 210 is arranged to abut, or to be integrally formed with, a connector portion 290c of the plug 290. The plug 290 comprises a plurality of electrical conductors, providing Neutral (290N), Earth (290E) and Live (290L) electrical conductors in use.

A single temperature sensing means 212 is located between one of the electrical conductors 290N (as shown) or 290L and the Earth conductor 290E; and is located adjacent to communication means 214. The communication means 214 is arranged to send temperature data via a data line 214a. The data line 214a is provided by a conductive core forming part of a main cable 270 arranged to connect the plug 290 to an electrical load such as an electric vehicle or to a controller (not shown).

Figure 7 shows the device 410 of Figure 5b integrated into an electrical connection 400. The connection 400 comprises a hand grip 400a, an insertion portion 400b, and a plurality of conductors 400c. It may be seen from the Figure, that the temperature sensing means 412U, 412L and 412E are positioned to measure the surface temperatures of the upper and lower parts of the hand grip 400a and the temperature of the conductors 400c respectively.

Figure 8 shows an example of a vehicle charging system 700 according to a further aspect of the present invention. The vehicle charging system 700 comprises a vehicle charging plug 3 connected by a length of electrically conductive cable 7 to a charge point connection 400. The charge point connection 400 comprises a device 410 as described in the preceding paragraphs and according to an aspect of the present invention. The vehicle charging plug 3 is shown in engagement with the vehicle 200 via the vehicle mounted charging socket 5. The charge point connection 400 is shown being positioned for insertion into a power outlet at a vehicle charging station 44.

In the example shown, a controller 77 is integrated into the vehicle charging system 700. The controller 77 may be integrated into the charge point connection 400 or into an in-line receptacle located along the length of the electrically conductive cable 7. The controller 77 comprises a microprocessor 75 configured to monitor temperature data from any temperature sensing means in operation within the charge point connection 400. The microprocessor 75 of the controller 77 is further configured to limit the electrical current drawn by the vehicle 200 during a charge cycle in dependence on the temperature data received from said temperature sensing means.

In the example, the vehicle charging system 700 comprises at least a section of cable capable of communicating temperature data to the controller 77. This section of cable, shown generally at 70a, may be limited between the charge point connection 400 and the controller 77; or may run the full length of the cable 7 so as to permit monitoring of the temperature data by systems on-board the vehicle 1.

The charge point connection 400 shown in the example is provided with an integrated means of indicating the status of at least one parameter of the charge point connection 400. An integrated status indicator 450 may be provided by a visible or audible indication to the user. It is envisaged that this status indicator will be provided by at least one of the following: a light emitting diode LED, a display comprising a plurality of LED's, a liquid crystal display LCD, or a sound emitting device such as a buzzer. The status indicator 450 is arranged to warn the user if the temperature of an exterior surface of the charge point connection 400 exceeds a pre-determined threshold. Depending on the configuration of the controller 77, the status indicator may also be arranged to display information such as the maximum charging current drawn during the charge cycle, the duration of the charge cycle and whether the controller 77 imposed a limit on the charging current due to excessive heating of the charge point connector 400.

Figure 9 shows an example of a logic table used by the controller 77 of the vehicle charging system 700 of Figure 8. In this example, the microprocessor 75 within the controller 77 is provided with a memory in which to store the logic table shown.

The logic table is used by the controller 77 to control the status indicator 450 and the current drawn during the charging cycle in dependence on the temperature of the charge-point connection. The controller 77 is activated upon initiation of the charge cycle; the charge cycle being initiated once the vehicle 200 and power outlet 44 are correctly connected by the vehicle charging system 700.

In this example, the controller 77 monitors the surface temperature of the charge-point connection, and uses four bands of increasing temperature upon which to make a decision. The first temperature band, band 1 represents a surface temperature of up to approximately 25°C. Band 2 represents a surface temperature up to approximately 45°C. Band 3 ranges up to around 60°C; while a surface temperature over 60°C falls into band 4. In practice, some hysteresis would be built in, for example switching from band 1 to band 2 at 23-27°C, so that the controller is not switching continuously.

It may be seen from the table that the controller 77 takes no action to limit the flow of current to the vehicle 200 up to the temperature limit of band 2. Instead, the controller 77 drives the status indicator 450 to provide an indication to the user as to the temperature of the charge-point connection and/or the state of charge of the vehicle 1. If the surface temperature of the charge-point connection rises to temperature band 3, the controller 77 will incrementally limit the current drawn until the temperature falls back within temperature band 2; then slowly increases the current drawn until the measured temperature remains constant. At this point, the controller 77 determines that the maximum current is being drawn from the power outlet 44 in use when the temperature of the charge-point connector remains within acceptable limits for comfort.

If the surface temperature of the charge-point connection rises quickly during the charging cycle, the surface temperature may exceed the limits of band 3. Alternatively, the controller 77 may predict that, given the rate of change of temperature, measured by the temperature sensing means in the charge-point connection, there is a significant probability of an electrical fault in the outlet 44. At which point, even if the measured surface temperature does not exceed band 3, the controller will immediately shut-down the charging cycle and generate an appropriate warning via the status indicator, such as flashing red to indicate a fault.

It is envisaged that the controller is arranged to wait until the surface temperature of the charge-point connection falls within temperature band 2 before attempting to re-initialize a charging cycle. If the same fault occurs more than a pre-determined number of times, the controller 77 may be arranged to notify the vehicle 200 which may be equipped with means to notify the user, by generating an automated message to the user via a text message or E-mail etc.

In an embodiment of the present invention, the controller 77 is arranged to monitor the temperature data and the supply voltage provided by the power outlet 44 during the charge cycle. In this case, once activated, the controller 77 is arranged to measure the voltage available from the power outlet 44 before permitting current flow. The controller 77 then stores the initial temperature reading from each temperature sensing means to determine the temperature of the charge-point connection. A charge controller (not shown) will determine the available voltage from the power outlet 44 and identify the active conductors in the vehicle charge plug. The appropriate charging current and an appropriate charging cycle will then commence.

During the charging cycle, the controller 77 monitors the voltage supplied by the power outlet 44 and measures the temperature data from the temperature sensing means in the charge-point connection. The controller 77 compares: the voltage drop at the power outlet 44; the rate of charge of said power storage means; and the change in temperature of the charge-point connection during the charging cycle with a list of charging profiles held in the memory. In dependence on the rate of change of the voltage drop at the power outlet 44 and temperature of the charge-point connection during the charging cycle, the controller 77 is arranged to vary the current drawn by the vehicle from the electrical power supply, so as to optimise the rate of charge whilst not exceeding a pre-determined temperature threshold of the charge-point connection.

Figure 10 is a block diagram showing the constitution of a vehicle charging system 800 according to a further aspect of the present invention. Similarly to the vehicle charging system 700 of Figure 8, the vehicle charging system 800 comprises a vehicle charging plug 3 connected by a length of electrically conductive cable 7 to a charge point connection 400 as the second plug of the invention. The vehicle charging plug 3 as the first plug of the invention is shown in engagement with the vehicle 200 via the vehicle mounted charging socket 5. The charge point connection 400 is shown being positioned for insertion into a power outlet at a vehicle charging station 44. As described with reference to Figure 7, the charge point connection 400 contains the temperature sensing means 412U, 412L and 412E in the form of multiple temperature sensors. The temperature sensing means 412U, 412L and 412E are positioned to measure the surface temperatures of the upper and lower parts of the hand grip 400a (Figure 7) and the temperature of the conductors 400c (Figure 7), respectively.

In the example shown, the vehicle charging system 800 further includes a controller 87 as an electric vehicle supply equipment (EVSE), which is connected to both the charge point connection 400 and the vehicle charging plug 3 through the conductive cable 7. The controller 87 includes a signal generator 81 for generating pulse signals corresponding to a rated current to be fed to the electric vehicle 200 through the conductive cable 7, a power switch 82 for cutting off the conductive cable 7 for preventing earth leakage and overcurrent during the charge cycle, current detecting means 83 for detecting current flowing through the conductive cable 7 during the charging cycle, indicators 84 (as user interface) for informing a user of the present system's charging status (e.g. ready, charge or fault) and a microcontroller 85 for controlling the operation of the signal generator 81 and also ON/OFF state of the power switch 83 based on plug temperatures detected by the temperature sensing means 412U, 421L and 412E and charging current by the current detecting means 83 during the charging cycle.

The signal generator 81 includes a CPU (Central Processing Unit) driven by electric power supplied from an outside power source such as the power outlet 44, ROM (Read Only Memory) and RAM (Random Access Memory) and an oscillator for generating pulse signals, although they are not shown in the figure. The pulse signals generated by the signal generator 81 are outputted to a charging control device (not shown) provided in the electric vehicle 200 through a control pilot line 71. The control pilot line 71 serves as a communication line between the controller 87 of the vehicle charge system 800 and the charge control device on the side of the electric vehicle 200. Also, the control pilot line 71 allows the controller 87 to inform the charging control device of the electric vehicle 200 of how much current is available. In arrangement, the control pilot line 71 may be incorporated into the conductive cable 7.

Next, the operation of the controller 87 in case of charging the electric vehicle 200 through the conductive cable will be described with reference to Figures 11, 12a and 12b. Figure 11 is a flow chart explaining the operation of the controller 87 to maintain a plug temperature of the charge point connection 400 (i.e. the second plug) close to a predetermined temperature, such as a comfortable temperature for a user to handle the second plug in charging the electric vehicle 200, and also maintain a plug current flowing through the second plug in charging within a predetermined range, for example, current between a maximum rated current for the second plug and a minimum current.

Note, a routine represented by the flow chart of Figure 11 is executed by the microcontroller 85 at regular intervals (loop time), for example, every 0.5 seconds to detect the plug temperature of the second plug. Additionally, a program for executing the operation of Figure 11 is stored in a predetermined area in the microcontroller 85.

As shown in Figure 8, when the charge point connection 400 is connected to the power outlet 44, the controller 87 is energized to start the charging operation of the vehicle charging system 800, so that the routine of Figure 11 is started. By way of example, a maximum comfortable temperature T_{com} as the target temperature is preset at e.g. 55 °C for this algorithm. During the charging operation, by the flow chart of Figure 11, the charge current will be increased until the target temperature is reached or the above maximum rated current is reached.

When the routine is started, it is executed at step S301 to set variables used in this program to initial values (e.g. 0). As the variables, the illustrated calculation program contains two variables, that is, one is an error (i.e. difference between the detected plug temperature T and the maximum comfort temperature T_{com}) obtained in the previous routine, which will be referred to as "previous error" and the other is a cumulative value of such an error, which will be referred to as "integral", after.

After setting variables to initial values, then the routine goes to step S302. At step S302, a not-shown timer to count up the loop time (e.g. 0.5 second) is reset to zero and additionally, the present plug temperature is measured by the temperature sensing means 412U, 421L and 412E. As for the detection of the present plug temperature, if multiple temperature sensors are accommodated in one plug (as the second plug of Figure 7), all of temperatures detected by the sensors may be sampled and thereupon, the highest temperature may be adopted in the following calculation.
That is, if it is required to control the outside temperature of the plug in view of improving a user's comfort, some sensors are arranged nearer to the outside of the plug. In such a case, the system has to scale each of the temperature readings from respective sensors and choose the highest one.

At step S302, it is further executed to calculate an error (difference) between the maximum comfort temperature T_{com} and the present plug temperature measured and determined in the above way.

At next step S303, a new integral value of error in this routine is calculated by multiplying the error calculated at step S302 by the loop time and then, the so-calculated integral value is added to the integral value of errors accumulated in the past routines. As for this integral, it is noted that if the detected temperature T is near the comfort temperature T_{com}, the integral will serve to adjust the charging current to make the present temperature become closer to the comfort temperature T_{com} with time, until they (temperatures T and T_{com}) are both together.

At step S304, it is executed to calculate the rate of a change from the error obtained in the previous routine to the error obtained at step S302 in this routine by the following calculation:

"derivative" = (error - previous error) / loop time ····(1)

wherein "derivative" is a slope of a curve shown in Figure 12A; and
"loop time" is a time interval when a sample from the temperature sensor is taken.

Here, it is noted that the "derivative" serves to moderate the rise of the curve of Figure 12A to make it fast when the detected plug temperature T is relatively far from the maximum comfort temperature T_{com}, and to slow the rise down to prevent an overshoot of temperature when the detected plug temperature T is close to the maximum comfort temperature T_{com},

At next step S305, it is executed to calculate a new charge current as the target charge current to be controlled by the controller 87 of the vehicle charge system 800 from the variables of "error", "integral" and "derivative" obtained at the preceding steps in this routine by the following calculation:

$$\text{new current} = k_1 \times \text{"error"} + k_2 \times \text{"integral"} + k_3 \times \text{"derivative"} \quad \cdots\cdots (2)$$

wherein, ki is a proportional scaler (constant);
k_2 is a integral scaler (constant); and
k_3 is a derivative scaler (constant).

Here, it is noted that three scalers in the above calculation (2) are constants that reduce the effect of each element (i.e. error, integral, derivative) on the output current. This calculation is used to tune the behavior of this algorithm to suit the vehicle charge system 800.

After the new charge current is calculated in the above way, the routine goes to step S306. At sequent steps, it is executed to compare the so-calculated new charge current with the maximum rated current (e.g. 13A) and the minimum current (e.g. 6A) preset for the second plug. In detail, at step S306, it is executed to judge whether the new charge current as the target current is more than the maximum rated current or not. If the judgment at step S306 is Yes, that is, when the new charge current is more than the maximum rated current, then the routine goes to step S307 where the new charge current is changed to the maximum rated current to prevent overshoot of the charge current.

On the contrary, if the judgment at step S306 is No, then the routine goes to step S308. At step S308, it is executed to judge whether the new charge current as the target current is less than the minimum current or not. If the judgment at step S308 is Yes, then the routine goes to step S309 where the charging operation of the vehicle charge system 800 is shut down by turning off the power switch 82 since there is a possibility that the system 800 is under fault condition due to loss of temperature control at the minimum current.

If the judgment at step S308 is No, that is, when it is expected that the calculated new charge current is within a predetermined current range between the maximum rated current (e.g. 13A) and the minimum current for the second plug, then the routine goes to step S310. At step S310, it is executed to replace the previous error by the above error obtained at step S302 in this routine and also to send the information about the calculated new charge current from the microcontroller 85 to the signal generator 81 as PWM generator. Then, receiving the information about the new charge current as the target current, the signal generator 81 generates the pulse signals to the charging control device in the electric vehicle 200 through the control pilot line 71.

At next step S311, it is executed to judge whether the loop time (e.g. 0.5 sec.) has been reached by executing this routine or not. If the judgment at step S311 is No, that is, when the loop time has not been reached yet, then the judgment at step S311 will be repeated until the loop time is reached.

If it is judged that the loop time has been reached (Yes at step S311), then the routine returns to step S302 where the next routine is started.

As for the maximum charging current used at step S306, it is noted that there is a possibility that the maximum charging current is set above the rated plug (or socket) current, for example, 20 Amp or 30 Amp for the maximum charging current despite a rated plug (or socket) current of 15 Amp. In such a situation, however, the vehicle charge system is preferably constructed so as to match to the capability of the plug (socket), that is, resetting of the maximum charging current equal to or less than the rated plug (socket) current. In other words, although the above situation is normally acceptable, this situation may be controlled so as to attain a much faster charging in most cases with the temperature control algorithm of the embodiment. Generally, if much electric power is charged to the electric vehicle during the charging cycle, then any plug (socket) would be overheated. However, according to the invention, as the heating of the plug is controlled, the rate of charge can be maximized whilst not exceeding the maximum comfort temperature.

Figures *12A* shows an example of temporal change in the plug temperature according to the above-mentioned embodiment, while Figure 12B shows an example of temporal change in the plug current corresponding to the plug temperature shown in Figure 12A.

In Figure 1*2A*, an uppermost broken line at 60°C denotes a maximum safe temperature as the plug temperature, while an intermediate broken line at 55°C denotes the maximum comfort temperature as the target temperature. The behavior of the plug temperature accomplished by the above-mentioned algorithm of the embodiment is indicated with a solid line.

In Figure 12B, an uppermost broken line at 13 amps denotes a maximum rated plug current, while a solid line denotes an example of change in the plug current according to the above-mentioned embodiment.

From these figures, it will be understood that as the plug temperature approaches the maximum comfort temperature, the plug current as the target is gradually reduced from the maximum plug rated current, so that the inclination of a solid-line curve of Figure 12A (i.e. "derivative" in the flow chart of Figure 11) is weakened in view of preventing an overshoot of the plug temperature. Additionally, after the maximum comfort temperature has been reached, an actual plug temperature is substantially maintained at the maximum comfort temperature by controlling the plug current through the signal generator 81.

For comparison, Figures 12A and 12B also incorporate the temporal changes in both plug temperature and plug current according to two kinds of vehicle charge systems in prior art. In these prior art systems, once the detected plug temperature exceeds the maximum comfort temperature, the operation of the system is either shut down or controlled so as to reduce the plug current to a predetermined current far from the maximum rated current. Accordingly, it is expected, due to such an extremely-reduced plug current, the charging time for each charging cycle is remarkably long in comparison with that of the present invention, causing the charging efficiency of the system to be reduced. Figures 12A and 12B show temperature and current variation for the first ten minutes of charging, to clearly show the effects of current control. The applicant has determined that over a typical overnight charging time of ten hours, the method according to the invention typically allows 25.3kWh (kilowatt hours) of energy to be transferred from an electricity supply to an EV battery. The Prior Art 1 method allows 16.2kWh to be transferred, while the Prior Art 2 method allows just 0.15kWh to be transferred.

In the above embodiment, the illustrated algorithm is contemplated so as to maximize the rate of charging whilst not exceeding the maximum comfort temperature for the second plug. In a variation, the algorithm may be modified so as to automatically adjust the charging current in dependence on the degree of ageing or dirtiness of the plug (and socket) on use. Then, with the modification of the algorithm, the charging current could be always maximized and additionally, the charging time would be minimized as much as possible. It should be noted that the term "dirtiness" includes corrosion within its scope.

It will be appreciated by one skilled in the art that aspects of the present invention may be adapted to equipment arranged to comply with existing and future regulations relating to the charging of electrical vehicles. An example of which would be the IEC Regulations, concerning current control during the charging cycle and specifically defining modes of current control during charging. It will be appreciated that the device and associated temperature sensing means may be integrated into a mains electric socket, into the charging lead, or into alternative arrangements of in-line and vehicle mounted electrical connections. Furthermore, the invention may be applied to other high current electrical equipment, for reasons of comfort, user confidence, and/or safety.

Other advantages will be apparent to one skilled in the art and the present examples and embodiments are to be considered illustrative and not restrictive. The invention is not to be limited to the details given herein, but may be modified within the scope and equivalence of the appended claims.

For example, although data line 214a and communication circuit 414 are shown as electrical cables, the signals sent therethrough could be converted to light signals, and communicated via fibre optic cables. Alternatively, data could be transmitted by radio signals. Furthermore, the EVSE unit 6 shown in Figure 4 may contain the controller 77 of Figure 8, or vice versa.

CLAIMS

1. A method of charging a power storage means of a vehicle using a charging system comprising the following electrical connections:

a first plug arranged to cooperate with a corresponding first socket mounted on a vehicle;

a second plug arranged to cooperate with a corresponding second socket of an electrical power supply; and

a cable connecting the first and second plugs;

the charging system also comprising at least one control means comprising an electronic memory device;

wherein at least one of the electrical connections comprises temperature sensing means, and support means for supporting the temperature sensing means in close proximity to at least one electrical conductor within said electrical connection;

the method comprising:

measuring the temperature of the at least one electrical connection during the charging cycle;

comparing the temperature of the electrical connection during the charging cycle with preset threshold data held in the electronic memory device; and

in dependence on the temperature of the electrical connection during the charging cycle, varying the current drawn by the power storage means from the electrical power supply so as to maximize the rate of charge whilst not exceeding a pre-determined electrical connection temperature.

2. A method according to claim 1, wherein the electrical connection comprising temperature sensing means is the second plug.

3. A method according to claim 1 or claim 2, wherein the pre-determined electrical connection temperature is a maximum safe temperature, which has been determined to be a maximum temperature at which unguarded human skin can touch an electrical connection without damage to said unguarded human skin.

4. A method according to claim 1 or claim 2, wherein the pre-determined electrical connection temperature is a maximum comfort temperature, which has been

determined to be a maximum temperature at which unguarded human skin can comfortably touch an electrical connection without incurring an unacceptable level of pain.

5. A method according to claim 1 or claim 2, wherein the pre-determined electrical connection temperature is an intermediate maximum temperature between the maximum safe temperature according to claim 3 and the maximum comfort temperature according to claim 4.

6. A method according to claim 5, wherein the current drawn by the power storage means from the electrical power supply is controlled by the control means so that the electrical connection temperature is allowed to oscillate between the intermediate maximum temperature according to claim 5 and the maximum comfort temperature according to claim 4.

7. A method according to claim 6, wherein the current drawn by the power storage means from the electrical power supply is controlled by the control means so that the electrical connection temperature has a mean temperature corresponding to the maximum comfort temperature according to claim 4.

8. A method according to any preceding claim, wherein the method further comprises:

measuring the temperature of the at least one electrical connection before initiating a charging cycle;

measuring a rate of change of the temperature of the electrical connection;

comparing the rate of change of the temperature of the electrical connection during the charging cycle with preset threshold data held in an electronic memory device; and

varying the current drawn by the power storage means from the electrical power supply in dependence on the rate of change of temperature of the electrical connection during the charging cycle so as to maximize the rate of charge whilst not exceeding a pre-determined electrical connection temperature.

9. A method according to any preceding claim, wherein the method further comprises:

measuring the voltage available from said electrical power supply;

initiating said charging cycle appropriate to the voltage available from the electrical power supply;

measuring the voltage supplied from the electrical power supply during the charging cycle;

calculating the voltage drop, which is the reduction in voltage during the charging cycle;

comparing the voltage drop at the electrical power supply during the charging cycle with preset threshold data held in an electronic memory device; and

in dependence on the electrical voltage drop at the power supply during the charging cycle, varying the current drawn by the power storage means from the electrical power supply so as to optimise the rate of charge whist not exceeding a pre-determined electrical voltage drop at the power supply.

10. A method according to claim 9, wherein the method further comprises:

calculating the rate of change of the voltage drop at the electrical power supply during the charging cycle;

comparing the rate of change of the voltage drop at the electrical power supply during the charging cycle with preset threshold held in an electronic memory device; and

in dependence on the rate of change of the voltage drop at the power supply during the charging cycle, varying the current drawn by the power storage means from the electrical power supply so as to optimise the rate of charge whilst not exceeding a pre-determined rate of change of the electrical voltage drop at the power supply.

11. A method according to any preceding claim, wherein the power storage means is charged according to the following schedule:

i) where a measured characteristic comprising temperature, rate of change of temperature, voltage drop, rate of change of voltage, or rate of charge of the power storage means exceeds a first threshold held in an electronic memory device, the charging current is reduced to a value greater than zero; and

ii) where the measured characteristic rate falls below a second threshold held in an electronic memory device, the charging current is increased.

12. A method according to claim 2, wherein the temperature sensing means

comprises multiple temperature sensors in the second plug, and the method further comprises:

sampling all of temperatures detected by the multiple temperature sensors; and

establishing a highest one of the temperatures as the temperature of the electrical connection.

13. A method according to any preceding claim, wherein the method further comprises:

calculating a maximum charging current to be drawn by the power storage means from the electrical power supply by a predetermined calculating expression; and

if the calculated maximum charging current is more than a rated current for the electrical connection, changing the calculated maximum charging current to the rated current during the charging cycle so as to maximize the rate of charge whilst not exceeding a predetermined electrical connection temperature.

14. A method according to claim 1, wherein the method further comprises:

measuring the degree of either ageing or dirtiness about the electrical connection; and

in dependence on the degree of either ageing or dirtiness about the electrical connection, varying the current drawn by the power storage means from the electrical power supply so as to maximize the rate of charge whilst not exceeding a predetermined electrical connection temperature.

15. A method according to any preceding claim, wherein the control means is arranged to provide an indication to a user of the temperature of at least one electrical connection in dependence on the temperature data from the temperature sensing means.

16. A method according to any preceding claim, wherein the method further comprises measuring the voltage available from said electrical power supply; and wherein the control means is arranged to provide an indication to a user of the supply voltage of the electrical power supply in dependence on the voltage data generated by the control means.

17. A method according to claim 16, wherein the method further comprises

calculating the power available from said electrical power supply; and wherein the control means is arranged to provide an indication to a user of the power available from the electrical power supply in dependence on the voltage data and controlled current data generated by the control means.

18. A method according to claim 17, wherein the method further comprises calculating the remaining charge time according to the state of charge of the power storage means and the power available from the electrical power supply; and wherein the control means is arranged to provide an indication to a user of the remaining charge time of the power storage means.

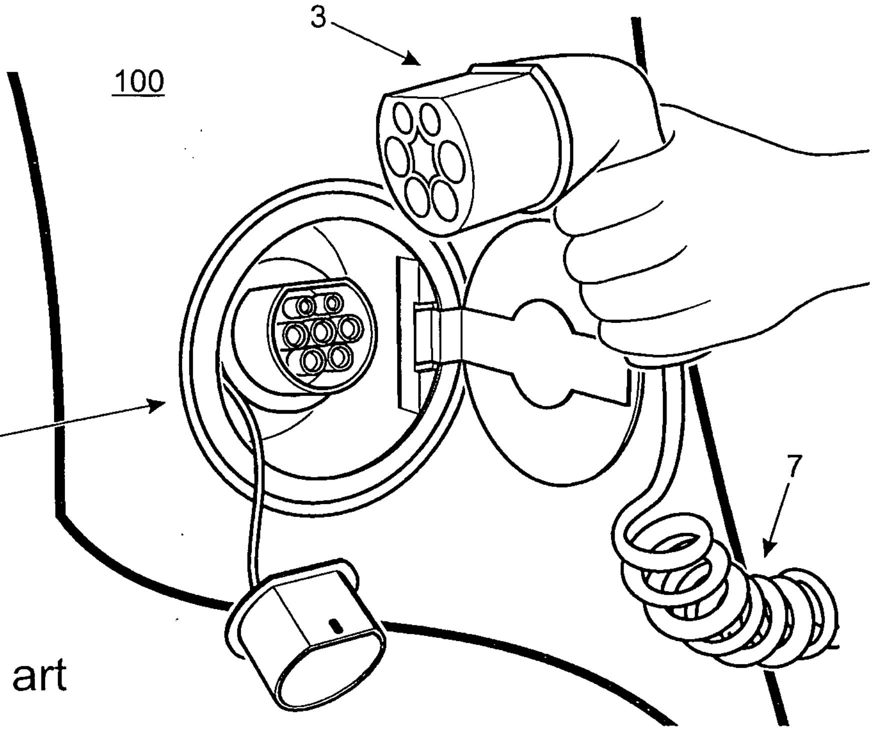
19. A method according to claim 17 or claim 18, wherein the method further comprises comparing the power available from the socket of the electrical power supply with the rated power output of said socket; and wherein the control means is arranged to provide an indication to a user of the condition of the electrical power supply socket in dependence on the comparison of available power to rated power.

20. A method as claimed in any preceding claim, wherein one or both of the first and second plugs comprise status indicator means disposed so as to be visible or audible to a user and arranged to indicate data comprising any one of: a state of charge of a power storage means of the vehicle; a temperature of at least one of the first and second plugs and the first and second sockets; a duration of electrical connection between the electrical power supply and the vehicle; a cost of electricity used by the power storage means; customer identification details; vehicle identification details; and a maximum current drawn from the electrical power supply.

21. An electric vehicle power storage means charging system adapted to use a charging method according to any preceding claim.

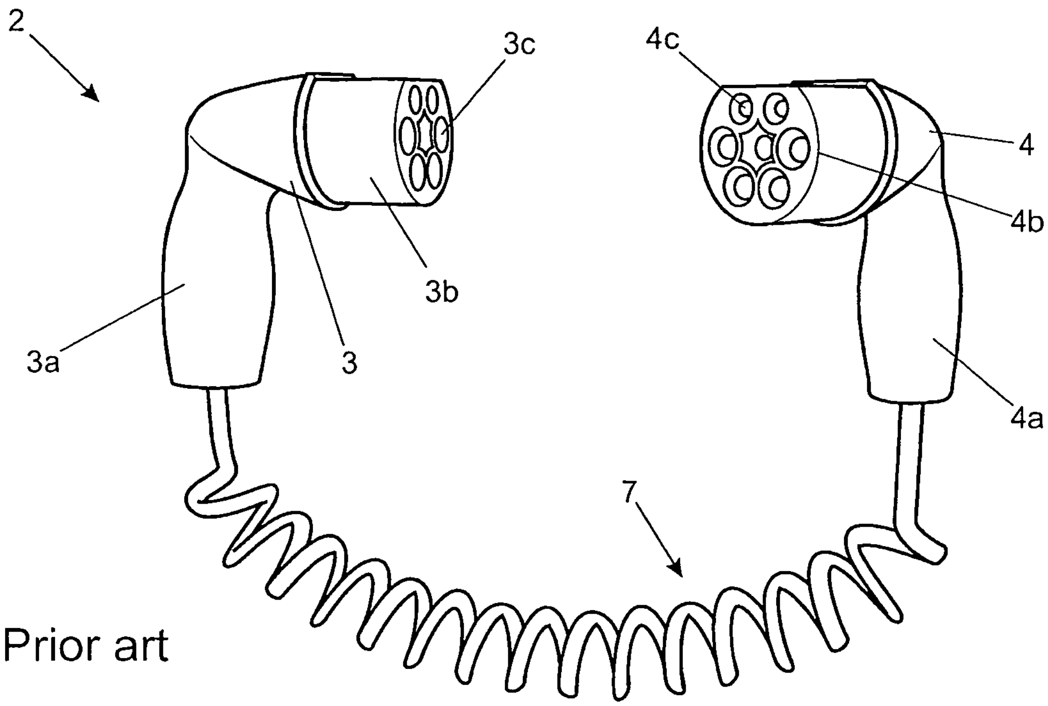
22. An electric vehicle adapted to use a power storage means charging method or system according to any preceding claim.

[DRAWINGS]
[FIG. 1]



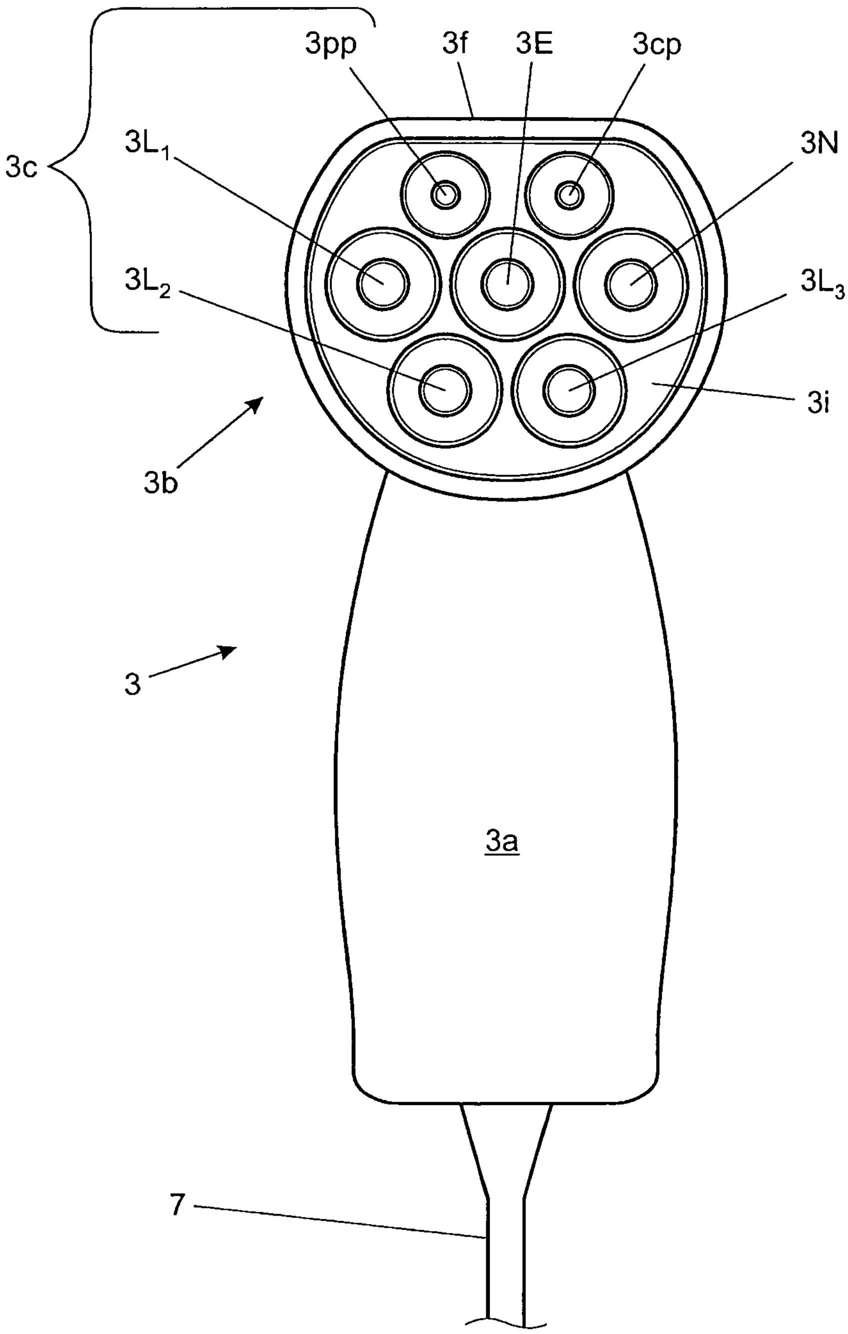
Prior art

[FIG. 2]



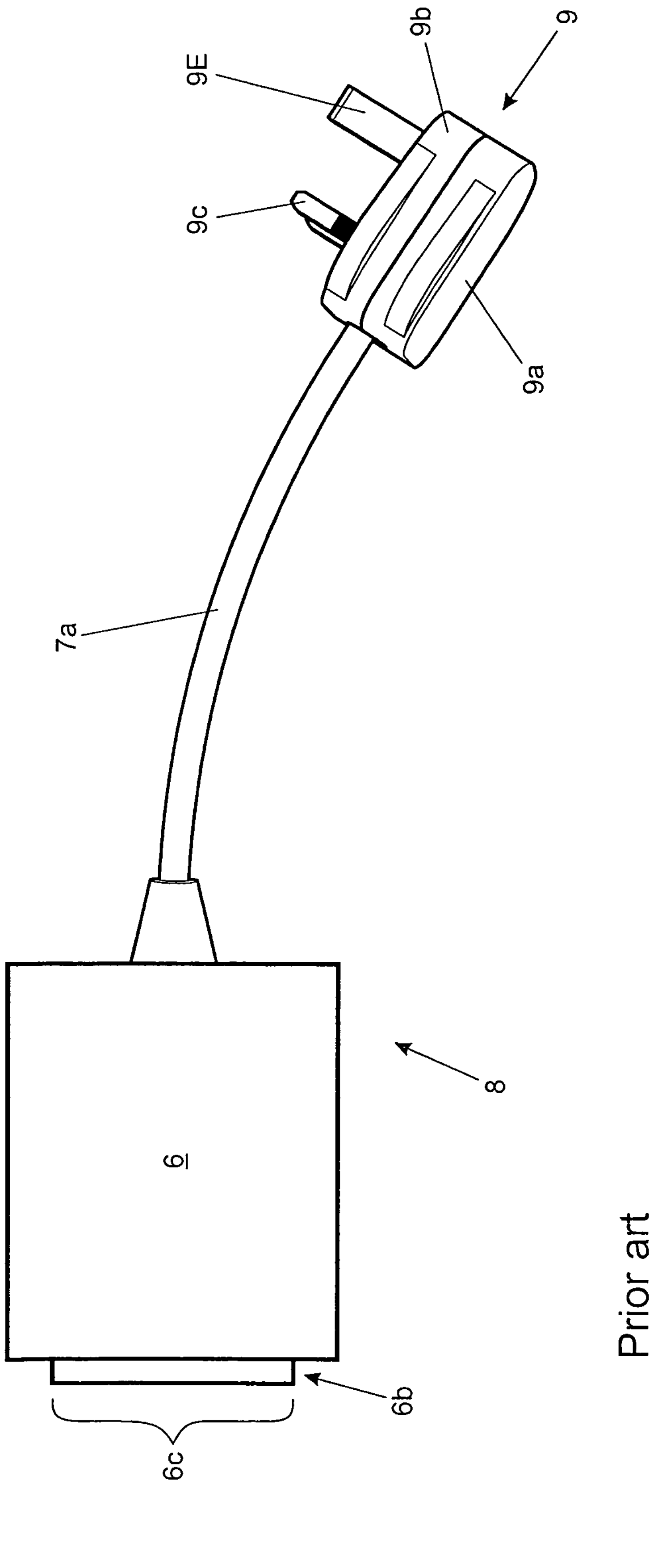
Prior art

[FIG. 3]

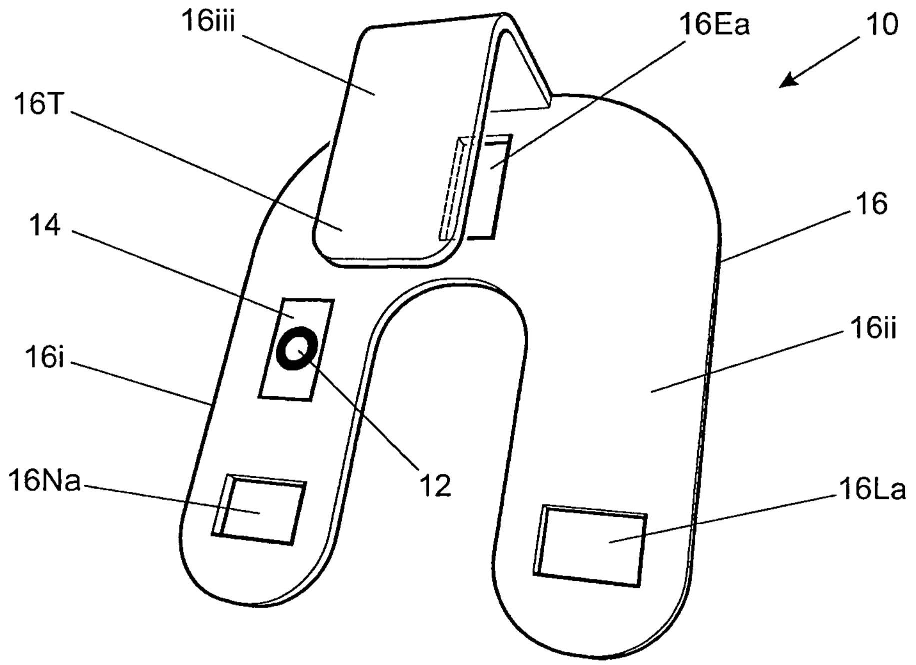


Prior art

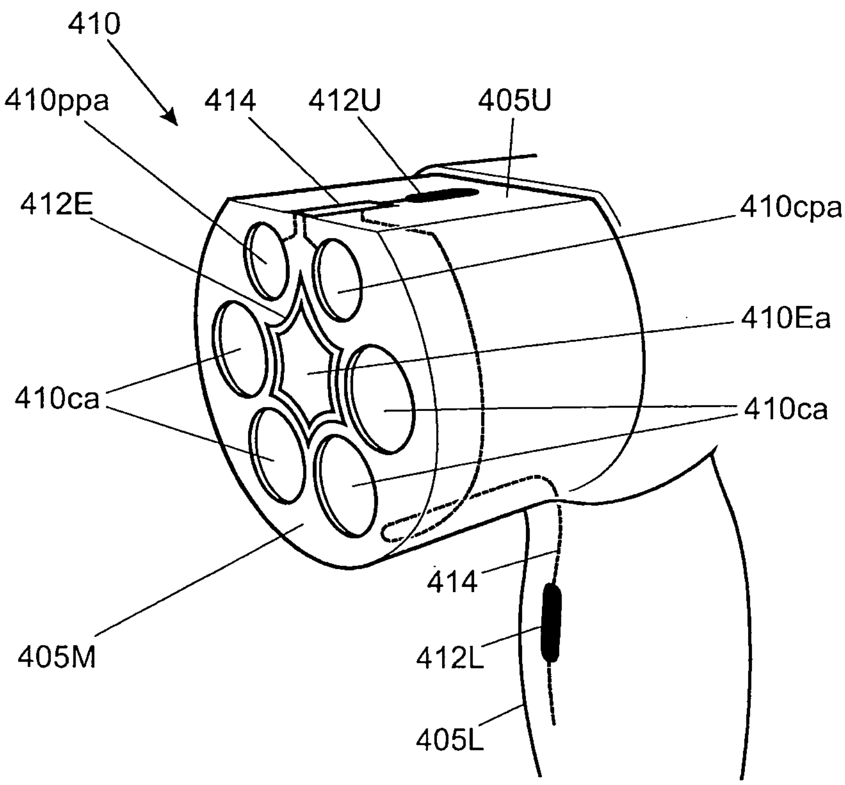
[FIG. 4]



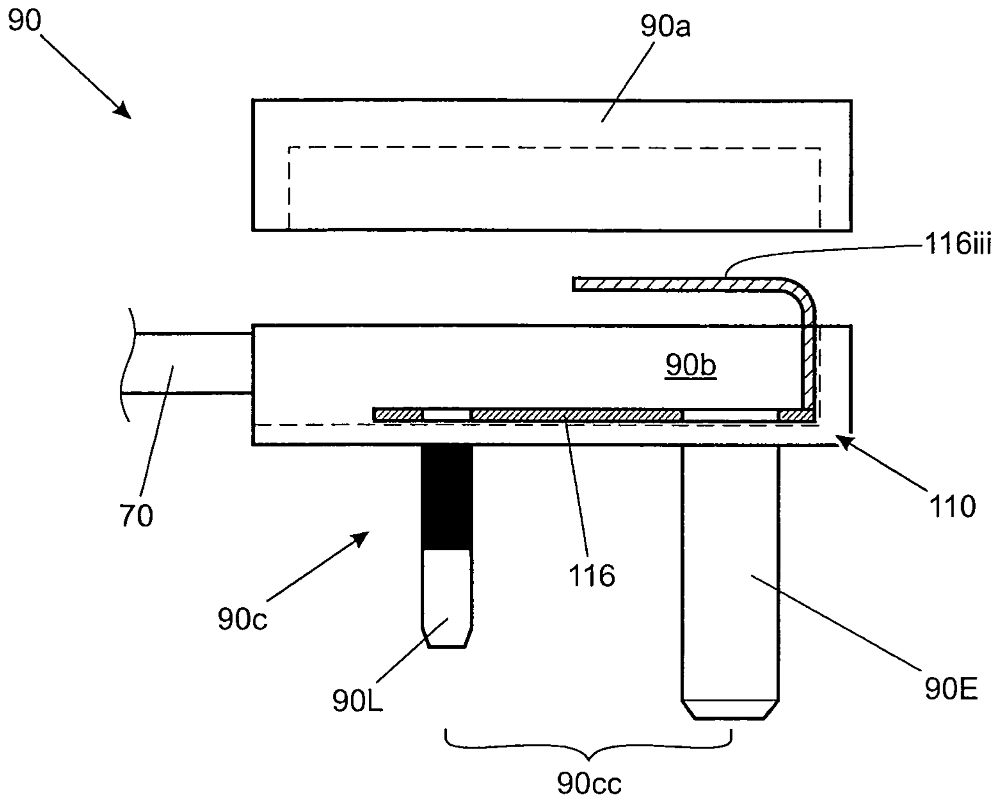
[FIG. 5A]


16iii
16Ea
10
16T
16
14
16ii
16i
12
16Na
16La

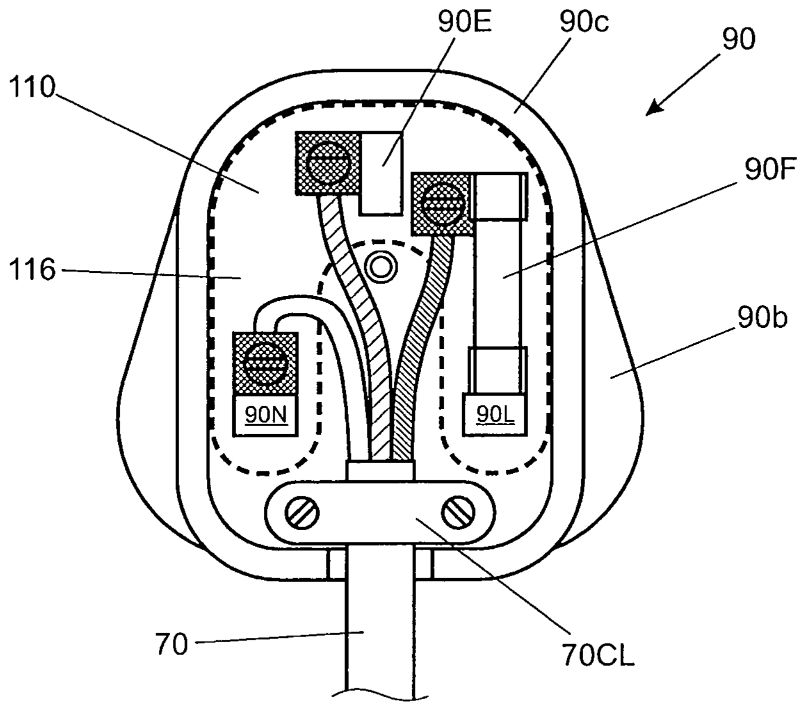
[FIG. 5B]


410
410ppa
414
412U
405U
412E
410cpa
410Ea
410ca
410ca
414
405M
412L
405L

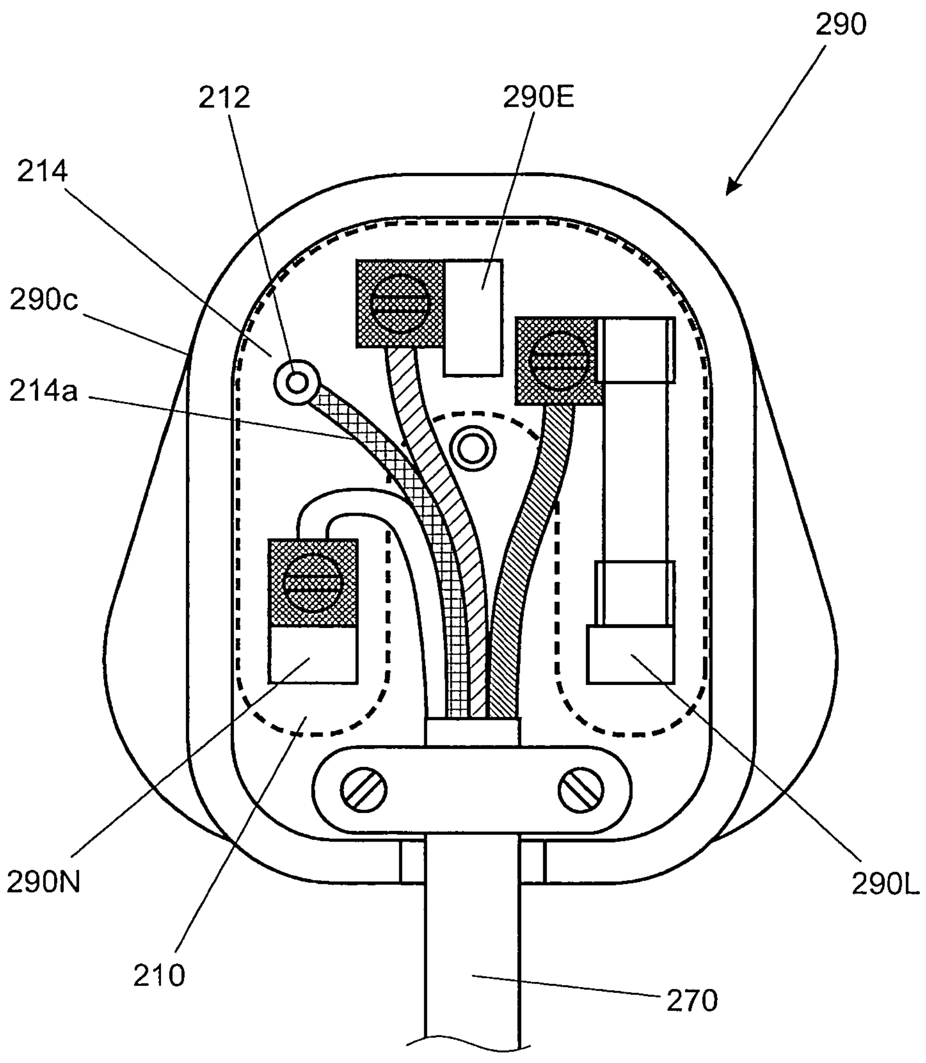
[FIG. 6A]


90
90a
116iii
90b
70
110
116
90c
90L
90E
90cc

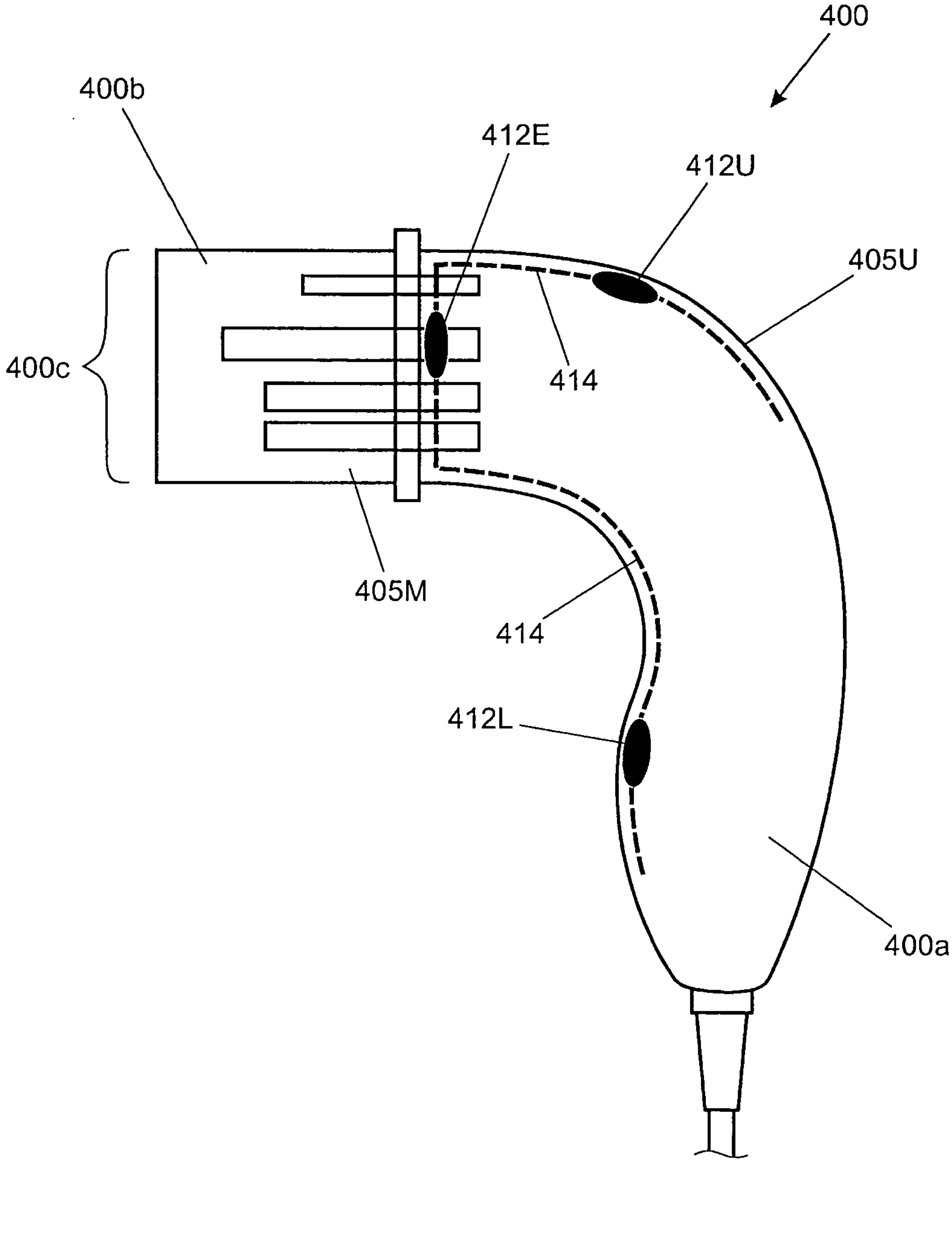
[FIG. 6B]


90E
90c
90
110
90F
116
90b
90N
90L
70
70CL

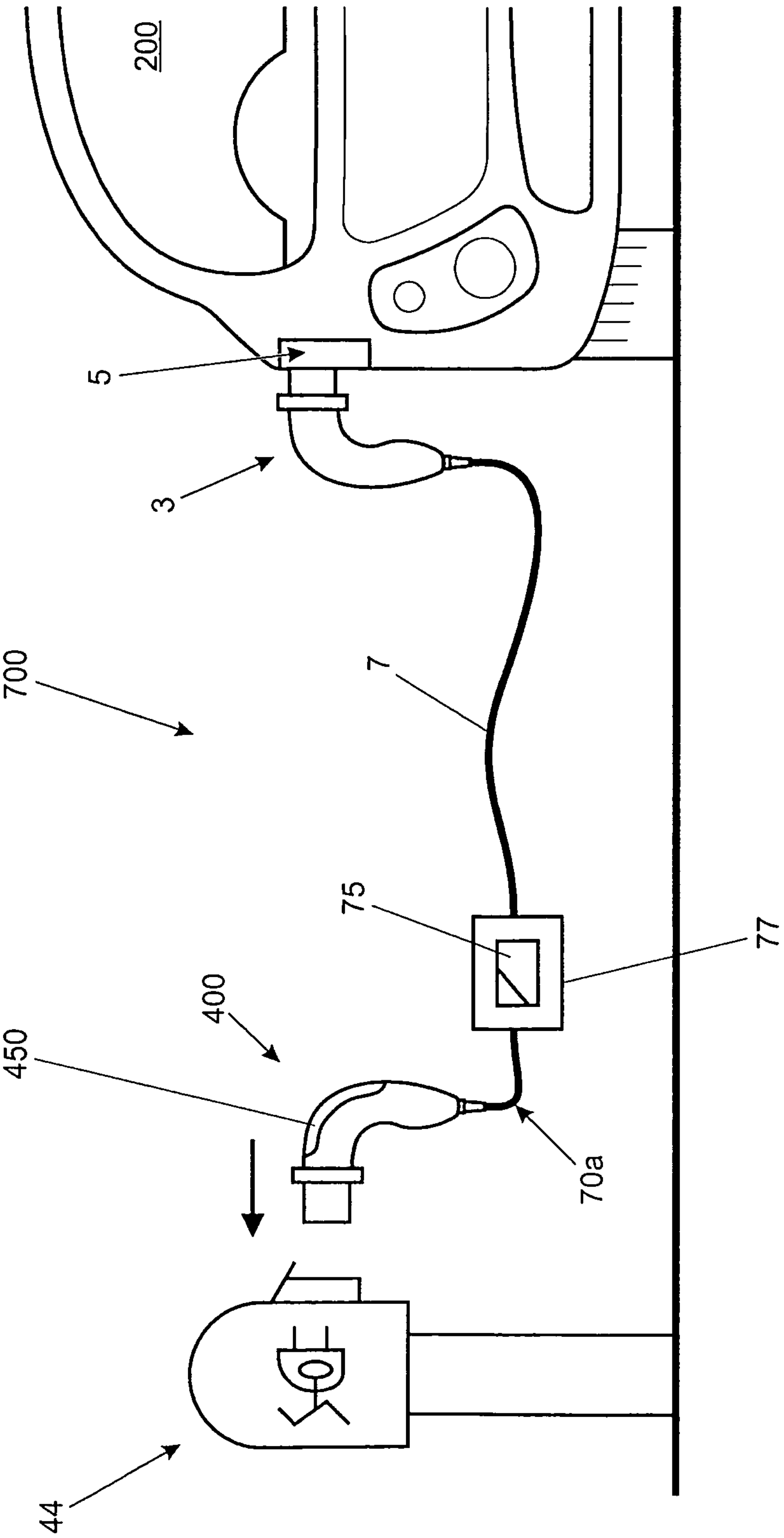
[FIG. 6C]



[FIG. 7]



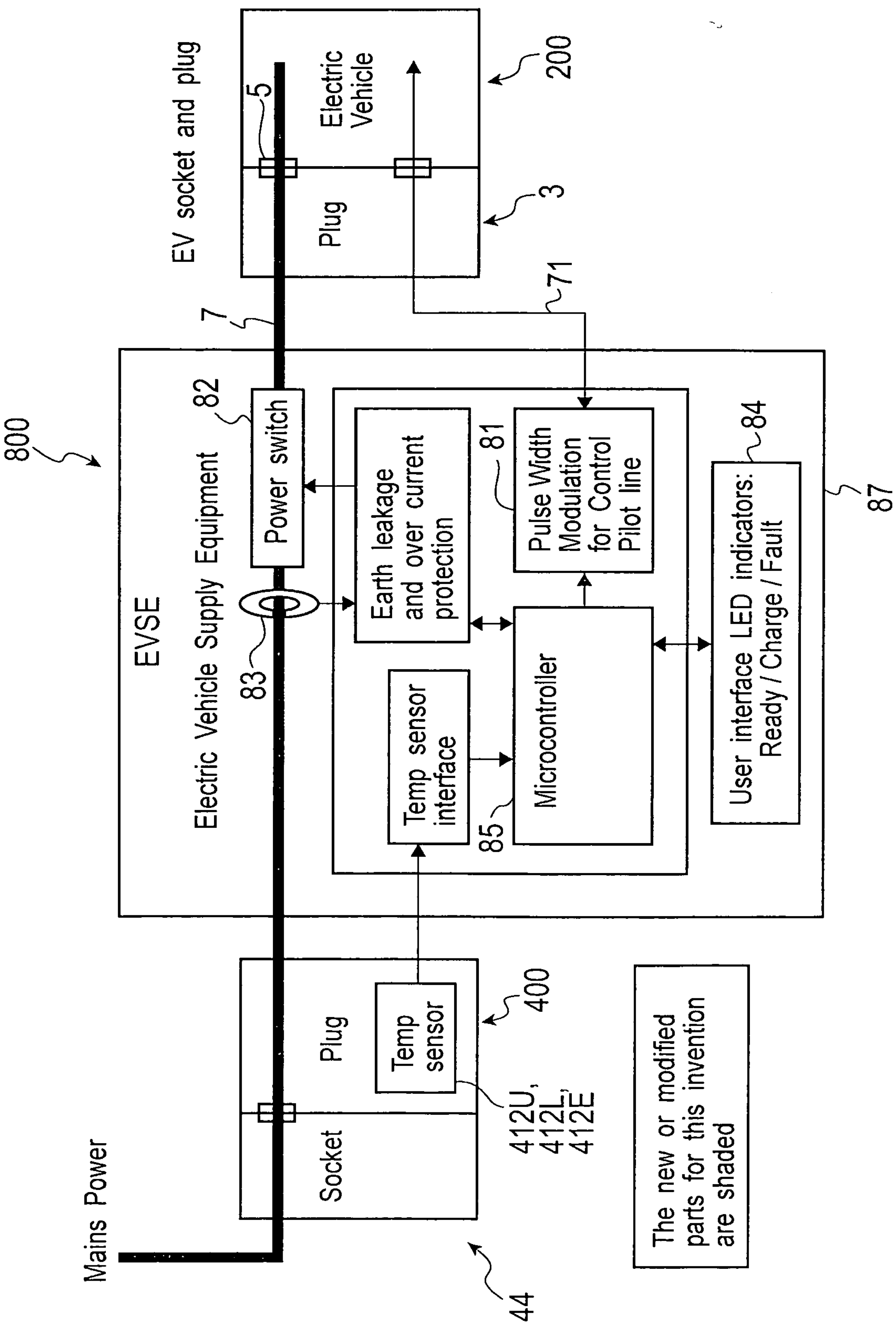
[FIG. 8]



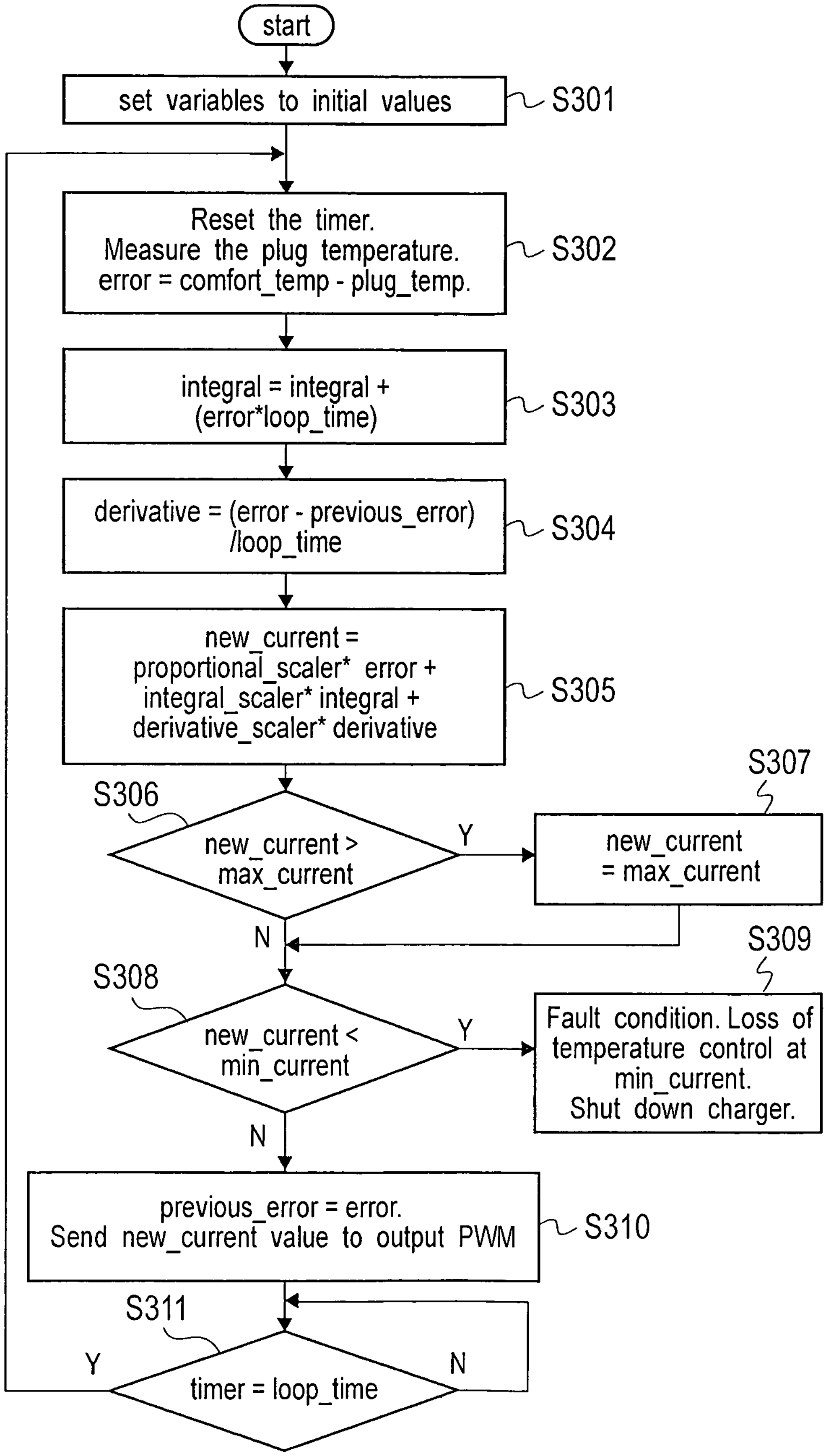
[FIG. 9]

	Temperature band			
	1	2	3	4
Controller action	No Action	Indicate status only	Indicate status Limit current	Indicate status Cease charging
Current limit	Max rated current	Max rated current	Maximum current without exceeding temperature band 2	Cease charging until temperature returns to temperature band 2
Status indicator during charge	Flashing green	Flash alternate yellow then green	No Flash alternate orange then yellow	Flash red
Status indicator charge completed	Continuous green	Continuous yellow	Continuous orange	Continuous red

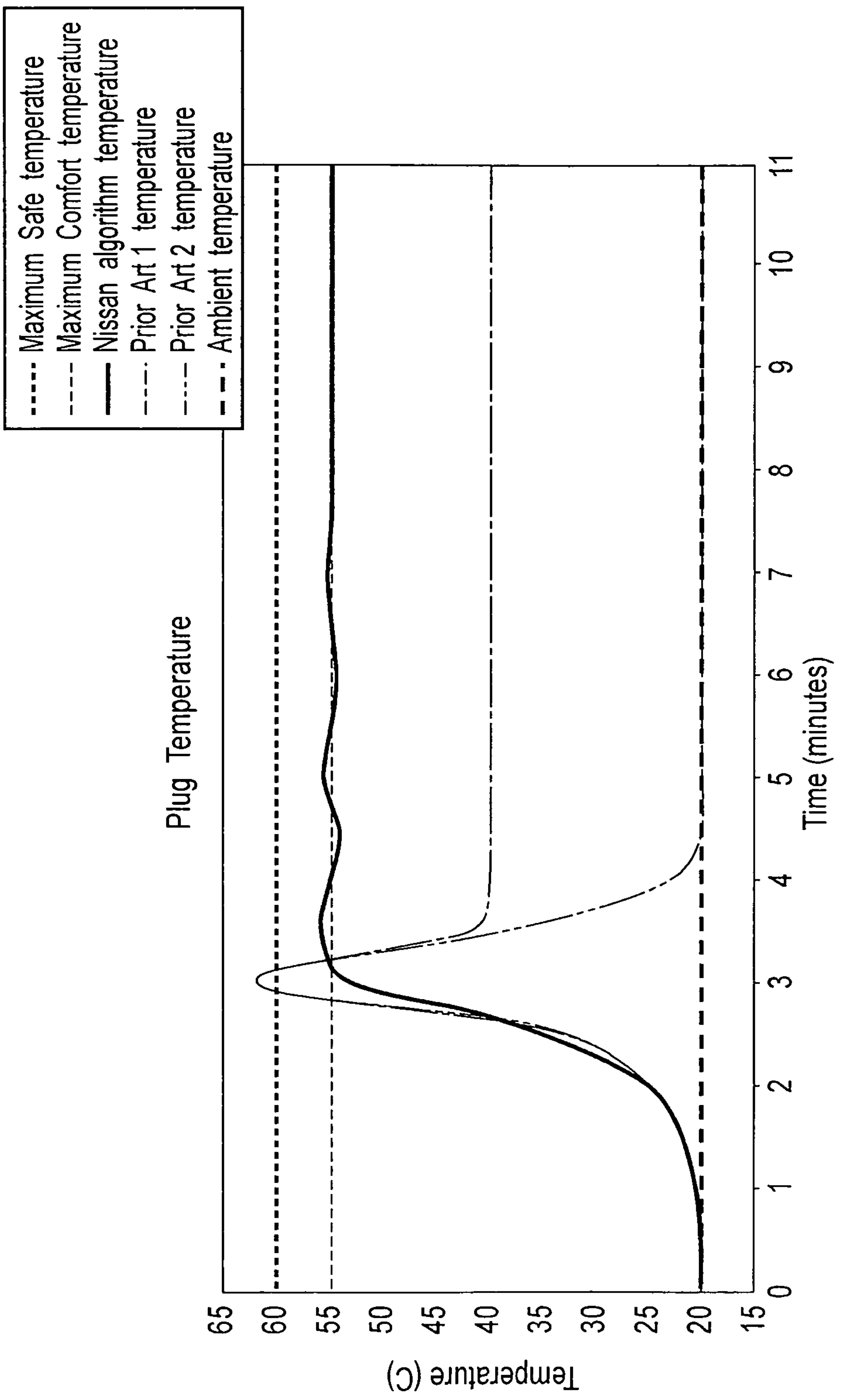
[FIG. 10]


EV socket and plug
Electric Vehicle
Plug
200
3
5
7
71
800
EVSE
Electric Vehicle Supply Equipment
Power switch
82
83
Earth leakage and over current protection
Pulse Width Modulation for Control Pilot line
81
Temp sensor interface
Microcontroller
85
User interface LED indicators: Ready / Charge / Fault
84
87
Mains Power
Socket
Plug
Temp sensor
400
412U, 412L, 412E
44
The new or modified parts for this invention are shaded

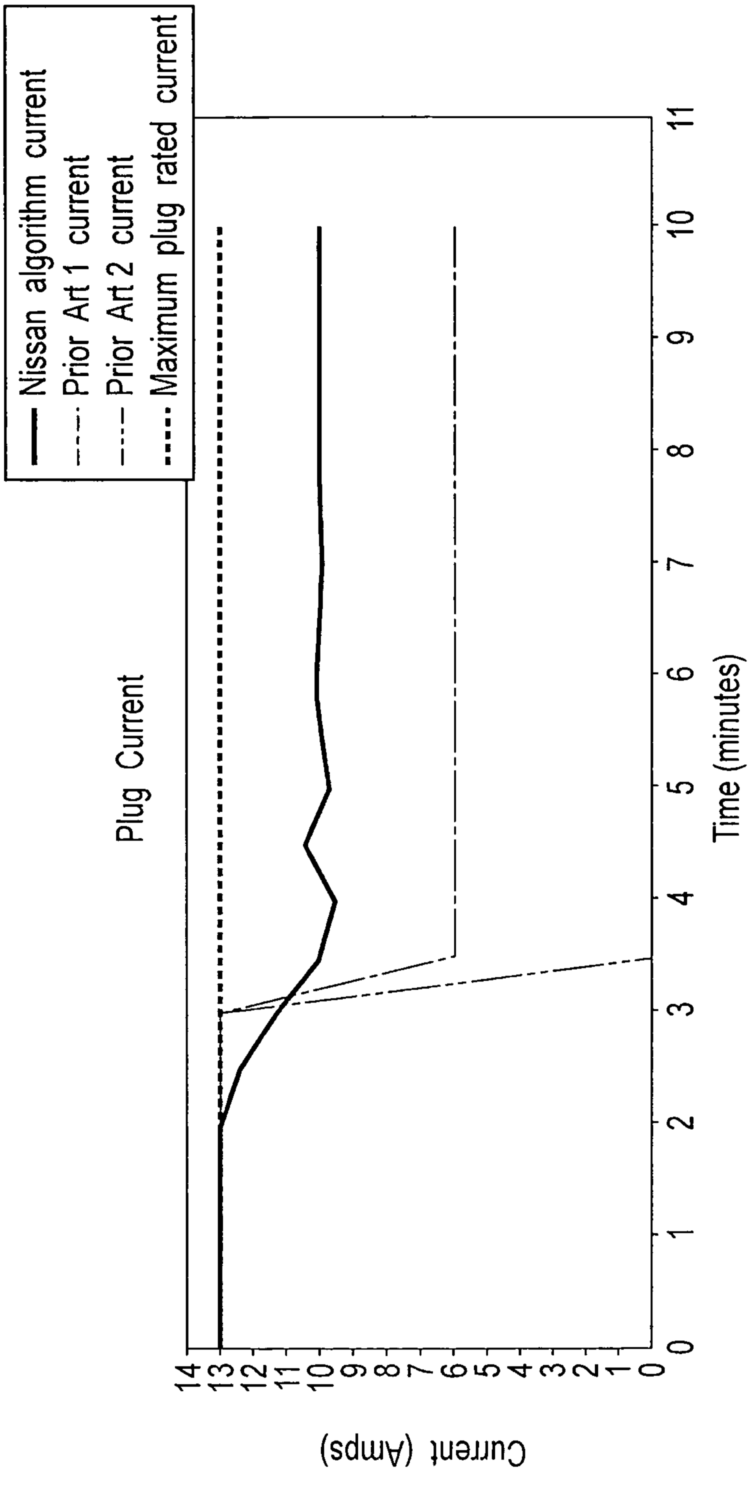
[FIG. 11]


start
set variables to initial values
S301
Reset the timer.
Measure the plug temperature.
error = comfort_temp - plug_temp.
S302
integral = integral +
(error*loop_time)
S303
derivative = (error - previous_error)
/loop_time
S304
new_current =
proportional_scaler* error +
integral_scaler* integral +
derivative_scaler* derivative
S305
S306
new_current >
max_current
Y
N
S307
new_current
= max_current
S308
new_current <
min_current
Y
N
S309
Fault condition. Loss of
temperature control at
min_current.
Shut down charger.
previous_error = error.
Send new_current value to output PWM
S310
S311
timer = loop_time
Y
N

[FIG. 12A]


Plug Temperature
Maximum Safe temperature
Maximum Comfort temperature
Nissan algorithm temperature
Prior Art 1 temperature
Prior Art 2 temperature
Ambient temperature
Temperature (C)
Time (minutes)
65
60
55
50
45
40
35
30
25
20
15
0
1
2
3
4
5
6
7
8
9
10
11

[FIG. 12B]


Plug Current
Nissan algorithm current
Prior Art 1 current
Prior Art 2 current
Maximum plug rated current
Current (Amps)
Time (minutes)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14