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(54) **SYSTEMS AND METHODS FOR CHARGING THE BATTERY OF AN ELECTRIC VEHICLE**

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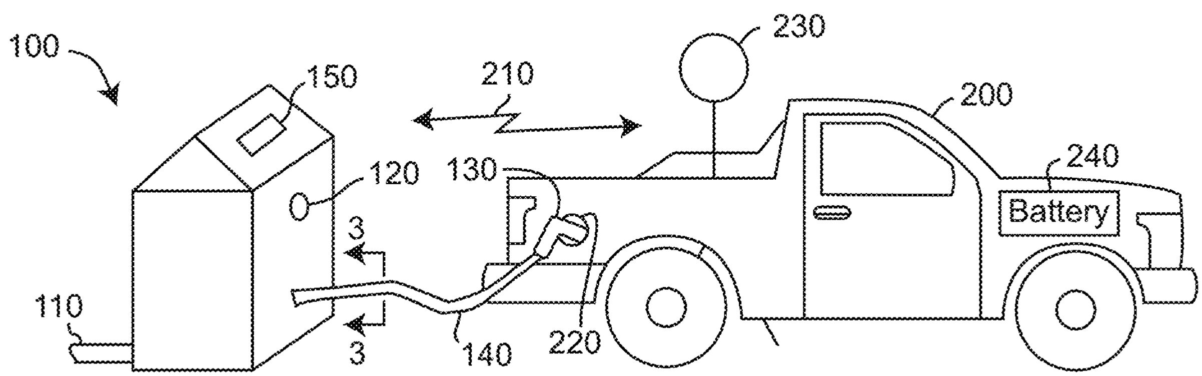
(57) **ABSTRACT**

A system and method for charging a battery of an electric vehicle. The method includes removing a coolant from the electrical cable that provides energy to the electric vehicle prior to handling of the electrical cable by a user. Removing the coolant from the electrical cable decreases a weight of the cable and increases the flexibility of the cable thereby enabling the user to more easily manipulate the electrical cable to connect the electrical cable to and disconnect the electrical cable from the electric vehicle.



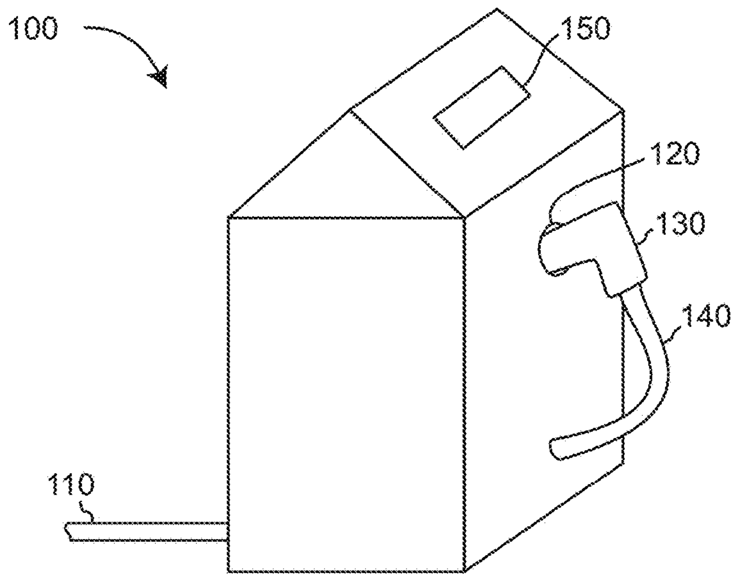

100
150
120
130
140
110

FIG. 1

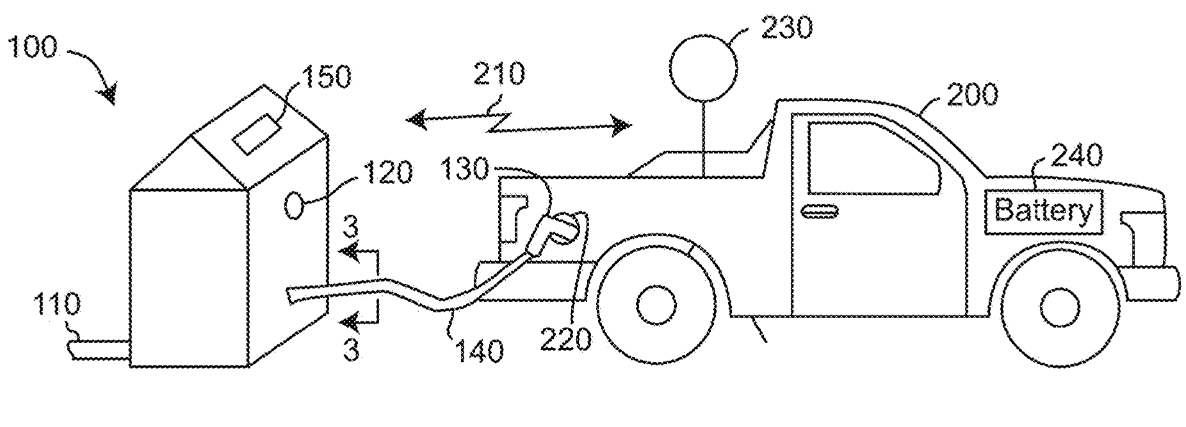

100
150
210
230
200
240
Battery
120
130
3
3
110
140
220

FIG. 2

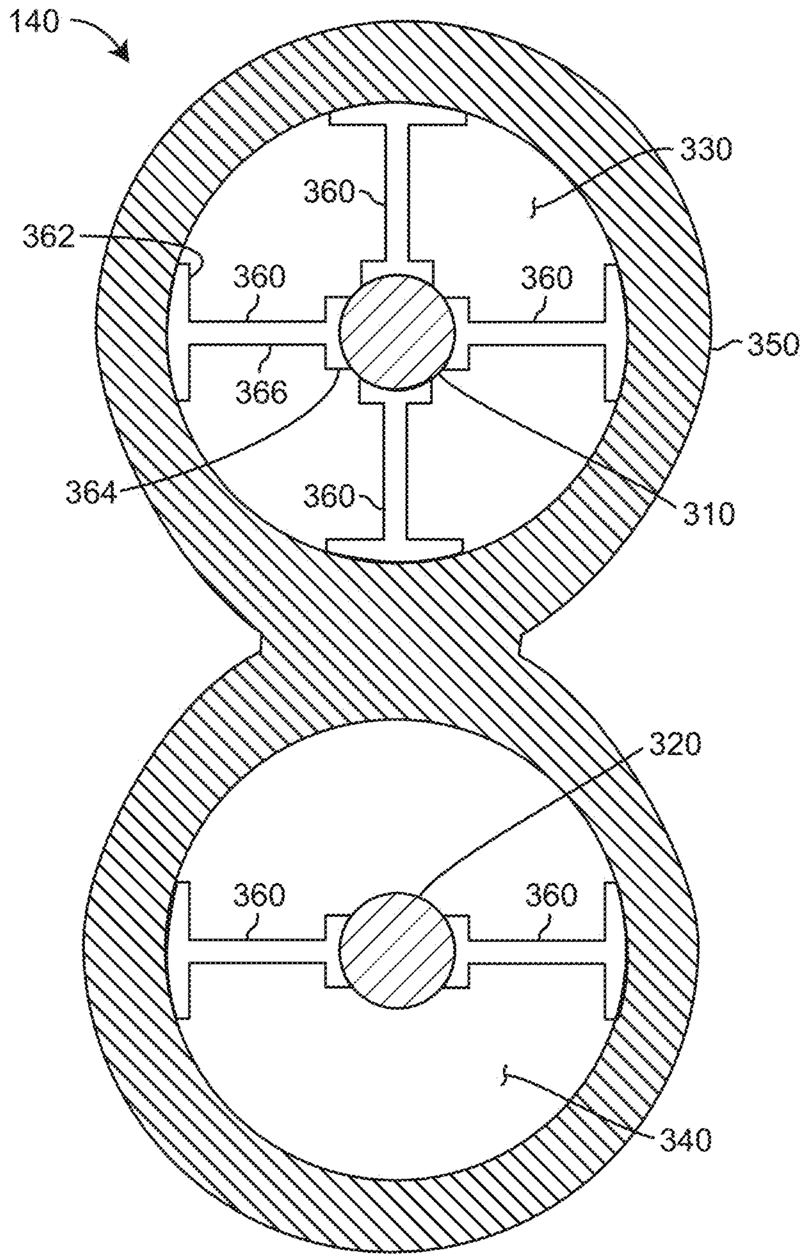


FIG. 3

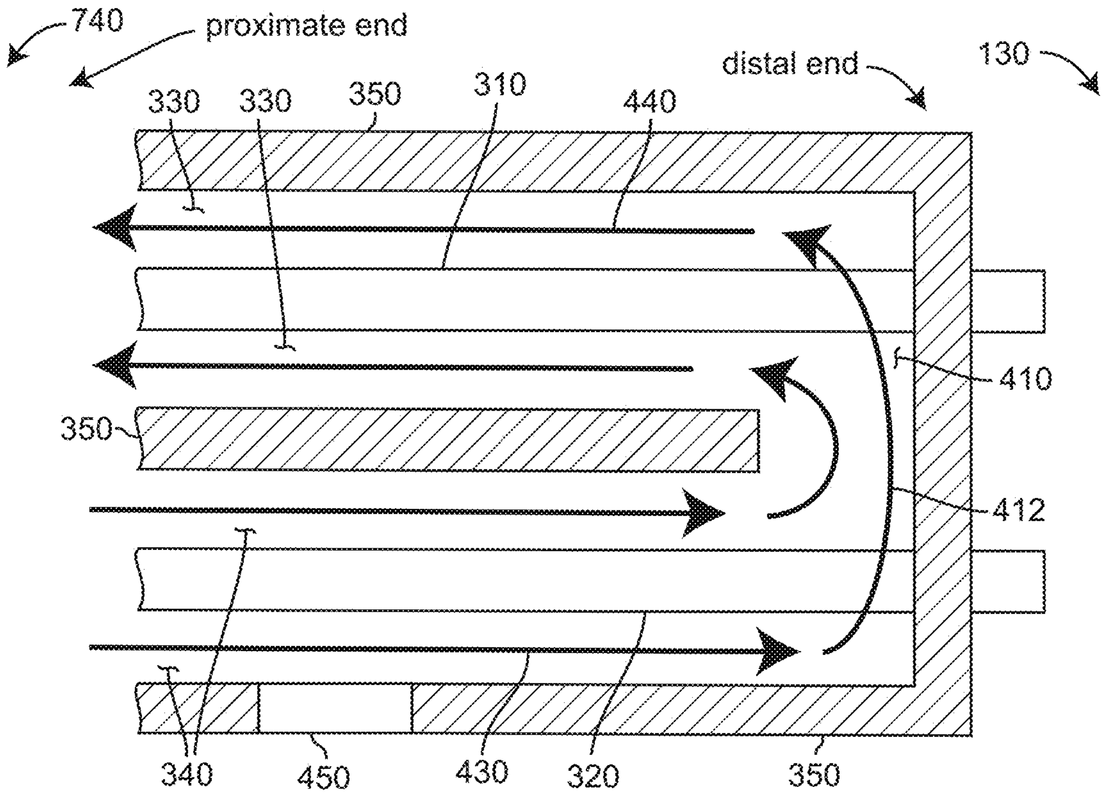

740
proximate end
distal end
130
330
330
350
310
440
410
350
412
340
450
430
320
350

FIG. 4

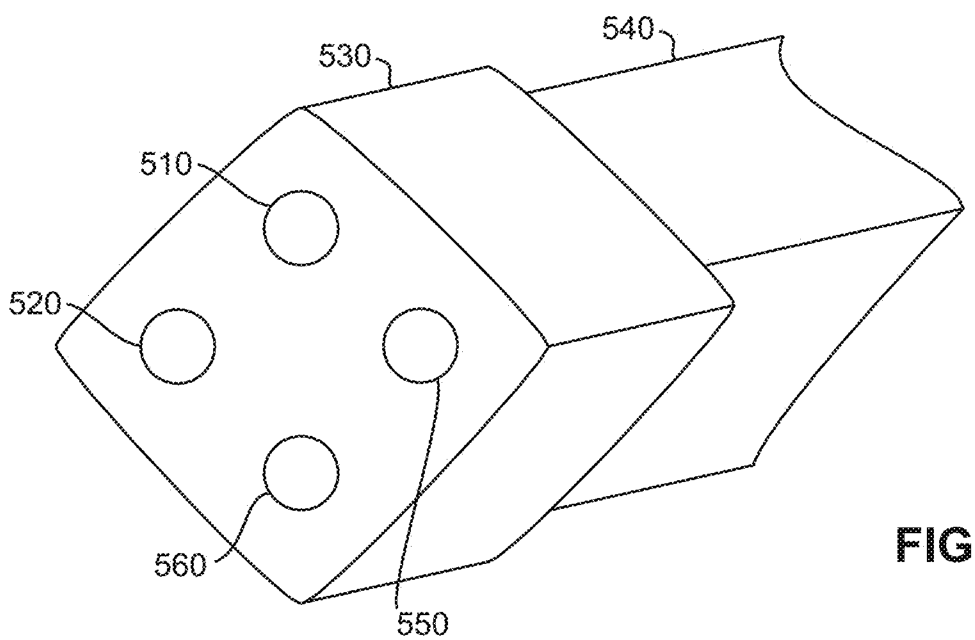
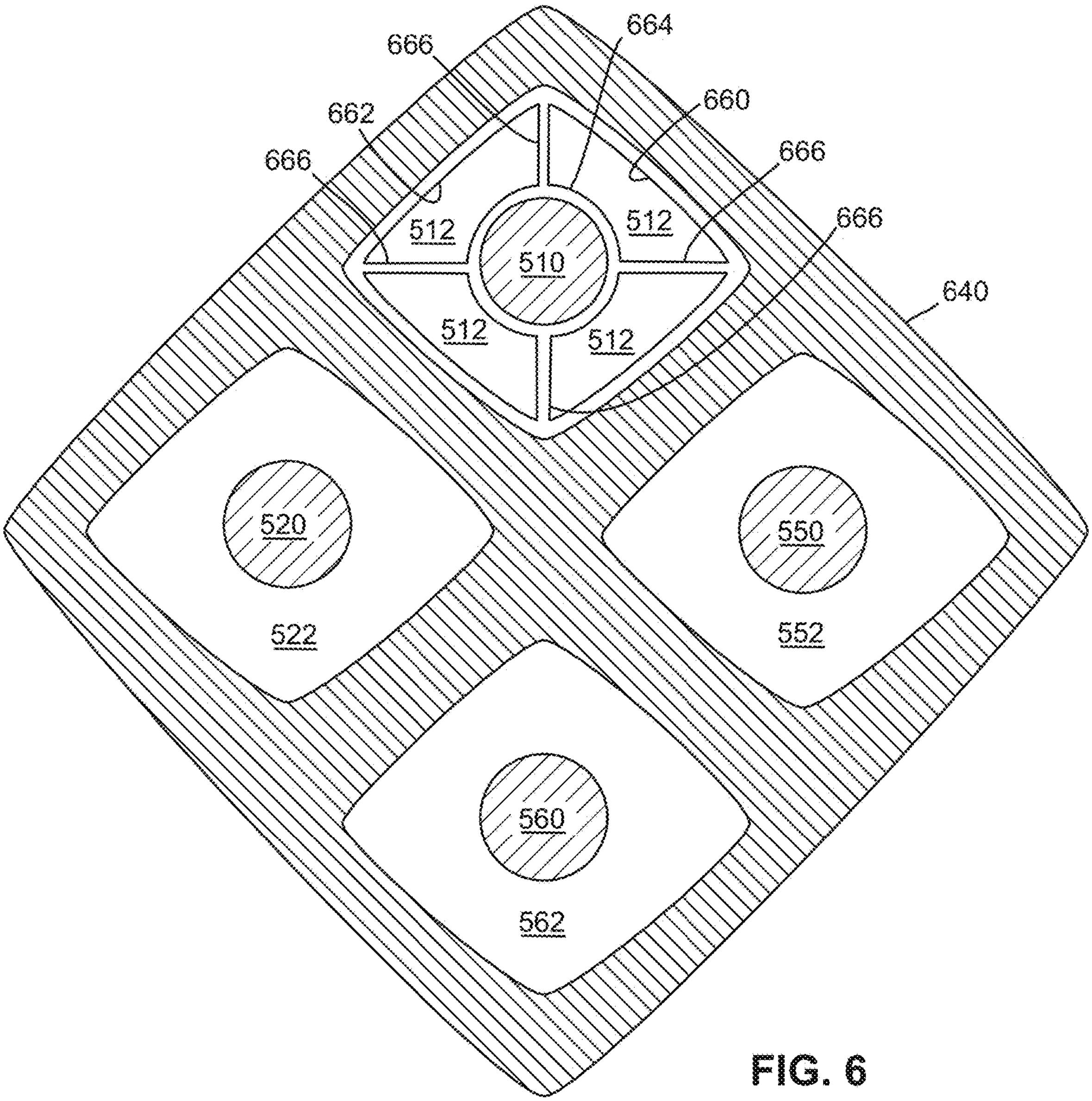

540
530
510
520
560
550

FIG. 5



666
664
660
662
666
666
666
512
512
510
512
512
640
520
550
522
552
560
562

FIG. 6

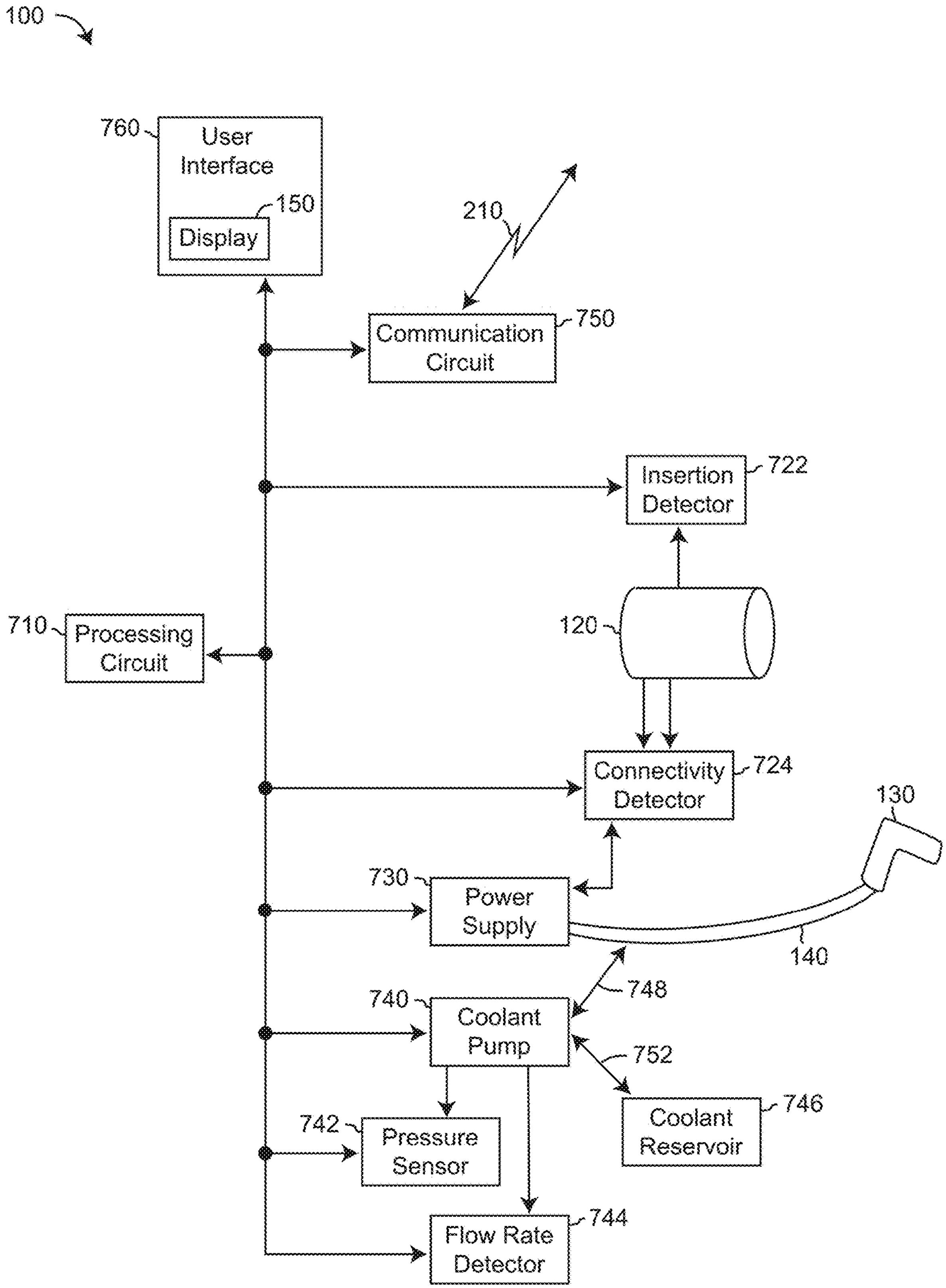

100
760
User Interface
150
Display
210
Communication Circuit
750
Insertion Detector
722
120
710
Processing Circuit
Connectivity Detector
724
130
730
Power Supply
140
748
740
Coolant Pump
752
Coolant Reservoir
746
742
Pressure Sensor
Flow Rate Detector
744

FIG. 7

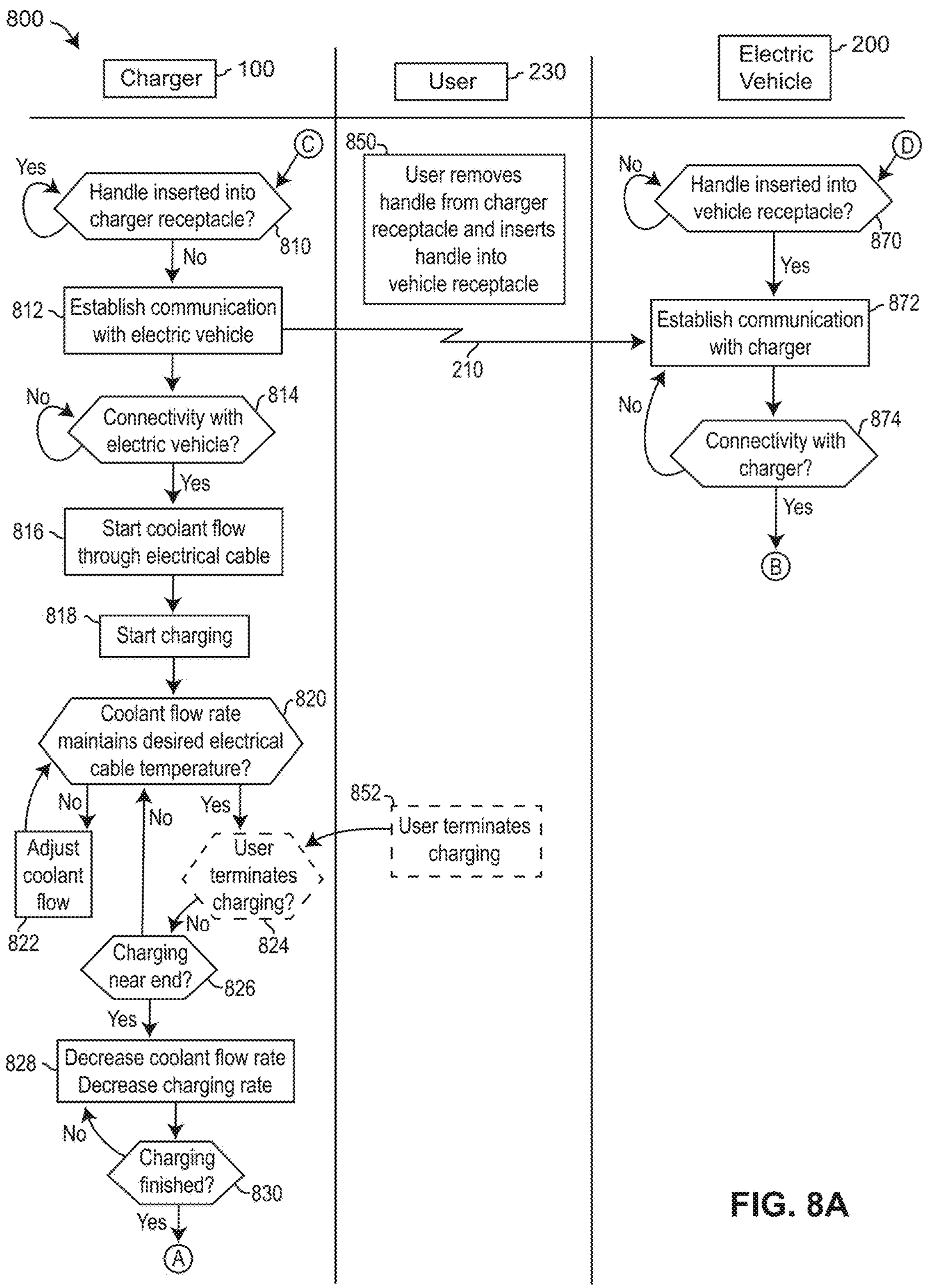

800
Charger
100
User
230
Electric Vehicle
200
C
Yes
Handle inserted into charger receptacle?
810
No
812
Establish communication with electric vehicle
No
814
Connectivity with electric vehicle?
Yes
816
Start coolant flow through electrical cable
818
Start charging
820
Coolant flow rate maintains desired electrical cable temperature?
No
No
Yes
Adjust coolant flow
822
User terminates charging?
824
No
Charging near end?
826
Yes
828
Decrease coolant flow rate
Decrease charging rate
No
Charging finished?
830
Yes
A
850
User removes handle from charger receptacle and inserts handle into vehicle receptacle
210
852
User terminates charging
D
No
Handle inserted into vehicle receptacle?
870
Yes
Establish communication with charger
872
No
874
Connectivity with charger?
Yes
B

FIG. 8A

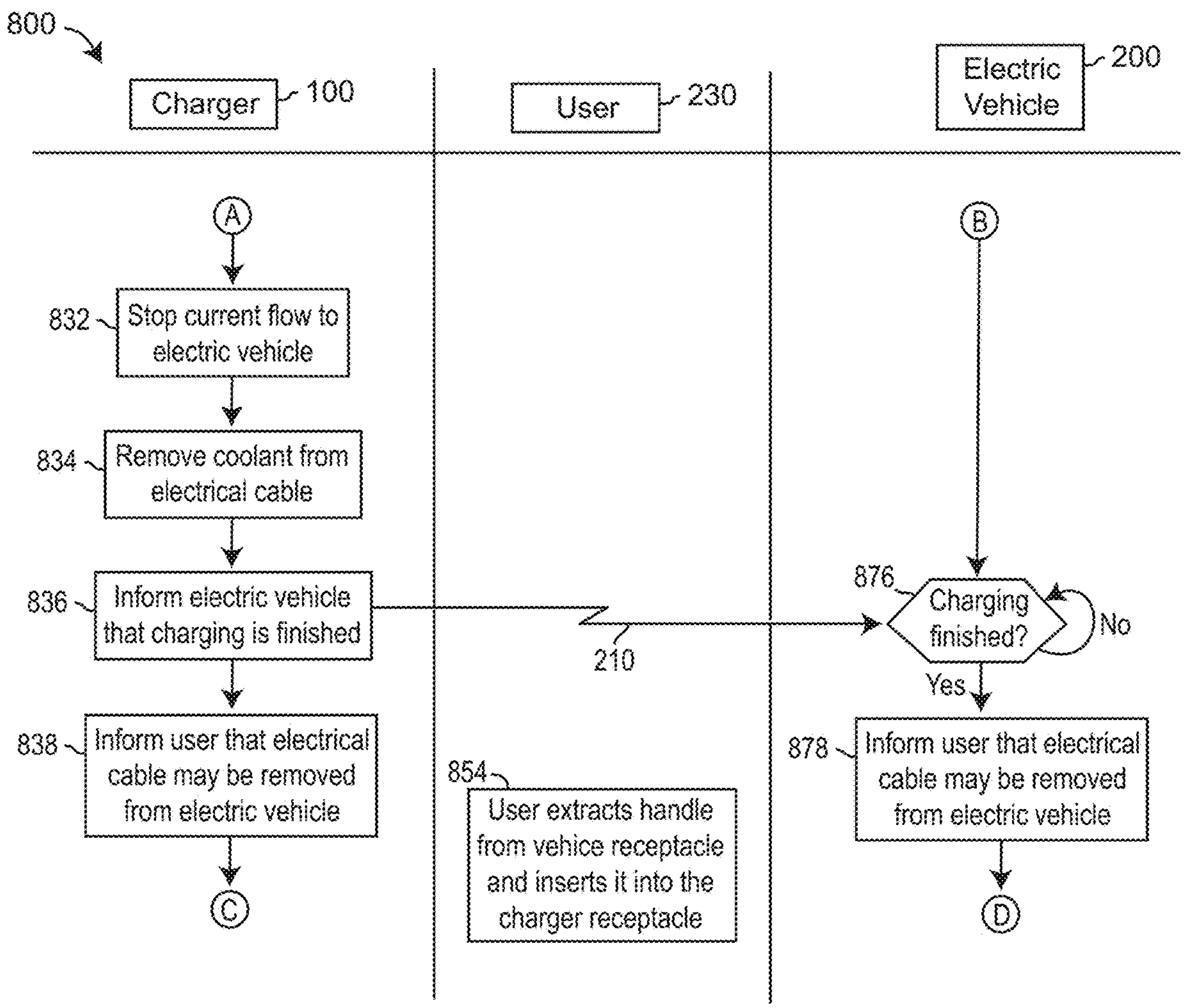

800
Charger
100
User
230
Electric Vehicle
200
A
B
832
Stop current flow to electric vehicle
834
Remove coolant from electrical cable
836
Inform electric vehicle that charging is finished
210
876
Charging finished?
No
Yes
838
Inform user that electrical cable may be removed from electric vehicle
854
User extracts handle from vehice receptacle and inserts it into the charger receptacle
878
Inform user that electrical cable may be removed from electric vehicle
C
D

FIG. 8B

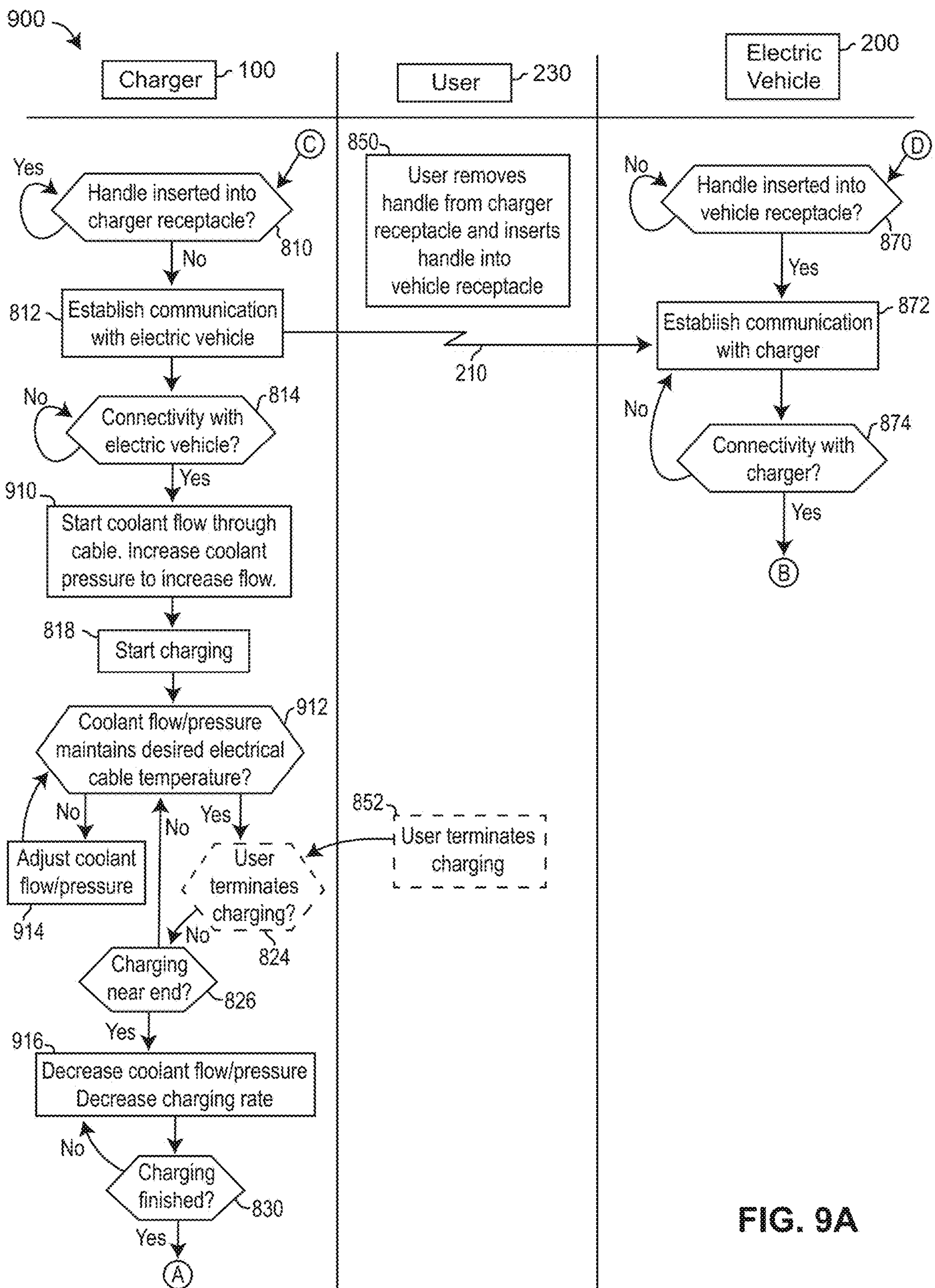

900
Charger
100
User
230
Electric Vehicle
200
C
Yes
Handle inserted into charger receptacle?
810
No
850
User removes handle from charger receptacle and inserts handle into vehicle receptacle
D
No
Handle inserted into vehicle receptacle?
870
Yes
812
Establish communication with electric vehicle
210
872
Establish communication with charger
No
814
Connectivity with electric vehicle?
Yes
No
874
Connectivity with charger?
Yes
B
910
Start coolant flow through cable. Increase coolant pressure to increase flow.
818
Start charging
912
Coolant flow/pressure maintains desired electrical cable temperature?
No
Yes
No
Adjust coolant flow/pressure
914
852
User terminates charging
User terminates charging?
824
No
Charging near end?
826
Yes
916
Decrease coolant flow/pressure
Decrease charging rate
No
Charging finished?
830
Yes
A

FIG. 9A

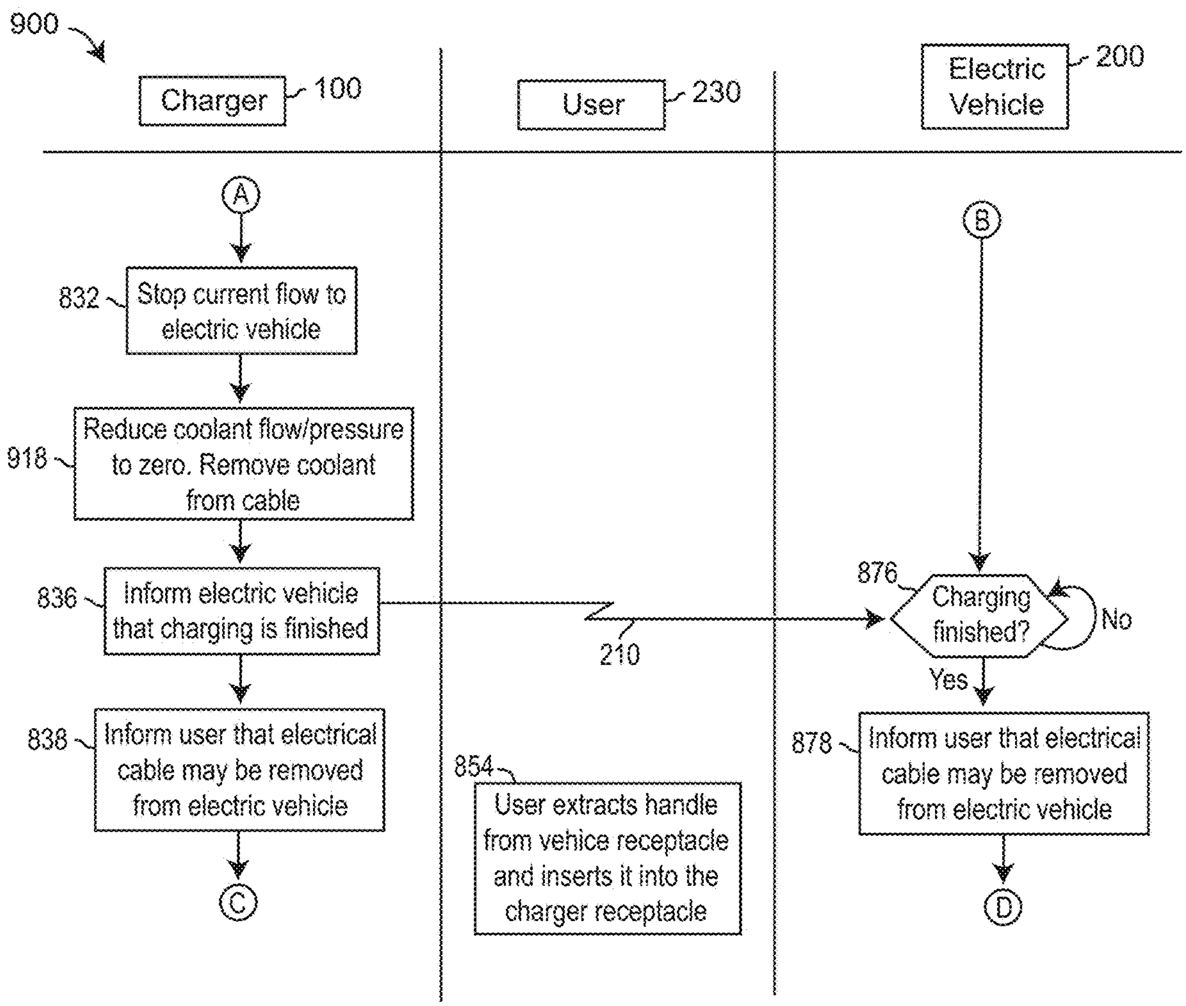

900
Charger
100
User
230
Electric Vehicle
200
A
832
Stop current flow to electric vehicle
918
Reduce coolant flow/pressure to zero. Remove coolant from cable
836
Inform electric vehicle that charging is finished
838
Inform user that electrical cable may be removed from electric vehicle
C
210
854
User extracts handle from vehice receptacle and inserts it into the charger receptacle
B
876
Charging finished?
No
Yes
878
Inform user that electrical cable may be removed from electric vehicle
D

FIG. 9B

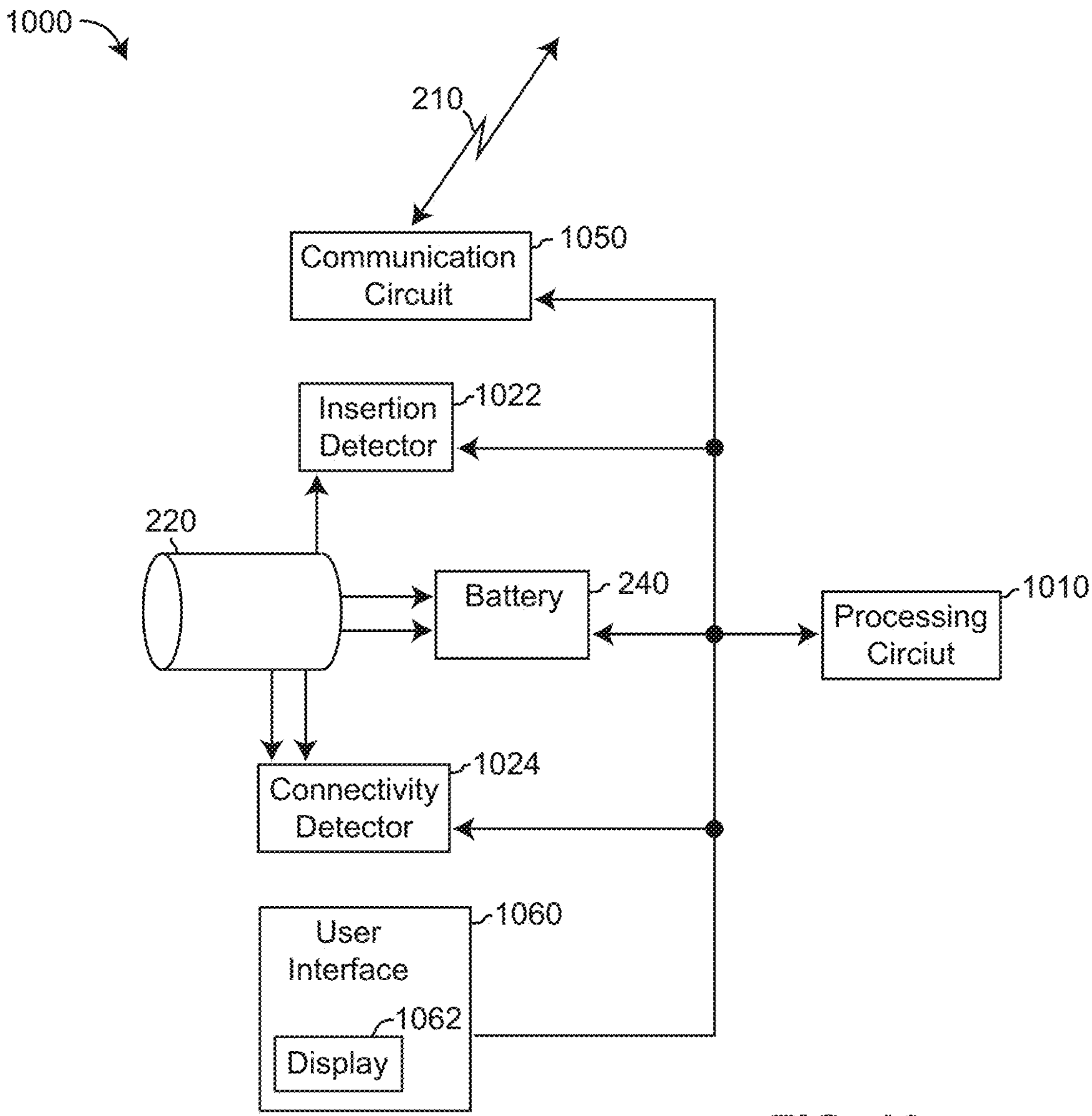

1000
210
Communication Circuit
1050
Insertion Detector
1022
220
Battery
240
Processing Circiut
1010
Connectivity Detector
1024
User Interface
1060
1062
Display

FIG. 10

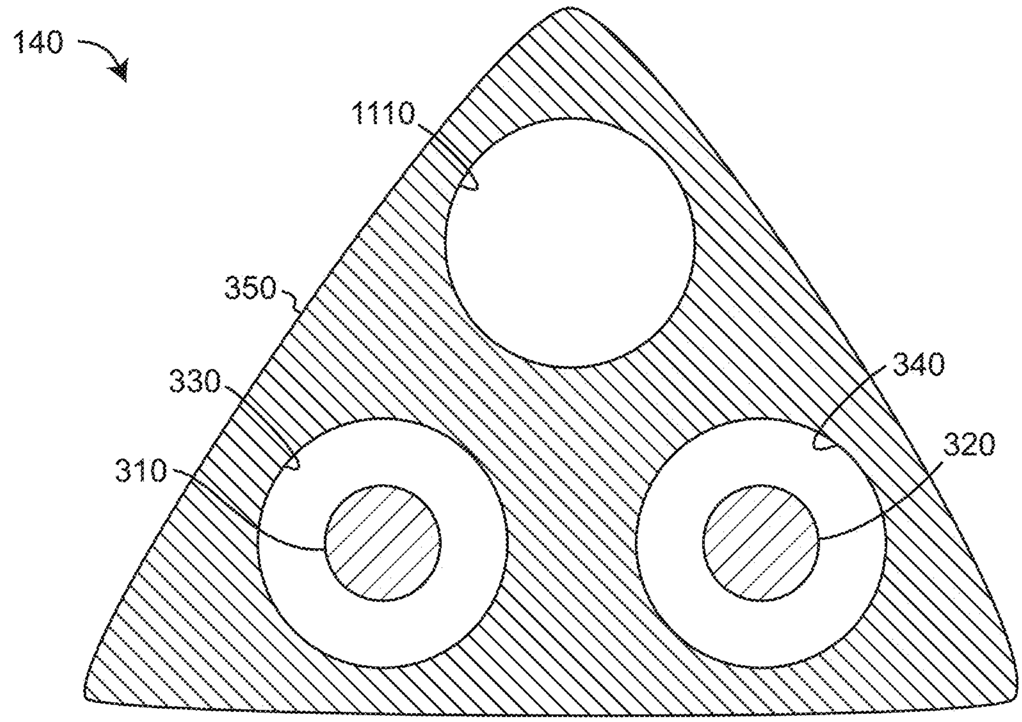

140
1110
350
330
340
320
310

FIG. 11

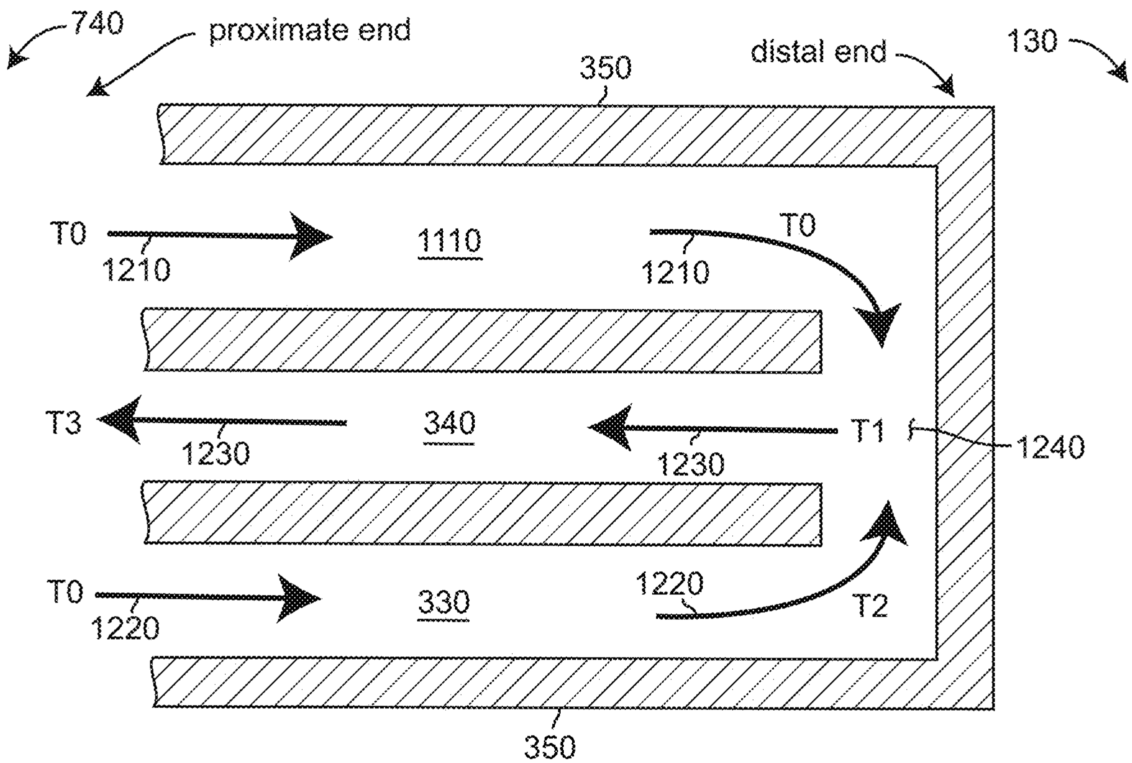

740
proximate end
distal end
130
350
T0
1210
1110
T0
1210
T3
1230
340
1230
T1
1240
T0
1220
330
1220
T2
350

FIG. 12

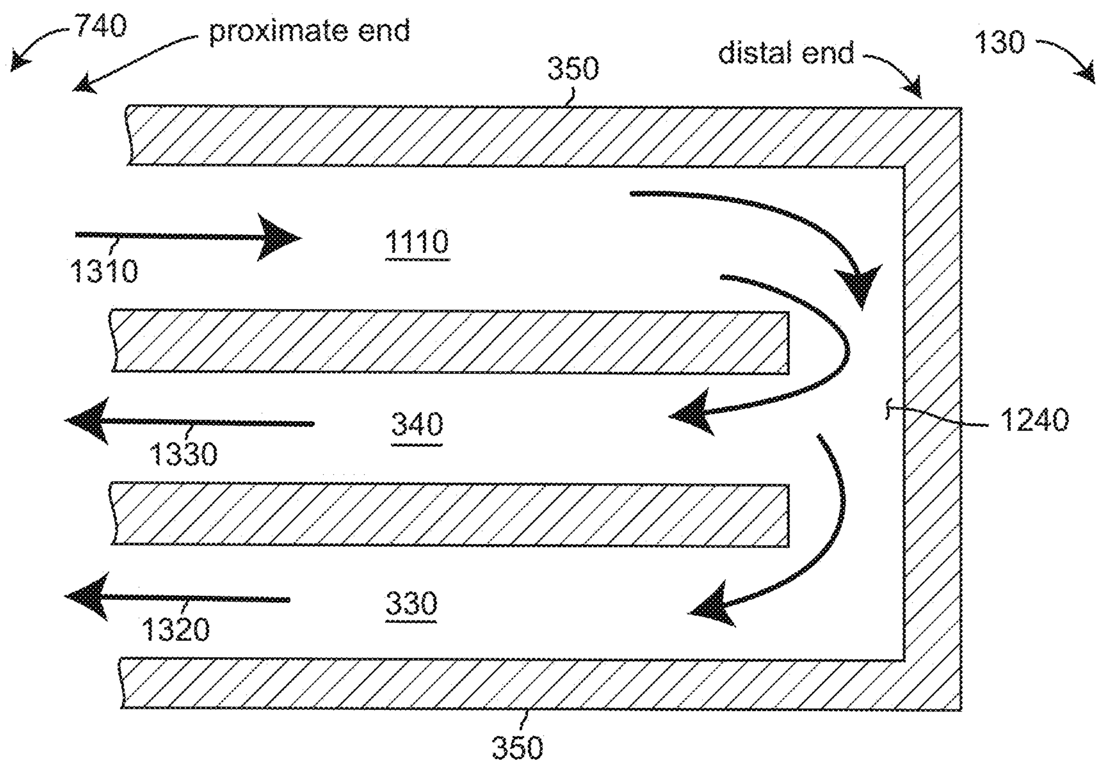

740
proximate end
distal end
130
350
1110
1310
340
1330
1240
330
1320
350

FIG. 13

SYSTEMS AND METHODS FOR CHARGING THE BATTERY OF AN ELECTRIC VEHICLE

BACKGROUND

[0001] Embodiments of the present invention relate to a charger for charging the battery of an electric vehicle.

[0002] A battery stores electrical energy that may be provided to an electric vehicle (also referred to as a Battery Electric Vehicle or EV) to operate the electric vehicle. The battery must be recharged from time to time for continued operation of the electric vehicle. A charger (also referred to as electric vehicle service equipment) is used to provide energy to the battery of the electric vehicle. The charger includes, inter alia, a power supply and an electrical cable. The electrical cable carries energy from a power supply (e.g., line power) to the electric vehicle. A coolant may be used to cool the electrical cable during use; however, the coolant can make the electrical cable heavy and difficult for a user to lift or move. Users may benefit from a charger that removes the coolant from the electrical cable while it is being manipulated by a user.

SUMMARY

[0003] A charger is used to provide energy to a battery of an electric vehicle to recharge the battery. An electrical cable extends from the charger to the electric vehicle. The electrical cable provides the energy from the charger to the battery. The current carried by the electrical cable can be very high to decrease the amount of time required to recharge the battery. The high current can increase the temperature of the conductors in the electrical cable. If the current is high enough, the heat caused by the current flow could damage the conductors.

[0004] The conductors of the electrical cable may be cooled so that the conductors may carry the high current without damage. In an example embodiment, a liquid is used as a coolant to cool the conductors. The liquid circulates around the conductors to extract heat from the conductors to cool the conductors. In another example embodiment, the coolant (e.g., medium) changes phase from a liquid to a gas to cool the conductors. The change in phase of the cooling medium extract heat from the conductors. In either embodiment, the coolant fills and/or circulates through channels that surround the conductors of the electrical cable. A pump circulates the coolant through the channels. The presence of the coolant in the channels of the electrical cable increases the weight of the electrical cable thereby making it more difficult for a user to lift the electrical cable to extend it from the charger to the electric vehicle prior to charging the battery. Further, pressurizing the coolant in the channels of the electrical cable reduces the flexibility of the cable which also makes the electrical cable more difficult for the user to manipulate (e.g., handled, moved, lifted).

[0005] In an example embodiment, the charger cooperates with the electric vehicle to determine when the electrical cable is in use to deliver energy to the electric vehicle. When the electrical cable is not in use, the charger evacuates (e.g., removes) the coolant from the electrical cable. Before the electrical cable delivers energy, the charger fills and/or circulates coolant through the electrical cable. The user does not manipulate the electrical cable while it delivers energy to the electric vehicle, so during the time that the electrical cable is manipulated by the user, the coolant has been evacuated from the electrical cable thereby decreasing the weight of electrical cable and increasing its flexibility.

BRIEF DESCRIPTION OF THE DRAWING

[0006] Embodiments of the present invention will be described with reference to the figures of the drawing. The figures present non-limiting example embodiments of the present disclosure. Elements that have the same reference number are either identical or similar in purpose and function, unless otherwise indicated in the written description.

[0007] FIG. **1** is a diagram of an example embodiment of a charger according to various aspects of the present disclosure.

[0008] FIG. **2** is a diagram of the charger of FIG. **1** connected to an electric vehicle by the electrical cable.

[0009] FIG. **3** is a cross-section diagram of an example embodiment of an electrical cable.

[0010] FIG. **4** is a cross-section diagram along a length of the example embodiment of the electrical cable of FIG. **3**.

[0011] FIG. **5** is diagram of another example embodiment of a handle and another example embodiment of an electrical cable.

[0012] FIG. **6** is a cross-section diagram of the second example embodiment of the electrical cable of FIG. **5**.

[0013] FIG. **7** is a diagram of an example embodiment of the charger of FIG. **1**.

[0014] FIGS. **8**A and **8**B are flow diagrams of an example method for charging an electric vehicle using an electrical cable that is cooled using a liquid coolant.

[0015] FIGS. **9**A and **9**B are a flow diagram of an example method for charging an electric vehicle using an electrical cable that is cooled using a phase-change coolant.

[0016] FIG. **10** is a diagram of an example embodiment of an electric vehicle system for charging the battery of the electric vehicle.

[0017] FIG. **11** is a diagram of another example embodiment of an electrical cable.

[0018] FIG. **12** is a cross-section diagram along a length of the example embodiment of the electrical cable of FIG. **11**.

[0019] FIG. **13** is a cross-section diagram along a length of the example embodiment of the electrical cable of FIG. **11** while evacuating the coolant from the electrical cable.

DETAILED DESCRIPTION

Overview

[0020] In an example embodiment, charger **100** delivers energy to electric vehicle **200** to charge battery **240**. Prior to delivering energy to electric vehicle **200**, handle **130/530** is inserted into receptacle **120** of the charger **100** and no current flows through electrical cable **140/540**. Further, there is no coolant in the channels (e.g., **330**, **340**, **512**, **522**, **552**, **562**, **1110**) of the electrical cable **140/540** because there is no need to cool the conductors (e.g., **310**, **320**, **510**, **520**, **550**, **560**) because no current flows through them.

[0021] When the user **230** determines that it is time to charge the battery **240**, the user **230** positions the electric vehicle **200** proximate to the charger **100**. The user **230** removes the handle **130/530** from the receptacle **120**, stretches the electrical cable **140/540** from the charger **100** towards the electric vehicle **200** and inserts the handle **130/530** into the receptacle **220** of the electric vehicle **200**. The electrical cable **140/540** extends from the charger **100** to the electric vehicle **200**. While the user moves the handle **130/530** from the receptacle **120** to the receptacle **220**, no current flows through the electrical cable **140/540**. Further, there is no coolant in the channels (e.g., **330**, **340**, **512**, **522**, **552**, **562**, **1110**) of electrical cable **140/540**.

[0022] Once the handle **130** is connected to the receptacle **220** of the electric vehicle **200**, energy may be delivered from the charger **100** to the battery **240** via the conductors (e.g., **310**, **320**, **510**, **520**, **550**, **560**) of the electrical cable **140/540**. As the current flows through the conductors, the temperature of the conductors increases. To protect the conductors from damage, prior to starting the current flow, the coolant pump **740** pumps a coolant into the channels (e.g., **330**, **340**, **512**, **522**, **552**, **562**, **1110**) of the electrical cable **140/540**. The coolant cools the conductors to maintain the temperature of the conductors at a temperature or in a range of temperatures that does not damage the conductors. The coolant pump **740** circulates the coolant through the channels before, while and/or after electrical energy in the form of an electrical current is provided to the electric vehicle **200** to charge the battery **240**.

[0023] After the battery **240** has been charged, the charger **100** ceases to deliver energy to the battery **240** via the electrical cable **140/540**. Once the current flowing through the conductors (e.g., **330**, **340**, **512**, **522**, **552**, **562**, **1110**) is reduced to a threshold amount, or zero, the coolant pump **740** pumps the coolant out of the channels thereby evacuating the channels, so that they hold little or no coolant. The evacuated channels may contain a gas whether air or the coolant in gas form. Once the channels have been evacuated, the charger **100** and/or the electric vehicle **200** informs the user **230** that the user **230** may remove the handle **130/530** from the receptacle **220**. The user **230** removes the handle **130/530** from the receptacle **220**, moves the handle **130/530** and the electrical cable **140/540** toward the charger **100** and inserts the handle **130/540** into the receptacle **120**.

[0024] Because the coolant is present in the channels (e.g., **330**, **340**, **512**, **522**, **552**, **562**, **1110**) only while, or for a time after, the current flows through the conductors (e.g., **310**, **320**, **510**, **520**, **550**, **560**), each time the user **230** manipulates (handles, moves, left) e.g., the handle **130/530** and the electrical cable **140/540**, there is little or no liquid coolant in the channels thereby reducing the weight of the electrical cable **140/540** and increasing its flexibility to ease handling by the user **230**.

Charger

[0025] The charger **100**, as best shown in FIGS. **1-2** and **7**, delivers energy to the electric vehicle **200** to recharge the battery **240**. The charger **100** includes the receptacle **120**, the handle **130** or the handle **530**, the electrical cable **140** or the electrical cable **540** and the display **150**. The user **230** manipulates the handle **130/530** and the electrical cable **140/540** to electrically and mechanically connect the charger **100** to the electric vehicle **200**. As discussed above, the electrical cable **140/540** weighs less and is more flexible when the channels **330** and **340** or **512**, **522**, **552** and **562** and **1110** do not hold coolant or the coolant is in the form of a gas at little or no pressure. According to various aspects of the present disclosure, the charger **100** evacuates the liquid coolant from the channels or decreases the pressure of a gaseous coolant at the times when the user **230** must manipulate the handle **130/530** and the electrical cable **140/540**.

[0026] The user provides information to and receives information from the charger **100** via the display **150**. In another example embodiment, the user **230** communicates with the charger **100** via an electronic device and a wireless communication link **210**. The display **150** may include controls (e.g., buttons, touchscreen) for the user **230** to operate to provide information to the charger **100**. The charger **100** may provide information to the user **230** by presenting the information on the display **150**. The charger **100** may inform the user **230** when charging is complete and when the handle **130** may be removed from the receptacle **220**. The processing circuit **710** may control the coolant pump **740** so that when charging is complete or almost complete, the coolant pump **740** pumps most if not all of the liquid coolant out of the channels (e.g., **330**, **340**, **512**, **522**, **552**, **562**, **1110**) back into the coolant reservoir **746** to reduce the weight and to increase the flexibility of the electrical cable **140/540**.

[0027] The charger **100** further includes processing circuit **710**, insertion detector **722**, connectivity detector **724**, power supply **730**, coolant pump **740**, pressure sensor **742**, flow rate detector **744**, coolant reservoir **746**, communication circuit **750** and user interface **760**. The processing circuit **710** may control some or all of the components of the charger **100** partially or completely. The processing circuit **710** is configured to execute a stored program to perform its functions, which thereby performs the functions of the charger **100**.

[0028] The communication circuit **750** communicates (e.g., transmits, receives) via wireless communication link **210**. The communication circuit **1050** of the electric vehicle **200** may communicate with the communication circuit **750** via the communication link **210**. The communication circuit **750** may communicate with an electronic device (e.g., tablet, smart phone) via wireless communication link **210**. In an example embodiment, the processing circuit **710** is configured to provide information to the communication circuit **750** for transmission. The communication circuit **750** is configured to receive information via the communication link **210** and to provide the information to the processing circuit **710**.

[0029] The user interface **760** includes the display **150**, which, as discussed above, presents information to and may receive information from (e.g., touchscreen) the user **230**. The power supply **730** receives power from power source **110** (e.g., electric utility, generator, source of renewable energy). The coolant pump **740** circulates coolant from the coolant reservoir **746** through the electric cable **140/540** to cool the conductors (e.g., **310**, **320**, **510**, **520**, **550**, **560**). Pressure sensor **742** detects the pressure of the coolant in the channels (e.g., passages, voids) of the electrical cable **140/540**. The flow rate detector **744** detects the rate of flow of the coolant through the electrical cable **140/540**.

[0030] The processing circuit **710** may control the power supply **730** to start and stop energy delivery to the electric vehicle **200**. The processing circuit **710** may provide information to the user **230** via the display **150** with respect to the status (e.g., stage, state, progress) of the charging process. The processing circuit **710** may monitor and control the rate of energy delivery to the electric vehicle **200**. The processing circuit **710** may monitor the temperature of the conductors (e.g., **310**, **320**, **510**, **520**, **550**, **560**). The processing circuit may increase or decrease the rate of energy delivery in accordance with the temperature of the conductors **310** and

320. The processing circuit may increase or decrease the rate of coolant flow and/or pressure in accordance with the temperature of the conductors. The processing circuit **710** may receive information from the coolant pump **740**, the pressure sensor **742** and/or the flow rate detector **744**. The processing circuit **710** may control the coolant pump **740** in accordance with the temperature of the conductors and/or the information from the coolant pump **740**, the pressure sensor **742** and/or the flow rate detector **744**.

[0031] In an example embodiment, the processing circuit **710** is configured to instruct the coolant pump to increase the pressure and/or the flow rate of the coolant through the channels (e.g., **330**, **340**, **512**, **522**, **552**, **562**, **1110**) to decrease the temperature of the conductors (e.g., **310**, **320**, **510**, **520**, **550**, **560**). As the temperature of the conductors decreases, the processing circuit is configured to control the power supply **730** to increase the rate of delivery to the electric vehicle **200**. The processing circuit **710** may balance the rate of delivery of energy, the pressure and/or flow rate of the coolant in the channels and the temperature of the conductors to decrease an amount of time needed to recharge the battery **240**.

[0032] The insertion detector **722** is configured to detect the physical presence of the handle **130/530** in the receptacle **120**. While the handle **130/530** is inserted into the receptacle **120**, the handle **130/530** and the conductors (e.g., **310**, **320**, **510**, **520**, **550**, **560**) may be electrically connected to the connectivity detector **724**. The connectivity detector **724** may report data to the processing circuit **710**. The connectivity detector **724** may electrically connect the conductors **310** and **322** the power supply **730** while the handle **130/530** is inserted into the receptacle **120**. The handle **130/530** and the conductors may electrically connect to the power supply **730** for testing purposes and/or to short out (e.g., ground) the conductors when not in use to protect the user **230** from any potential electric shock.

Electric Vehicle Charging System

[0033] In an example embodiment, the electric vehicle **200** includes the charging system **1000**. In an example embodiment, a charging system **1000** includes receptacle **220**, processing circuit **1010**, insertion detector **1022**, connectivity detector **1024**, communication circuit **1040** and user interface **1560**. The processing circuit **1010** controls some or all of the components of the charging system **1000** completely or partially. The insertion detector **1022** detects the physical presence of the handle **130/530** in the receptacle **220**. Insertion detector **1022** may further include a lock that locks (e.g., holds, affixes) the handle **130/530** in the receptacle **220** during the charging process. Locking the handle **130/530** in the receptacle **220** prohibits the user **230** from removing the handle **130/530** from the receptacle **220** during the charging process and in particular while high currents flow from the charger **100** to the electric vehicle **200**. The lock may further fix the position of the handle **130/530** with respect to the receptacle **220** to maintain an electrical connection between the handle **130/530** and the conductors (e.g., **310**, **320**, **510**, **520**, **550**, **560**) with the electric vehicle **200**.

[0034] The connectivity detector **1024** is configured to detect whether the handle **130/530** and thereby the conductors (e.g., **310**, **320**, **510**, **520**, **550**, **560**) are electrically connected to the electric vehicle charging system **1000** and thereby to the battery **240**. Energy cannot be delivered from the charger **100** to the battery **240** unless there is an electrical connection between the charger **100** and the electric vehicle charging system **1000**. In an example embodiment, the connectivity detector **1024** is configured to determine when the handle **130/530** and thereby the conductors (e.g., **310**, **320**, **510**, **520**, **550**, **560**) are electrically connected to the charging system **1000**. In one embodiment, the connectivity detector **1024** detects that the handle **130/530** is electrically connected to the electric vehicle charging system **1000**. The connectivity detector **1024** reports the connection to the charger **100** via the electrical cable **140/540**. In another embodiment, the connectivity detector **1024** reports the status of the connection to the processing circuit **1010**. The processing circuit **1010** transmits the status of the connection to the processing circuit **710** via the communication link **210**. The processing circuit **1010** may report when the handle **130/530** is electrically connected to the electric vehicle charging system **1000** and when the handle **130/530** is not electrically connected to the electric vehicle charging system **1000**.

[0035] The processing circuit **710** may receive the status of the connection between the handle **130/530** and the electric vehicle charging system **1000** from the processing circuit **1010** via the communication circuit **1050**, the communication link **210** and the communication circuit **750**. The processing circuit **710** may use the information regarding the status of the connection to provide coolant to or evacuate coolant from the channels (e.g., **330**, **340**, **512**, **522**, **552**, **562**, **1110**) of the electrical cable **140/540**. In an example embodiment, the processing circuit **710** controls the coolant pump **740** to provide coolant to the electrical cable **140/540** only while the handle **130/530** is inserted into and electrically connected to the electric vehicle charging system **1000**. Once the battery **240** has been charged, but prior to permitting the user **230** to remove the handle **130/530** from the receptacle **220**, the processing circuit **710** may instruct the coolant pump **740** to evacuate the channels of most or all of the liquid coolant and/or reduce the pressure of the gas in the channels.

[0036] Once the coolant has been evacuated and/or the pressure reduced, the processing circuit **710** may inform the user via display **150** that the handle **130/530** may be removed from the receptacle **220**. The processing circuit **710** may also inform the user **230** that the handle **130/530** may be removed from the receptacle **220** by transmitting a message to the processing circuit **1010** via the communication circuit **750**, the communication link **210** and the communication circuit **1050** to the processing circuit **1010**. The processing circuit **1010** may inform the user via the display **1062** that the handle **130/530** may be removed from the receptacle **220**.

Electrical Cable—First Embodiment

[0037] In a first example embodiment of an electrical cable, the electrical cable **140** includes the conductor **310**, the conductor **320**, the channel **330**, the channel **340** and housing (e.g., case, receptacle, sheath) **350**. The housing **350** is formed of an insulator (e.g., electrically insulating) material. Housing **350** encases (e.g., encloses, encircles) the conductors **310** and **320** and forms the channels **330** and **340**. The inside diameters of the channels **330** and **340** are greater than the outer (e.g., outside) diameter of the conductors **310** and **320** respectively thereby leaving room for a coolant to flow around the conductors **310** and **320**. The housing **350** separates the conductors **310** and **320** mechanically and electrically. The housing **350** protects the user **230** from forming an electric circuit with the conductor **310** and/or the conductor **320** thereby protecting the user **230** from electrical shock. The channels **330** and **340**, as discussed above, may hold a coolant (e.g., a flow of coolant). The coolant comes into physical contact with the conductors **310** and **320**. The coolant transfers heat from the conductors **310** and **320** into the coolant. In an example embodiment, the coolant is a liquid. The liquid coolant circulates through the channels **330**, **340** and **410**. Heat is transferred from the conductors **310** and **320** into the liquid. Heat is carried away from the conductors **310** and **320** by the circulating liquid coolant. Heat is removed from the liquid coolant by the coolant pump **740**, or a separate refrigeration unit that is part of the circulation loop, thereby removing heat from the conductors **310** and **320**. In this example embodiment, the coolant remains a liquid as it receives, transfers and loses heat.

[0038] In another example embodiment, the coolant is a liquid that changes phase to remove heat from the conductors **310** and **320**. In this embodiment, the coolant pump **740** pumps a liquid into the channels **330** and **340** and removes a gas to remove heat from the conductors **310** and **320**. The coolant pump **740** removes energy from the gas thereby allowing the gas to become a liquid. In this example embodiment, a portion of the channels **330**, **340** and **410** may contain or transport the coolant in its liquid form, while the remaining portion of the channels contains the coolant in its gaseous form.

[0039] The coolant pump **740** controls the amount of coolant present in the channels **330** and **340**. As the amount of coolant in the channels **330** and **340** increases, the weight of the electrical cable **140** increases. As the amount of coolant in the channels **330** and **340** decreases, the weight of the electrical cable **140** decreases. The flexibility of the electrical cable **140** is also inversely proportional to the amount of coolant present in the channels **330** and **340** and the pressure of the coolant.

[0040] The processing circuit **710** is further configured to control the coolant pump **740** to evacuate coolant from the channels **330** and **340** prior to manipulation of the electrical cable **140** by the user **230**. The processing circuit **710** may also control the coolant pump **740** to decrease the pressure of the coolant in the channels **330** and **340** prior to manipulation of the electrical cable **140** by the user **230**. Reducing the amount and/or the pressure of the coolant in the channels **330** and **340** decreases the weight and increases the flexibility of electrical cable **140** to allow the user **230** to more easily lift and move the handle **130** and the electrical cable **140**.

[0041] In this example embodiment, the coolant pump **740** pumps a coolant into channel **330**, which may be referred to as the inlet channel **330**. The coolant pumped into the inlet channel **330** circulates through the inlet channel **330** as inward coolant flow **430**. Somewhere in the handle, the connecting channel **410** connects the inlet channel **330** to the channel **340**, which may be referred to as the outlet channel **340**. The coolant pump **740** continues to pump coolant into the inlet channel **330** thereby resulting in inward current flow **430**, connecting coolant flow **412** and outward coolant flow **440**. The pump provides inward coolant flow **430** into the inlet channel **330** and receives the outward coolant flow **440** from the outlet channel **340**. As the coolant circulates through the inlet channel **340**, the connecting channel **410** and the outlet channel **340**, the coolant extracts heat from the conductors **310** and **320** and delivers that heat in the form of the heated coolant to coolant pump **740** via flow **748**. Coolant reservoir **746** provides coolant to and receive coolant from the coolant pump via flow **752**.

[0042] The coolant pump **740**, in combination with the processing circuit **710**, is configured to set the pressure of the coolant that flows through the channels **330**, **410** and **340**. Pressure sensor **742** detects the pressure of the coolant exiting and/or entering the coolant pump **740**. Pressure sensors may be positioned along a length of the electrical cable **140/540** to enable the pressure sensor **742** to detect the pressure of the coolant at any position along the electrical cable **140/540**. The processing circuit **710** may also be configured to calculate the pressure of the coolant inside the channels **330**, **410** and **340** and along the length of the electrical cable **140/540** using the information provided by the pressure sensor **742**.

[0043] The flow rate detector **744** detects the rate of flow of coolant into the inlet channel **340** and/or out of the outlet channel **340**. The processing circuit **710** may also be configured to calculate the flow rate of the coolant inside the channels **330**, **410** and **340** using the information provided by the flow rate detector **744**.

Electrical Cable—Second Embodiment

[0044] In a second example embodiment of an electrical cable, the electrical cable **540** includes the conductor **510**, the conductor **520**, the conductor **550**, the conductor **560**, the channel **512**, the channel **522**, the channel **552**, the channel **562** and the housing **640**. The housing **640** is formed of an insulator material. Housing **640** encases the conductors **510**, **520**, **550** and **560** and forms the channels **512**, **522**, **552** and **562**. The inside diameters of the channels **512**, **522**, **552** and **562** are greater than the outer (e.g., outside) diameter of the conductors **510**, **520**, **550** and **560** respectively thereby leaving room for the coolant to flow around the conductors **510**, **520**, **550** and **560**. The channels **512**, **522**, **552** and **562** may combine with each other in any manner to permit the flow of coolant through the channels. Any number of channels may function as inlet channels while any number of other channels may function as outlet channels.

[0045] The housing **640** separates the conductors **510**, **520**, **550** and **560** mechanically and electrically. The housing **640** protects the user **230** from forming an electric circuit with the conductors **510**, **520**, **550** and/or **560** thereby protecting the user **230** from electrical shock. The channels **512**, **522**, **552** and **562**, as discussed above, may hold a coolant (e.g., a flow of coolant). The coolant comes into physical contact with the conductors **510**, **520**, **550** and **560**. The coolant transfers heat from the conductors **510**, **520**, **550** and **560** into the coolant. In an example embodiment, the coolant is a liquid. The liquid coolant circulates through the channels **512**, **522**, **552** and **562**. Heat is transferred from the conductors **510**, **520**, **550** and **560** into the liquid. Heat is carried away from the conductors **510**, **520**, **550** and **560** by the circulating liquid coolant. Heat is removed from the liquid coolant by the coolant pump **740**, or a separate refrigeration unit that is part of the circulation loop, thereby removing heat from the conductors **510**, **520**, **550** and **560**. In this example embodiment, the coolant remains a liquid as it receives, transfers and loses heat.

[0046] In another example embodiment, the coolant is a liquid that changes phase to remove heat from the conductors **510**, **520**, **550** and **560**. In this embodiment, the coolant pump **740** pumps a liquid into the channels **512**, **522**, **552** and **562** and removes a gas to remove heat from the conductors **510**, **520**, **550** and **560**. The coolant pump **740** removes energy from the gas thereby allowing the gas to become a liquid. In this example embodiment, a portion of the channels **512**, **522**, **552** and **562** may contain or transport the coolant in its liquid form, while the remaining portion of the channels contains the coolant in its gaseous form.

[0047] The coolant pump **740** controls the amount of coolant present in the channels **512**, **522**, **552** and **562**. As the amount of coolant in the channels **512**, **522**, **552** and **562** increases, the weight of the electrical cable **540** increases. As the amount of coolant in the channels **512**, **522**, **552** and **562** decreases, the weight of the electrical cable **540** decreases. The flexibility of the electrical cable **540** is also inversely proportional to the amount of coolant present in the channels **512**, **522**, **552** and **562** and/or the pressure thereof.

[0048] The processing circuit **710** further controls the coolant pump **740** to evacuate coolant from the channels **512**, **522**, **552** and **562** prior to manipulation of the electrical cable **540** by the user **230**. The processing circuit **710** may also control the coolant pump **740** to decrease the pressure of the coolant in the channels **512**, **522**, **552** and **562** prior to manipulation of the electrical cable **540** by the user **230**. Reducing the amount and/or the pressure of the coolant in the channels **512**, **522**, **552** and **562** decreases the weight and increases the flexibility of electrical cable **540** to allow the user **230** to more easily lift and move the handle **530** and the electrical cable **540**.

[0049] In an example embodiment, the coolant pump **740** pumps a coolant into channels **512** and **522**, which may be referred to as inlet channels **512** and **522**. The coolant pumped into the inlet channels **512** and **52** circulates through the inlet channels **512** and **52** as an inward coolant flow. Somewhere in the handle, the channels **512**, **522**, **552** and **562** meet a common cavity. The inward coolant flow enters the cavity and exits into channels **552** and **562**, which may be referred to as outlet channels **552** and **562**. The coolant that flows through the outlet channels **552** and **562** maybe referred to as an outward coolant flow. The outward coolant flow travels the length of the outlet channels **552** and **562** to the coolant pump **740**. The coolant pump **740** continues to pump coolant into the inlet channels **512** and **522** to circulate coolant through the channels **512**, **522**, **552** and **562**. As the coolant circulates through the channels **512**, **522**, **552** and **562**, the coolant extracts heat from the conductors **510**, **520**, **550** and **560** and delivers that heat in the form of the heated coolant to coolant pump **740** via flow **748**. Coolant reservoir **746** provides coolant to and receive coolant from the coolant pump via flow **752**.

[0050] The coolant pump **740**, in combination with the processing circuit **710**, sets the pressure of the coolant that flows through the channels **512**, **522**, **552** and **562**. Pressure sensor **742** is configured to detect the pressure of the coolant exiting and/or entering the coolant pump **740**. The processing circuit **710** may be configured to calculate the pressure of the coolant inside the channels **512**, **522**, **552** and **562** using the information provided by the pressure sensor **742**.

[0051] The flow rate detector **744** detects the rate of flow of coolant into the inlet channels **512** and **522** and/or out of the outlet channels **552** and **562**. The processing circuit **710** may be configured to calculate the flow rate of the coolant inside the channels **512**, **522**, **552** and **562** using the information provided by the flow rate detector **744**.

Spacers

[0052] In an example embodiment, an electrical cable includes two or more spacers (e.g., separators, castings) **360/660**. A spacer **360/660** fixes (e.g., sets, establishes) a space between an outer surface of a conductor (e.g., **310**, **320**, **510**, **520**, **550**, **560**) and the inner surface of a channel (e.g., **330**, **340**, **512**, **522**, **552**, **562**). The spacer **360/660** establishes (e.g., fixes) a space between the outer surface of the conductor and inner surface of the channel to provide an area for the flow of coolant. The spacer **360/660** maintains the space between the outer surface of the conductor and the inner surface of the channel as the user **230** moves and manipulates the electrical cable **140/540**. The spacers **360/660** maintain an open passage around and along a length of a conductor for the flow of coolant to contact and pass along the length of the conductor. In other words, the spacers keep the channel open for the flow of coolant on all sides around the conductor. The spacers **360/660** maintain the open passage along the length of the conductors regardless of the position of the electrical cable **140/540** with respect to the charger **100** and/or the electric vehicle **200**. The spacers **360/660** maintain a minimum distance between the outer surface of the conductor and the inner surface of the channel. The minimum distance enables a minimum amount of coolant to surround the conductor along the length of the conductor. Cooling all sides of the conductor (e.g., entire diameter) with a minimum amount of coolant flow decreases hotspots along the conductor.

[0053] In an example embodiment, a spacer **360** includes a base **362**, a stem **366** and a head **364**. The base **362** is positioned against and/or embedded in an inner surface of the channel (e.g., channel **330** as shown in FIG. **3**). The head **364** is positioned against and/or embedded in the conductor (e.g., conductor **310** as shown in FIG. **3**). The stem **366** is positioned between the base **362** and the head **364**. The stem **366** fixes the distance between the base **362** and the head **364**. The stem **366** fixes the distance between the outer surface of the conductor and the inner surface of the channel. The stem **366** establishes the height of the channel (e.g., passage/channel **330** of FIG. **3**). The stem **366** establishes the area around and along the length of the conductor through which the coolant moves.

[0054] In an example embodiment, two spacers **360** are positioned across the conductor opposite to each other. In another example embodiment, four spacers **360** are positioned around the conductor with the spacers **360** of one pair opposite each other and the spacers **360** of the other pair opposite each other. In an example embodiment, the base **362** is curved to fit along the inner surface of the channel. An example embodiment, the head **364** is curved to fit along the outer surface of the conductor. In an example embodiment, the depth (e.g., into page in FIG. **3**) of the base **362**, the head **364** and/or the stem **366** is between 0.5 cm and 5 cm. In another example embodiment, the depth of the base **362**, the head **364** and/or the stem **366** is the length of the conductor. In other words, the spacers run along the entire length or nearly the entire length of the conductor. In an example embodiment, spacer pairs positioned opposite each other are positioned between 0 and 30 cm apart from each other along the length of the conductor. In an example embodiment, the height of the stem **366** is between 1 cm and 8 cm.

[0055] In another example embodiment, a spacer **660** includes an outer band **662**, a plurality of standoffs **666** and an inner band **664**. The outer band **662** contacts, is embedded in and/or is encircled by an inner surface of the channel (e.g., channel **512** as shown in FIG. **6**). The inner band **664** encircles and/or is embedded in the conductor (e.g., conductor **510** as shown in FIG. **6**). The plurality of standoffs **666** are positioned between the inner band **664** and the outer band **662**. The plurality of standoffs **666** fix the distance between the outer band **662** and the inner band **664**. The plurality of standoffs **666** fix the distance between the outer surface of the conductor and the inner surface of the channel. The plurality of standoffs **666** establish the height of the channel (e.g., channel **512** of FIG. **6**). The plurality of standoffs **666** establish the area around and along the length of the conductor through which the coolant moves.

[0056] In an example embodiment, the outer band **662** is shaped to fit along the inner surface of the channel. The inner band **664** is shaped to fit along the outer surface of the conductor. In an example embodiment, the depth (e.g., into page in FIG. **6**) of the outer band **662** and/or the inner band **664** is between 0.5 cm and 5 cm. In another example embodiment, the depth of the outer band **662**, the inner band **664** and/or the standoffs **666** is the length of the conductor. In other words, the inner band **664** encircles the outer surface conductor along the entire length or almost the entire length of the conductor. The outer band **662** is positioned along the inner surface of the channel along the entire or almost the entire length of the channel. In an example embodiment, the height of each standoff of the plurality of standoffs **666** is between 1 cm and 8 cm.

[0057] In an example embodiment, the spacers **360/660** are formed of an electrically insulating material. In another example embodiment, the spacers **360/660** are formed of an electrically insulating, but thermally conductive material. In another example embodiment, the spacers **360/660** are formed of an electrically and thermally conductive material (e.g., metal). In the embodiments in which the spacers **360/660** are formed of thermally conductive material, the spacers **360/660** increase the thermal surface area of the conductor thereby increasing the amount of heat that can be transferred from the conductor into the coolant. For example, the surface area of the inner portion of the base **362** or the outer band **662** (e.g., the portion not in contact with the inner surface of the channel), the surface area of the stem **366** or standoff **666**, and the surface area of the outer portion of the head **364** or inner band **664** (e.g., the portion not in contact with the conductor) come into contact with the coolant, thereby providing increased surface area for the transfer of heat from the conductor to the coolant. In this embodiment, the spacers **360/660** receive heat from the conductor. As the coolant passes over the conductor and the spacers **360/660**, both the conductor and the spacers **360/660** transfer heat to the coolant, but because the spacers **360/660** increase the surface area of the conductors, the transfer of heat from the conductor and the spacers **360/660** to coolant is more effective than an embodiment that does not include the spacers **360/660**.

Evacuating Coolant from the Channels

[0058] As discussed above, after the process of charging the battery **240** of the electric vehicle **200** is completed, the liquid coolant is evacuated (e.g., removed) from the channels (e.g., **330**, **340**, **512**, **522**, **552**, **562**, **1110**) of the electrical cable **140/540** or the pressure of a gaseous coolant in the channels (e.g., **330**, **340**, **512**, **522**, **552**, **562**, **1110**) is reduced to make it easier for the user **230** to move the electrical cable **140/540**.

[0059] Liquid coolant may be removed from the channels (e.g., **330**, **340**, **512**, **522**, **552**, **562**, **1110**) of the electrical cable **140/540** in any manner. In describing example embodiments of methods for removing the coolant from the electrical cables **140/540**, the term proximate end of the electrical cable **140/540** and/or the channels (e.g., **330**, **340**, **512**, **522**, **552**, **562**, **1110**) refers to the portion of electrical cable **140/540** and/or the channels (e.g., **330**, **340**, **512**, **522**, **552**, **562**, **1110**) proximate to the charger **100**. The term distal end refers to the portion of electrical cable **140/540** and/or the channels (e.g., **330**, **340**, **512**, **522**, **552**, **562**, **1110**) proximate to the handle **130/530** attached to the electrical cable **140/540**.

[0060] In an example embodiment, the processing circuit is configured to control the components of the charger **100** to perform the following steps to evacuate the liquid coolant from the channels. Step (1): the coolant pump **740** ceases to pump the liquid coolant through the channels (e.g., **330**, **340**, **512**, **522**, **552**, **562**, **1110**) of the electrical cable **140/540**.

[0061] Step (2): the coolant pump **740** applies a vacuum force to the proximate end all of the chambers. In an example embodiment, the vacuum force is applied via the flow **748**.

[0062] Step (3): the relief valve **450**, positioned at any location along the length of the electrical cable **140/540** or at the handle **130/530** opens allowing air (e.g., a gas) into at least one of the channels. In FIG. **4**, the relief valve **450** is shown positioned at the distal end of the electrical cable **140**. In an example embodiment, the relief valve **450** is configured to open automatically upon application of the vacuum pressure to the channels. In another example embodiment, the relief valve **450** is an electromechanical device controlled by the processing circuit **710**. The air flowing into the channels via the relief valve **450** enables the vacuum pressure applied by the coolant pump **740** to evacuate (e.g., suck, remove) most or all of the liquid coolant out of all of the chambers. The coolant pump **740** directs the coolant from the channels and any gas that may enter the coolant pump **740** into the coolant reservoir **746**. The coolant pump **740** may remove any gas from the liquid prior to sending the liquid to the coolant reservoir **746**. In another embodiment, the coolant pump **740** removes the gas from the liquid in the coolant reservoir **746**.

[0063] Step (4): the coolant pump **740** stops supplying vacuum force to all of the channels. Step (5): the relief valve **450** closes, due to the change in pressure or by command of the processing circuit **710**.

[0064] In another example embodiment, the processing circuit **710** is configured to control the components of the charger **100** to perform the following steps to evacuate the liquid coolant from the channels.

[0065] Step (1): the coolant pump **740** ceases to pump the liquid coolant through the channels (e.g., **330**, **340**, **512**, **522**, **552**, **562**, **1110**) of the electrical cable **140/540**.

[0066] Step (2): the coolant pump **740** pumps a gas (e.g., air) into at least one channel (e.g., inlet channel) of the electrical cable **140/540**. The gas forces the liquid coolant out of the other channels (e.g., outlet channel). The coolant pump **740** receives the liquid coolant from other channels. The coolant pump **740** moves the liquid coolant into the coolant reservoir **746**.

[0067] Step (3): once most or all of the liquid coolant is forced from the channels, the coolant pump **740** ceases to provide gas into the channel.

[0068] Step (4): The coolant pump **740** reduces the pressure of the gas in the channels. The coolant pump **740** reduces the pressure of the gas preferably to the pressure of a single atmosphere.

[0069] Step (5): The coolant pump **740** removes any gas from the liquid prior to sending the liquid to the coolant reservoir **746** or removes any gas from the liquid in the coolant reservoir **746**.

[0070] In another example embodiment, the processing circuit **710** is configured to control the components of the charger **100** to perform the following steps to evacuate the phase change coolant from the channels.

[0071] Step (1): the coolant pump **740** ceases to pump the coolant that cools via phase change through the channels (e.g., **330**, **340**, **512**, **522**, **552**, **562**, **1110**) of the electrical cable **140/540**.

[0072] Step (2): the coolant pump **740** pumps a gas (e.g., coolant in gaseous form) into at least one channel (e.g., inlet channel) of the electrical cable **140/540**. The gas forces the coolant that is in liquid form out of the other channels (e.g., outlet channel). The coolant pump **740** receives the coolant from other channels.

[0073] Step (3): once most or all of the coolant that is in liquid form is forced from the channels, the coolant pump **740** ceases to provide the gas into the channel. The coolant that is in gaseous form begins to cool and moves to its liquid state. The coolant that changes from the gas state to the liquid state inside the channels of the electrical cable **140/540** may leave a small amount of liquid in the channels. The small amount of liquid may be left in the channels if it does not impede the movement of the electrical cable **140/540** by the user **230**. If the small amount of liquid left in the channels does impede movement of the electrical cable **140/540** by the user **230**, it may be forced out of the channels as described above.

[0074] Step (4): The coolant pump **740** reduces the pressure of the gas in the channels. The coolant pump **740** reduces the pressure of the gas preferably to the pressure of a single atmosphere.

[0075] Step (5): the coolant cools and goes into its liquid state. The coolant pump **740** moves the liquid coolant into the coolant reservoir **746**.

[0076] In another example embodiment, a small air compressor is positioned in the handle **130/530** at the distal end of the electrical cable **140/540**. The air compressor is configured to be controlled by the processing circuit **710**. The air compressor is configured to force pressurized air (e.g., high-pressure gas) into the distal ends of the channels. As the pressurized air enters the channels at the distal end, the coolant in the channels is pushed along the channels and out of the proximate ends into the coolant pump **740**. The coolant pump **740** receives the coolant, whether in liquid or gas state until the channels are evacuated. Once the channels are evacuated, the processing circuit **710** is configured to stop the operation of the air compressor. The coolant pump **740** may direct the coolant to the coolant reservoir **746**. The coolant pump **740** may remove any air injected into the coolant. The coolant pump may open and close the proximate ends of the channels to allow the air compressor to build up pressure inside the channels to better force the coolant from the channels into the coolant pump **740**. The coolant pump **740** and/or the processing circuit **710** may open and close the proximate ends of the channels any number of times to better evacuate coolant from the channels. The coolant pump **740** may close the proximate ends other channels until the air compressor increases the pressure inside the channels to a threshold. Once a threshold is reached, the coolant pump **740** may open the proximate ends of the channels to allow the coolant to flow from the channels into the coolant pump **740** and/or the coolant reservoir **746**.

[0077] In another example embodiment, the electrical cable **140/540** includes an additional channel (e.g., **1110**) for transporting a high-pressure gas from the coolant pump **740** to the handle **130/530** and the distal ends of the channels (e.g., **330**, **340**, **512**, **522**, **552**, **562**). Additional channel is not used to carry coolant. The coolant pump **740** provides a high-pressure gas to the distal ends of the channels via the additional channel to force the coolant in the channels toward and into the coolant pump **740** and/or the coolant reservoir **746**. The coolant pump **740** may very (e.g., increase, decrease, start, stop) the pressure of the additional channel to very the pressure inside the channels to better vacate the channels of coolant. Once the channels are vacated of coolant, the coolant pump **740** ceases to provide the high-pressure gas to the distal ends of the channels via the additional channel.

[0078] In another example embodiment, best seen in FIGS. **11-13**, the electrical cable **140** includes an additional channel **1110**. The additional channel **1110** does not surround a conductor. The additional channel **1110** may have the same diameter as channels **330** and **340** or it may be smaller. The additional channel **1110** may be used to transport coolant from the coolant pump **740** to the distal ends of the channels **330** and **340**, which channels do surround conductors. Delivering coolant from the coolant pump **740** to the distal ends of the channels **330** and **340** via channel **1110** provides coolant at a chilled (e.g., cooled, low, TO) temperature to the distal end of the electrical cable **140**. The advantage of providing chilled coolant to the distal end of the electrical cable **140** is that the coolant has not traveled along the length of a conductors and is not heated by the time it reaches the distal end of the electrical cable **140**.

[0079] As best shown in FIG. **12**, while battery **240** is being charged, coolant **1210** is pumped into channel **1110** and coolant **1220** is pumped into channel **330** both at temperature TO, which is the chilled temperature. When coolant **1210** reaches the chamber **1240** at the distal end of electrical cable **140**, its temperature is still TO. When coolant **1220** reaches the chamber **1240**, its temperature is T**2**, which is greater than T**0**, because it received (e.g., extracted) heat from conductor **310** along the way. The coolant **1210** and **1220** mix in chamber **1240** so that the temperature of the coolant flowing into the distal end of chamber **340** is temperature T**1**. Temperature T**1** is less than temperature T**2**, but greater than temperature T**0**. By the time the coolant **1230** has traveled from the distal end to the proximate end of the electrical cable **140**, its temperature has risen to be temperature T**3**. Temperature T**3** is greater than temperature T**2**. Using channel **1110** to provide coolant at temperature T**0** to the distal end of cable **140** decreases the temperature of the coolant entering channel **340** from the temperature T**2** to the temperature T**1** thereby providing additional cooling to the conductor **320** than it would otherwise have without using channel **1110**. In another example embodiment, the temperature of coolant **1210** is less than the temperature T**0** to reduce the temperature T**1** entering the distal end of channel **340**. However, the temperature T**0** may be the lowest temperature at which the coolant pump may provide coolant, so the coolant **1210** and **1120** are the same at the proximate ends of the channels **1110** and **330**.

[0080] Once the battery **240** has been charged, the channel **1110**, as best seen in FIG. **13**, may be used to clear the coolant from the channels **330** and **340**. To clear the coolant from the cable **140**, the coolant pump **740** forces a pressurized gas **1310** into the proximate end of channel **1110**. The pressurized gas **1310** pushes coolant from the proximate end to the distal end of channel **1110** into the chamber **1240**. The pressurized gas forces the coolant out of chamber **1240** into the distal ends of channels **330** and **340**. The pressurized gas forces the coolant **1320** and **1330** from the distal ends to the proximate ends of the channels **330** and **340** into the coolant pump **740** and/or the coolant reserve **746**. Once the pressurized gas has pushed the coolant out of the electrical cable **140**, the coolant pump **740** ceases to provide the high-pressure gas **1310**.

[0081] In another example embodiment, the handle **130/530** may include a chamber. After the user has connected the electrical cable **140/540** to the electric vehicle **200**, but before starting to charge the battery **240** of the electric vehicle **200**, the coolant pump **740** forces gas into the chamber at a high pressure so that the chamber holds the gas at the high pressure. The coolant pump **740** may provide the high-pressure gas to the chamber via one or more of the channels (e.g., **330**, **340**, **512**, **522**, **552**, **562**) since at this point they do not contain coolant. Once the chamber contains the high-pressure gas, the coolant pump **740** and/or the processing circuit **710** closes a valve to the chamber thereby trapping the high-pressure gas inside the chamber. While the electric vehicle is being charged, the coolant flows through the channels and the chamber retains high-pressure gas. Once charging is completed, the valve to the chamber is opened so that the high-pressure gas pushes against the coolant in the channels at the distal ends of the channels. The high-pressure gas exits the chamber and pushes the coolant from the channels to the proximate end of the electrical cable **140/540**. The high-pressure gas forces the coolant out of the channels (e.g., **330**, **340**, **512**, **522**, **552**, **562**) into the coolant pump **740** and/or the coolant reservoir **746** thereby evacuating the channels of coolant.

First Example Method for Charging an Electric Vehicle

[0082] The method **800** is a first example method for charging a battery of an electric vehicle. Method **800** is performed by the charger **100**, the user **230** and the electric vehicle **200**. In the example method **800**, the charger **100** is configured to perform the following operations: inserted **810**, establish **812**, connectivity **814**, start **816**, start **818**, coolant **820**, adjust **822**, user **824**, charging **826**, decrease **828**, finished **830**, stop **832**, remove **834**, inform **836** and inform **838**. The user **230** performs the following operations: removes **850**, terminates **852** and extracts **854**. The electric vehicle is configured to perform the following operations: handle **870**, establish **872**, connectivity **874**, finished **876** and inform **878**. The flow of the various operations of the example method **800** are shown in FIGS. **8**A and **8**B.

[0083] In inserted **810**, the charger **100** determines whether the handle **130** is inserted into the receptacle **120**. If the handle **130** is inserted into the receptacle **120**, the charger is in a quiescent state in which it is not being used to charge the electric vehicle **200**. If handle **130** is not inserted into the receptacle **120**, the charger may presently be in use or will soon be in use to charge the battery **240** of the electric vehicle **200**. Removal of handle **130** from the receptacle **120** causes operation of the charger **100** to move from inserted **810** to establish **812**.

[0084] In establish **812**, the charger **100** establishes communication with the electric vehicle **200** and/or the user **230** (e.g., user's electronic device) via the communication circuit **750**. Establishing communication enables the charger **100** communicate with the electric vehicle **200** and/or the user **230** via the communication link **210**.

[0085] In connectivity **814**, the charger **100** determines whether the handle **130/530** and therefore the electrical cable **140/540** is electrically connected to the electric vehicle **200**. If the handle **130/530** is electrically connected to the electric vehicle **200**, the operation of the charger **100** moves to start **816**.

[0086] In start **816**, the processing circuit **710** is configured to instruct the coolant pump **740** to start the flow of coolant through the electrical cable **140**. The operation start **816** moves the coolant from the coolant reservoir **746** into the channels (e.g., **330**, **340**, **512**, **522**, **552**, **562**, **1110**).

[0087] In start **818**, the processing circuit **710** is configured to instruct the power supply **730** to start providing electrical energy (e.g., a current) to the electric vehicle **200** via the electric cable **140** and the handle **130**. The processing circuit **710** may wait to execute start **818** until the conductors (e.g., **310**, **320**, **510**, **520**, **550**, **560**) in the electrical cable **140/540** reach a threshold temperature.

[0088] In coolant **820**, the processing circuit **710** is configured to monitor the pressure of the coolant and the flow of the coolant in coolant pump **740** and/or the electrical cable **140/540**. The processing circuit **710** is further configured to monitor the temperature of the conductors (e.g., **310**, **320**, **510**, **520**, **550**, **560**) and/or the coolant. The operation coolant **820** may further compare the temperature of the coolant and/or the conductors to a desired temperature or a desired range of temperatures. If the temperature of the coolant and/or the conductors is not at or near the desired temperature or within the desired temperature range, operation may move to adjust **822**. The execution of coolant **820** may be interrupted by the optional operation user **824**. While the temperature of the conductors is monitored, the operation charging **826** may detect when the charging process is near its end.

[0089] In adjust **822**, the processing circuit **710** is configured to adjust the pressure and/or the flow rate of the coolant in the electrical cable **140** to move the temperature of the conductors (e.g., **310**, **320**, **510**, **520**, **550**, **560**) to the desired temperature or to within the desired temperature range. For example, if the temperature of the conductors is higher than the desired temperature or range, the processing circuit **710** may increase the pressure and/or flow rate of the coolant to further cool the conductors. If the temperature of the conductors is lower than desired, the processing circuit **710** may decrease the pressure and/or flow rate of the coolant to allow the temperature of the conductors to increase.

[0090] User **824** is an optional operation. In user **824**, the processing circuit **710** is configured to determine whether the user **230** has requested termination of the charging process. If the user has requested termination of the charging process, operation moves to decrease **828**. If the user has not requested termination of the charging process, operation moves to charging **826**.

[0091] In charging **826**, the processing circuit **710** is configured to determine whether the charging process is near its end. The processing circuit **710** may communicate with the processing circuit **1010** to determine the status of the charging process. The processing circuit **1010** may monitor the voltage across battery **240** and/or the amount of charge stored by battery **240** to determine the status of the charging process. If the battery **240** is approaching the desired amount of energy to be stored, the processing circuit **1010** may inform the processing circuit **710** via the communication link **210** that charging is getting near to the end of the process. If charging is near the end of the process execution moves to decrease **828**.

[0092] In decrease **828**, the processing circuit **710** instructs the power supply **730** to decrease the charging rate or in other words the amount of energy being sent to the electric vehicle **200**. In accordance with the temperature of the conductors, the processing circuit **710** may also instruct the coolant pump **740** to decrease the flow rate and/or pressure of the coolant in the electrical cable **140/540**. Charging **826** and decrease **828** may be omitted so that control passes from user **824** or coolant **820** to finished **830**.

[0093] Finish **830** determines whether the charging process is finished. During finish **830**, the processing circuit **710** may further communicate with the processing circuit **1010** to receive additional information regarding charging from the electric vehicle **200**. When the charging process is complete, execution moves to stop **832**.

[0094] In stop **832**, the processing circuit **710** is configured to instruct the power supply **732** stop supplying energy to the electric vehicle **200**. In stop **832**, the amount of current provided to the battery **240** via the electrical cable **140/540** is reduced to zero. The flow of coolant may continue for a period of time after the flow of current ceases to further cool the conductors (e.g., **310**, **320**, **510**, **520**, **550**, **560**). Operation remains in stop **832** until the conductors have reached a desired temperature or temperature range.

[0095] In remove **834**, the processing circuit **710** is configured to instruct the coolant pump **740** to evacuate the coolant from the channels (e.g., **330**, **340**, **512**, **522**, **552**, **562**, **1110**) of the electrical cable **140/540**. The coolant pump **740** evacuates most if not all of the coolant from the electrical cable **140/540**. Various example embodiments of methods for evacuating the coolant from the electrical cable **140/540** are discussed above.

[0096] In inform **836**, the processing circuit **710** is configured to inform the user **230** via the display **150**, the display **1062** and/or an electronic device (e.g., cell phone, tablet) that the charging process is complete.

[0097] In inform **838**, the processing circuit **710** informs the user via the display **150**, the display **1062** and/or an electronic device that the charging handle **130/530** may be removed from the receptacle **220**. The processing circuit **710** may further request that the user insert the charging handle **130/530** into the receptacle **120**.

[0098] In removes **850**, the user removes the charging handle **130/530** from the receptacle **120**. The user inserts the charging handle **130/530** into the receptacle **220**. Six

[0099] Terminate **852** is an optional operation. In terminate **852**, the user **230** requests termination of the charging process. Terminate **852** may be used to terminate the charging process prematurely. The user may request termination via the user interface **760** of the charger **100** and/or the user interface **1060** of the electric vehicle charging system **1000**.

[0100] In extracts **854**, the user extracts the handle **130** from the receptacle **220** and inserts the handle **130** into the receptacle **120**. Because the coolant has been evacuated from the electrical cable **140/540** prior to performance of extracts **854**, the electrical cable **140/540** is much lighter and more flexible than if it were filled with coolant, so the electrical cable **140/540** is much easier to handle than it otherwise would be.

[0101] In handle **870**, the processing circuit **1010** is configured to determine whether the charging handle **130/530** is inserted into the receptacle **220**. If the charging handle **130/530** is inserted into the receptacle **220**, the charger **100** is or will soon be in an active state in which it is used to charge the battery **240**. If charging handle **130/530** is not inserted into the receptacle **220**, the charger cannot be used to charge the electric vehicle **200**. Inserting the charging handle **130/530** into the receptacle **220** causes operation to move from handle **870** to establish **872**.

[0102] In establish **872**, the processing circuit **1010** establishes communication with the processing circuit **710** via the communication circuits **1050** and **750**. Establishing communication enables the electric vehicle **200** to communicate with the charger **100** via the communication link **210**.

[0103] In connectivity **874**, the processing circuit **710** is configured to determine whether the charging handle **130/530** and therefore the electrical cable **140/540** is electrically connected to the electric vehicle **200**. If the charging handle **130/530** is electrically connected to the electric vehicle **200**, operation moves to finished **876**.

[0104] Finish **876** determines whether the charging process is finished. Processing circuit **710** may cooperate with processing circuit **1010** to determine when the charging process is finished. The processing circuit **1010** may monitor the voltage across the battery **240** and/or the amount of charge stored by the battery **240**. The processing circuit **710** may monitor the voltage across the conductors (e.g., **310**, **320**, **510**, **520**, **550**, **560**) and/or the amount of charge already provided to the battery **240**. Either processing circuit **710**, processing circuit **1010** or both may determine when charging the battery **240** is finished. The processing circuit **710** and **1010** may communicate with each other via the communication link **210** regarding the status of the charging process. When the charging process is complete, execution moves to inform **878**.

[0105] In inform **878**, the processing circuit **1010** informs the user **230** via the display **1062** and/or an electronic device that the electrical cable **140/540** may be removed from the receptacle **220**.

Second Example Method for Charging an Electric Vehicle

[0106] The method **900** is a second example method for charging a battery of an electric vehicle. The method **900** is performed by charger **100**, user **230** and electric vehicle **200**. In the method **900**, the charger **100** is configured to perform the following operations: inserted **810**, establish **812**, connectivity **814**, start **910**, start **818**, coolant **912**, adjust **914**, user **824**, charging **826**, decrease **916**, finished **830**, reduce **918**, inform **836** and inform **838**. The user **230** performs the following operations: removes **850**, terminates **852** and extract **854**. The electric vehicle is configured to perform the following operations: handle **870**, establish **872**, connectivity **874**, finished **876** and inform **878**. The flow of the various operations of the example method **900** are shown in FIGS. **9**A and **9**B.

[0107] The method **900** is for a coolant that changes phase to cool the conductors (e.g., **310**, **320**, **510**, **520**, **550**, **560**). Phase-change cooling uses the vaporization of a liquid to cool an object. A liquid may be injected into the channels (e.g., **330**, **340**, **512**, **522**, **552**, **562**, **1110**) of the electrical cable **140**/**540**. The heat from the conductors **310** and **320** causes the liquid to change from a liquid phase to a gas phase. The change in the phase of the liquid extracts heat from the conductors to cool them.

[0108] The operations inserted **810**, establish **812**, connectivity **814**, start **818**, user **824**, charging **826**, finished **830**, inform **836**, inform **838**, removes **850**, terminates **852**, extract **854**, handle **870**, establish **872**, connectivity **874**, finished **876** and inform **878** of the method **900** are the same as the similarly number operations in the example method **800**. The operations start **910**, coolant **912**, adjust **914**, decrease **916** and reduce **918** of method **900** differ from the operations start **816**, coolant **820**, adjust **822**, decrease **828** and remove **834** respectively of the method **800** in that method **900** deals with phase-change cooling whereas method **800** deals with cooling using a liquid that does not change phase.

[0109] In coolant **912**, the processing circuit **710** is configured to change either the flow of the liquid into the electrical cable **140**/**540** or the pressure of the gas in the channels (e.g., **330**, **340**, **512**, **522**, **552**, **562**, **1110**) to provide the cooling necessary to maintain the conductors (e.g., **310**, **320**, **510**, **520**, **550**, **560**) at a desired temperature or within a desired temperature range.

[0110] In adjust **914**, the processing circuit **710** is configured to change either the flow of liquid coolant into the channels (e.g., **330**, **340**, **512**, **522**, **552**, **562**, **1110**) of the electrical cable **140**/**540** or the pressure of the gas in the channels to either increase or decrease the amount of cooling performed to maintain the conductors at the desired temperature or within the desired temperature range.

[0111] In decrease **916**, the processing circuit **710** is configured to change either the flow of the liquid coolant into the channels (e.g., **330**, **340**, **512**, **522**, **552**, **562**, **1110**) of the electrical cable **140**/**540** and/or increases the extraction of gas from the channels to reduce the amount of coolant in the electrical cable **140**/**540**.

[0112] In reduce **918**, the processing circuit **710** is configured to control the coolant pump **740** to extract the coolant, regardless of phase, from the electrical cable **140**/**540** and/or to reduce the pressure of the gaseous coolant in the channels (e.g., **330**, **340**, **512**, **522**, **552**, **562**, **1110**). The objective being to remove as much coolant as possible, regardless of phase, from the electrical cable **140**/**540**.

Afterword

[0113] The foregoing description discusses implementations (e.g., embodiments), which may be changed or modified without departing from the scope of the present disclosure as defined in the claims. Examples listed in parentheses may be used in the alternative or in any practical combination. As used in the specification and claims, the words 'comprising', 'comprises', 'including', 'includes', 'having', and 'has' introduce an open-ended statement of component structures and/or functions. In the specification and claims, the words 'a' and 'an' are used as indefinite articles meaning 'one or more'. While for the sake of clarity of description, several specific embodiments have been described, the scope of the invention is intended to be measured by the claims as set forth below. In the claims, the term "provided" is used to definitively identify an object that is not a claimed element but an object that performs the function of a workpiece. For example, in the claim "an apparatus for aiming a provided barrel, the apparatus comprising: a housing, the barrel positioned in the housing", the barrel is not a claimed element of the apparatus, but an object that cooperates with the "housing" of the "apparatus" by being positioned in the "housing".

[0114] The location indicators "herein", "hereunder", "above", "below", or other word that refer to a location, whether specific or general, in the specification shall be construed to refer to any location in the specification whether the location is before or after the location indicator.

[0115] Methods described herein are illustrative examples, and as such are not intended to require or imply that any particular process (e.g., step) of the embodiment be performed in the order presented. Words such as "thereafter," "then," "next," etc. are not intended to limit the order of the processes, and these words are instead used to guide the reader through the description of the methods.

What is claimed is:

1. A charger for providing energy to a provided electric vehicle to charge a provided battery of the provided electric vehicle, the charger comprising:

a processing circuit;

a pump;

a power supply;

a coolant; and

an electrical cable, the electrical cable includes a first conductor, a second conductor, a first channel and a second channel, the first conductor positioned in the first channel, the second conductor positioned in the second channel; wherein:

the processing circuit is configured to detect an electrical connection between the first conductor, the second conductor and the provided electric vehicle;

responsive to detecting the electrical connection, the pump is configured to circulate the coolant through the first channel and the second channel to bring the coolant into contact with the first conductor and the second conductor to remove heat from the first conductor and the second conductor;

responsive to the pump circulating the coolant, the power supply is configured to provide energy through the first conductor and the second conductor to the provided battery;

the processing circuit is configured to detect when the provided battery is charged;

responsive to the processing circuit detecting that the provided battery is charged: (1) the power supply ceases to provide energy to the provided battery via the first conductor and the second conductor, and (2) the pump continues to circulate the coolant through the first channel and the second channel until a temperature of the first conductor and the second conductor reaches a threshold temperature; and

responsive to the first conductor and the second conductor reaching the desired temperature, the pump is configured to evacuate the coolant from the first channel and the second channel thereby reducing a weight of the electrical cable.

2. The charger of claim **1** wherein:

the electrical cable further includes a plurality of spacers;

the plurality of spacers are positioned along a length of the first conductor; and

the plurality of spacers establish a distance between an inner surface of the first channel and an outer surface of the first conductor to create a passage around the first conductor through which the coolant flows.

3. The charger of claim **2** wherein:

each spacer of the plurality of spacers is thermally conductive;

heat from the first conductor passes into the plurality of spacers; and

the coolant comes into contact with the first conductor and the plurality of spacers thereby removing heat from the first conductor and the plurality of spacers.

4. The charger of claim **2** wherein each spacer of the plurality of spacers comprises:

a base;

a head; and

a stem positioned between the base and the head; wherein:

the base contacts the inner surface of first channel;

the head contacts an outer surface of first conductor; and

the stem establishes the distance between the inner surface of the first channel and the outer surface of the first conductor.

5. The charger of claim **2** wherein each spacer of the plurality of spacers comprises:

an outer band;

an inner band; and

a plurality of standoffs positioned between the inner band and the outer band; wherein:

the inner surface of the first channel encircles and contacts the outer band;

the inner band encircles and contacts the outer surface of first conductor; and

the plurality of standoffs establish the distance between the inner surface of the first channel and the outer surface of the first conductor.

6. The charger of claim **1** wherein to evacuate the coolant from the first channel and the second channel, the pump is configured to:

apply a vacuum force to a proximate end of the first channel and the second channel;

open a relief valve positioned at or near a distal end of the first channel and the second channel to enable a gas to enter the distal end of the first channel and the second channel; and

evacuate the coolant from the first channel and the second channel via the proximate end of the first channel and the second channel.

7. The charger of claim **1** wherein to evacuate the coolant from the first channel and the second channel, the pump is configured to:

pump a gas into a proximate end of the first channel; and

receive the coolant via a proximate end of the second channel.

8. The charger of claim **1** wherein to evacuate the coolant from the first channel and the second channel, the pump is configured to:

evacuate the coolant that is in a liquid state from the first channel and the second channel; and

decrease a pressure of a gas that remains in the first channel and the second channel to at most one atmosphere.

9. The charger of claim **1** further the electrical cable comprising a third channel, the third channel separate from the first channel and the second channel, the third channel does not surround a conductor, wherein:

while charging the provided battery:

the pump pumps the coolant into a proximate end of the third channel; and

coolant from a distal end of the third channel mixes with coolant from a distal end of a first channel prior to entering a distal end of a second channel; and

while evacuating the coolant from the electrical cable:

the pump pumps a pressurized gas into the proximate end of the third channel; and

the pressurized gas forces the coolant via the distal end of the third channel and via a proximate end of the first channel and the second channel thereby evacuating the coolant from the first channel, the second channel and the third channel.

10. The charger of claim **1** wherein:

the electrical cable further includes a plurality of spacers;

the plurality of spacers are positioned along a length of the first channel and the second channel; and

the plurality of spacers establish a distance between an inner surface of the first channel and an outer surface of the first conductor, and between an inner surface of the second channel and an outer surface of the second conductor to create a first passage around the first conductor and a second passage around the second conductor through which the coolant flows.

11. A method for providing energy to an electric vehicle to charge a battery of the electric vehicle, the method comprising:

detecting an electrical connection between an electrical cable of a charger and the electric vehicle, the electrical cable includes a first conductor, a second conductor, a first channel and a second channel, the first conductor positioned inside the first channel and the second conductor positioned inside the second channel;

removing heat from the first conductor and the second conductor by pumping a coolant through the first channel and the second channel whereby the coolant comes into contact with the first conductor and the second conductor thereby extracting heat from the first conductor and the second conductor;

providing energy to the battery of the electric vehicle via the first conductor and the second conductor to charge the battery;

responsive to detecting that the battery is charged, stopping providing energy to the electric vehicle via the first conductor and the second conductor; and

removing the coolant from the first channel and the second channel thereby making it easier for a user to move or lift the electrical cable.

12. The method of claim **11** wherein removing heat from the first conductor and the second conductor comprises:

pumping the coolant into a proximate end the first channel, the coolant entering the first channel has a first temperature;

pumping the coolant along a length of the first channel and the second channel between an inner surface of the first channel and the second channel respectively and an outer surface of the first conductor and the second conductor respectively to bring the coolant into contact with the first conductor, the second conductor and a plurality of spacers that fix a distance between the inner surface of the first channel and the second channel and the outer surface of the first conductor and the second conductor respectively;

receiving the coolant from a proximate end of the second channel, the coolant exiting the proximate end of the second channel has a second temperature, the second temperature is greater than the first temperature; and

reducing a temperature of the coolant exiting the proximate end of the second channel from the second temperature to at most the first temperature prior to pumping the coolant back into the proximate end of the first channel.

13. The method of claim **11** wherein removing the coolant from the first channel and the second channel comprises:

applying a vacuum force to a proximate end of the first channel and the second channel;

opening a relief valve at or near a distal end of the first channel or the second channel to permit a gas to enter the distal end of first channel and the second channel; and

receiving the coolant from the first channel and the second channel via the proximate end of the first channel and the second channel.

14. The method of claim **11** wherein removing the coolant from the first channel and the second channel comprises:

applying a vacuum force to a proximate end of the first channel and the second channel;

releasing a high-pressure gas from a chamber into a distal end of the first channel and the second channel; and

receiving the coolant from the first channel and the second channel via the proximate end of the first channel and the second channel.

15. The method of claim **11** wherein removing the coolant from the first channel and the second channel comprises:

pumping a high-pressure gas into a proximate end of a third channel, the third channel separate from the first channel and the second channel, the third channel does not surround a conductor, a distal end of the third channel provides the high-pressure gas to a distal end of the first channel and the second channel; and

a high-pressure gas forces the coolant from the first channel, the second channel and the third channel via a proximate end of the first channel and the second channel.

16. The method of claim **11** wherein removing the coolant from the first channel and the second channel comprises:

releasing a pressurized gas from a chamber into a distal end of the first channel and the second channel; and

receiving the coolant from the first channel and the second channel via a proximate end of the first channel and the second channel.

17. A cable for providing energy to a provided electric vehicle to charge a provided battery of the provided electric vehicle, the cable comprising:

a housing having a first length and a channel along the first length, the channel having a first diameter and an inner surface;

a conductor having a second length, a second diameter and an outer surface, the second diameter less than the first diameter, the conductor positioned inside the channel along the first length, the second length greater than or equal to the first length; and

a plurality of spacers, the plurality of spacers positioned around the conductor along the first length of the channel, each spacer of the plurality of spacers contacts the inner surface of the channel and the outer surface of the conductor to establish a distance between the inner surface of the channel and the outer surface of the conductor, the plurality of spacers maintain the channel open around the conductor for a flow of a provided coolant, whereby the flow of the provided coolant contacts the outer surface of the conductor whereby heat is transferred from the conductor to the provided coolant at a first rate to reduce a temperature of the conductor.

18. The cable of claim **17** wherein:

the plurality of spacers are formed of a thermally conductive material;

contact between the outer surface of the conductor and the plurality of spacers transfers heat from the conductor to the plurality of spacers; and

the flow of the provided coolant contacts the plurality of spacers and the outer surface of the conductor whereby heat is transferred from the plurality of spacers and the conductor at a second rate, the second rate is greater than the first rate.

19. The cable of claim **18** wherein prior to handling of the cable by a user, a provided pump evacuates the provided coolant from the channel thereby reducing a weight of the cable.

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