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(54) Title: SYSTEM AND METHOD FOR DEICING OF POWER LINE CABLES

(57) Abstract: A system and method for deicing power transmission cables divides the cable into sections. Switches are provided at each end of a section for coupling the conductors together in parallel in a normal mode, and at least some of the conductors in series in an anti-icing mode. When the switches couple the conductors in series, an electrical resistance of the cable section is effectively increased allowing self-heating of the cable by power-line current to deice the cable; the switches couple the conductors in parallel for less loss during normal operation. In an alternative embodiment, the system provides current through a steel strength core of each cable to provide deicing, while during normal operation current flows through low resistance conductor layers. Backup hardware is provided to return the system to low resistance operation should a cable overtemperature state occur.



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SYSTEM AND METHOD FOR DEICING OF POWER LINE CABLES

RELATED APPLICATIONS

[0001] The present application claims priority to commonly owned United States Provisional Patent Application 61/381,867 filed September 10, 2010. The present application also claims priority to, and is a continuation-in-part of, United States Patent Application 12/193,650, filed 18 August 2008, which in turn claims priority to Provisional Patent Application Serial Number 61/041,875 filed April 2, 2008. Each of the above-mentioned applications is incorporated herein by reference.

FIELD

[0002] The present document relates to the field of overhead power transmission lines. In particular, it relates to systems and methods for preventing or removing excessive ice accumulation on cables of such power transmission lines to prevent damage due to weight of the excessive ice.

BACKGROUND

[0003] Ice storms are fairly common in some parts of the United States. These storms result in an accumulation of ice on structures, including overhead power transmission lines and associated poles and towers; this ice may reach thicknesses of several inches. Such ice storms fortunately represent only a small percentage of the total operating time of a power transmission line, any one power transmission line typically encounters such conditions only a few times per year.

[0004] The mass of ice accumulated causes significant problems by mechanically stressing cables and structures. For example, a cylinder of 2"-ice adds 5.7ton/mile weight to a 1"-conductor. The altered profile of the cable will also increase wind-induced stress, further increasing the chance for it to break. Accumulated ice has caused power transmission lines and poles to break, and towers to collapse; either of which interfere with power transmission and can cause serious risk of harm to persons and property on the surface.

[0005] Some power transmission lines are trolley wires used to transmit power to electric vehicles. Since ice is not a good conductor, ice on trolley wires can interfere with power transmission to the vehicles.

[0006] Power transmission lines are normally designed to have a constant, low, overall resistance, so as to avoid excessive power losses and operation of wires at high temperatures. As wire reaches high temperatures, whether due to electrical self-heating, high ambient temperatures, or both, it tends to lengthen and weaken. This lengthening can cause the lines to sag between poles or towers, possibly causing hazard to persons or property on the surface. Further, low resistance during normal operation is desirable to avoid excessive power losses – every kilowatt lost to heating of lines is a kilowatt that must be generated but does not reach a customer. Finally, excessive voltage drops in the transmission line due to high resistance may cause instability of the power grid system.

[0007] Many power transmission lines have cables that have several individual conductors, often spaced several inches apart and connected electrically in parallel for each phase. While allowing higher ampacity by improving cooling in high ambient temperatures over cables of conductors in thermal contact with each other, this design increases the amount of ice that may accumulate by providing additional surface for ice nucleation. For example, a system having two parallel transmission lines, each line having three cables with five conductors per cable separated by spacers, all coated with two inches of ice, could have over 172 tons of extra weight per mile. Further, such design is incompatible with single-switch deicing designs because only energized conductors, or conductors in thermal contact with energized conductors, get deiced.

[0008] Not only can the high weight and increased wind drag of iced-over lines cause breakage of lines and collapse of a tower, but the sudden shift in forces on a tower resulting from an initial break in a line or collapse of a pole or tower can cause additional, adjacent, towers or poles to crumple like dominos – repair crews may find not just one flattened tower but wreckage of a dozen or more adjacent towers tangled among downed lines. Sudden collapse of a transmission line can also cause damage to switching equipment and power plants, and can lead to instability in power grids. In the worst case, sudden collapse of a transmission line can cause enough capacity loss and instability in power grids that resulting blackouts may extend over multiple states. It is therefore desirable to prevent, reduce, or remove ice accumulation on these lines.

[0009] US Patent 6396132 to Couture and US Patent Applications 2003/0006652 and 2008/0061632 describe a system having load cells or other apparatus for detecting accumulated ice on a transmission line. In this system, when ice is detected

one or more parallel conductors of a phase of a transmission line are disconnected by opening parallel mechanical and electronic switches, such that current flowing in the transmission line is diverted through and deices a selected one or a few of the parallel conductors. A pattern of open switches is then rearranged to divert current through a different one or a few of the parallel conductors.

[0010] Other systems for deicing power transmission lines are known in the art. For example, US Patent 4190137 to Shimada, couples parallel lines of a trolley system into a loop, then superimposes a current around the loop upon power ordinarily transmitted through the loop to deice the lines. In an embodiment, Shimada discloses DC trolley lines, with a superimposed AC current around a loop of the trolley lines for inducing joule heating to deice the lines.

[0011] Power transmission lines do not carry the same amount of current at all times. Current transmitted over a line varies with a wide variety of factors including load conditions – which in turn vary with time of day and weather, a particular selection of power plants operating at a moment in time, and other factors. For example, a power transmission line carrying power from a wind and solar farm into the power grid will carry current that may vary greatly with cloud, time of day, and wind conditions. Even conventional power plants, such as those having multiple units, may provide transmission line current that will change with time, for example one unit of a two unit plant may be shut down for repairs. Similarly, power transmission lines connecting energy storage systems, including pumped storage plants and battery storage plants to the power grid may conduct current intermittently.

SUMMARY

[0012] A system for deicing of power transmission lines, the power transmission lines having cables (one for each phase of a 3-phase line, or one for each polarity of a DC line) having at least three mutually insulated conductors. The system has switches that when closed place all three conductors in parallel for normal, low resistance, operation, and when opened place all three conductors electrically in series to deice the cable. The system operates under control of a system controller.

[0013] In a particular embodiment, a transmission line is a line providing electric power to an electric vehicle, such as a locomotive, a tramcar, or a trolley bus. One of several conductors is in direct electric contact with a sliding mechanical linkage such

as a pantograph or trolley wire. In a particular embodiment, a conductor in contact with a pantograph is made of material having higher electrical resistivity but higher mechanical strength than the material of two other wires. For instance, a conductor for contacting pantographs can be made of steel, stainless steel, bronze, brass, or copper-clad or aluminum-clad steel while two parallel conductors are made of aluminum, aluminum alloy, or copper.

[0014] In a particular embodiment, each cable has at least five mutually insulated conductors, with all five in parallel for normal operation and all five in series for deicing. Other embodiments are disclosed with three, seven, and other numbers of conductors.

[0015] In another embodiment of a system for deicing cables of power transmission lines, each cable is divided into at least two sections. Each section has at least three conductors that are placed in parallel for normal operation and in series for deicing operation. A system controller is provided for sequentially deicing sections of the cables to prevent undue interference with power transmission by the transmission line.

[0016] In a particular embodiment, apparatus is provided for monitoring temperature of the cables, and for returning the conductors to parallel should overheating of a cable be detected.

[0017] In another embodiment, a switchbox for switching conductors of a transmission line cable between a parallel configuration and a series configuration has an energy storage device with charger, a control signal receiver for receiving commands and at least one switch controlled by the control signal receiver for determining current flow through at least one conductor of the cable, and apparatus for overriding the control signal receiver and placing the cable conductors in a parallel configuration if a high temperature is detected on a conductor of the cable.

[0018] In another embodiment, the cable need not have multiple conductors, but has an electrically resistive strength core – such as steel wire -- and at least one conductor, this system has a switchbox for diverting sufficient current from the conductor through the resistive strength core to deice the cable in a first operating mode, and wherein substantially all current passes through the conductor in a second operating mode.

[0019] In a particular embodiment, the switchbox diverts current through the strength core by placing or increasing an inductance in series with the conductor; the

strength core is in parallel with the combined series inductance and conductor and takes an increased current because of the inductive reactance of the inductance.

[0020] In another particular embodiment, the switchbox has a transformer and a switch, the transformer bypassed in normal operation and operating as a step up transformer to divert power into the strength core during a deicing mode.

[0021] In another particular embodiment, the switchbox incorporates devices for monitoring a temperature of the cable and for reducing current in the strength core towards normal operating levels should high temperatures be encountered.

[0022] A method is disclosed for deicing cables of a transmission line in which the cable has a section with several conductors between a first switchbox and a second switchbox. The section of cable has a normal operating mode where the conductors are electrically coupled in parallel. When ice is detected and deicing is desired, the switchboxes are reconfigured to couple some of the conductors electrically in series thereby placing the section of cable in a high resistance deicing mode. Current flowing in the section of cable resistively heats and deices the section of cable, when the switches of the switchboxes are reconfigured to return the section of cable to the normal operating mode.

[0023] In a particular embodiment of the method, current in the cable is monitored. In this embodiment, a controller selects between several deicing configurations of the switches according to the current in the cable. Further, if current is too low for deicing, the controller may request an increase of current in the cable.

BRIEF DESCRIPTION OF THE FIGURES

[0024] FIG. 1 is a schematic diagram of a system for preventing or removing ice accumulation from a power transmission line.

[0025] FIG. 1A illustrates an embodiment for preventing or removing ice accumulation from a trolley wire used to transmit power in a transportation system.

[0026] FIG. 1B illustrates an alternative embodiment of a cable for use with the system of FIG. 1A.

[0027] FIG. 2 is an electrical schematic of one section of one cable of an alternative embodiment of the system for preventing ice accumulation having five conductors per cable.

[0028] FIG. 2A is an electrical schematic of an alternative method of operating one section of cable of an alternative embodiment of the system for preventing ice accumulation having five conductors per cable.

[0029] FIG. 2B is an electrical schematic of an alternative method of operating one section of cable of an alternative embodiment of the system for preventing ice accumulation having five conductors per cable.

[0030] FIG. 2C is an electrical schematic of one section of one cable of an alternative embodiment of the system for preventing ice accumulation having six conductors per cable.

[0031] FIG. 2D is an electrical schematic of one section of one cable of an alternative embodiment having seven conductors per cable.

[0032] FIG. 2E is a cross sectional diagram of a cable having seven conductors and a steel strength member in thermal contact with each other.

[0033] FIG. 3 is a block diagram of a solar-battery-powered switchbox for use in the system.

[0034] FIG. 3A is a block diagram of an alternative switchbox for use in the system.

[0035] FIG. 4 illustrates a system having multiple cable sections each capable of independent or sequential deicing or anti-icing operation.

[0036] FIG. 5 illustrates a cross-section of a first cable for use with the system of FIG. 1.

[0037] Figure 6 illustrates a cross-section of a second cable for use with the system of FIG. 2.

[0038] Figure 7 illustrates a cross-section of a third cable for use with the system of FIG. 1.

[0039] FIG. 8 illustrates an alternative embodiment having series connected switches.

[0040] FIG. 9 illustrates a deicing system for power lines as proposed in PCT/US2004/27408.

[0041] FIG. 10 illustrates a cross section of a cable having a steel strength core electrically insulated from an outer conductive layer.

[0042] FIG. 11 illustrates a two-conductor, single-switch-per-section deicing system.

[0043] FIG. 12 is a schematic diagram of an inductive switchbox suitable for use with the deicing system of FIG. 11.

[0044] FIG. 12A is a schematic diagram illustrating an alternative core for use with the inductive switchbox of FIG. 12.

[0045] FIG. 13 is a schematic diagram of an alternative single-switchbox-per-section deicing system having a step-up transformer to reduce voltage loss in the cable.

[0046] FIG. 14 is a schematic diagram of an alternative embodiment having some features of Figures 1 and 7.

[0047] FIG. 15 is a schematic diagram of an alternative embodiment for use with cables having an even number of conductors.

[0048] FIG. 16 is a schematic diagram of a second alternative embodiment for use with cables having an even number of conductors.

[0049] FIG. 17 is a schematic drawing of another alternate embodiment for use with cables having a large, even, number of conductors.

DETAILED DESCRIPTION OF THE EMBODIMENTS

[0050] A system for electrically removing accumulated, or preventing accumulation of, ice on a power transmission line 100 is illustrated in FIG. 1. For simplicity, only one of the three cables 102 or phases of a typical three-phase AC line is shown. In the embodiment of FIG. 1, a cable 102 is constructed from three parallel conductors 104, 106, 108. The three conductors 104, 106, 108 are bundled together by insulating spacers 110 along cable 102.

[0051] Cable 102 is suspended by insulators 112 from towers 114, or in an alternative embodiment from poles (not shown). At ends of a section of cable 102, a first switch box 116 and second switch box 118 are suspended from insulator 112 along with cable 102. Each switch box 116, 118 contains a switch 120 and a switch actuator-controller 122.

[0052] For a given section of transmission line, the switch boxes 116, 118, are either in a first, switch-closed, state; or in a second switch-opened state. During normal operation, the switch boxes remain in the switch-closed state with all parallel conductors 104, 106, and 108 of cable 102 connected electrically in parallel. When ice accumulation along the power transmission line 100 is known or suspected, or when it is desired to prevent ice accumulation due to icing weather conditions, switches 120 of boxes 116, 118

are placed in the switch-opened state. This results in the three conductors 104, 106, 108 of cable 102 being connected electrically in series instead of in parallel, with one conductor 104 carrying power in the reverse direction, thereby increasing the effective resistance of the section of cable 102 by a factor of nine.

[0053] With the switches 120 in switch-opened state, and the effective resistance of cable 102 increased to nine times the normal condition, an increase by a corresponding factor of nine in voltage along the segment gives a corresponding increase by a factor of nine in self-heating of cable 102 over the normal switch-closed state provides heating of cable 102 to melt accumulated ice and to retard accumulation of additional ice. For purposes of the present document, anti-icing operation is operation of a cable segment in a manner that provides heating of cable 102 to either melt accumulated ice or to retard accumulation of additional ice

[0054] The switches 120 of switch boxes 116, 118 operate under control of a system controller 124. In one embodiment system controller 124 is located at a network operations center, in another embodiment system controller 124 is an automatic device capable of sensing local weather conditions and attached to a tower 114 near a section of cable 102 subject to ice accumulation and having switchboxes 116, 118 under its control. In this way, switches of both switchboxes 116 and 118 can be opened or closed essentially simultaneously even if switchboxes 116 and 118 are located one or more miles apart.

[0055] The embodiment of FIG. 1 is also applicable to a cable or a polarity of a DC transmission line or trolley power line, as illustrated in FIG. 1A. In the embodiment of FIG. 1A, there are three parallel conductors 150, 152, 154 coupled into a serpentine configuration between two switchboxes 156, 158. One of the three conductors, the contact conductor 154, is arranged so that it is accessible to contact with pantographs 160 or other trolley-wire contacting apparatus of an electrically powered vehicle 162.

[0056] Vehicle 162 may be an electric locomotive, a streetcar unit as illustrated, with return path for vehicle current through a rail 164. In an alternative embodiment, two sets of parallel conductors 154 and switchboxes 156, 158 are provided with dual trolley-wire contacting apparatus 160, one for each phase or polarity of a DC or AC trolley-wire system, such that vehicle 162 connects to both phases or polarities. In this alternative embodiment, vehicle 162 may be a rubber-tired vehicle such as the electrically powered busses that have operated in San Francisco for many years.

[0057] In the embodiment of FIG. 1A, switches 168, 166 may be opened to enter deicing mode, and closed for normal operating mode. Opening of these switches 168, 166, causes current flowing through the conductors 154, 152, 150, such as current being drawn by vehicles 162 in later sections of the system, to pass through all three conductors 154, 152, and 150 in sequence rather than in parallel, increasing current density and heating the conductors.

[0058] In the embodiment of FIG. 1A the contact conductor 154, may, but need not, be fabricated from material different from that of the other or non-contact conductors 152, 150. For example, the contact conductor may be a high-strength moderate-resistance bronze, brass, copper-clad steel, stainless steel, or aluminum-clad steel, with parallel conductors 150, 152 made of low resistance copper or aluminum. This embodiment has advantage in that the high strength contact conductor may be better able to resist mechanical stresses due to contact with the pantograph or trolley-wire contacting apparatus 160. Further, while it can be advisable to deice the non-contact conductors 152, 150 to avoid weight and wind related damage, ice on the contact conductor 154 may interfere with power transfer from the contact conductor 154 to the pantograph or other trolley wire contacting apparatus 160. Higher resistance of the contact conductor 154 may help to ensure prompt and rapid deicing of the contact conductor 154 to ensure continued operation of the vehicle 162 during icing conditions. In this alternative embodiment, opening of switches 166, 168 for a brief time can deice contact conductor 154 to ensure continued operation, while opening of switches 166, 168 repeatedly or for a longer time can deice the non-contact conductors 152, 150 when ice accumulation threatens weight or wind related damage.

[0059] While in some embodiments of the trolley system of FIG. 1A have separately strung non-contact conductors 150, 152 from the contact conductor 154, or has nearby conductors 150, 152, 154 separated by spacers; in an alternative embodiment, as illustrated in FIG. 1B, a contact conductor 154 may form a shell containing insulating material and non-contact conductors 150, 152.

[0060] This system 100 differs from that of Couture in that direction of current in one conductor 104 of the cable 102 is reversed, and in that Couture deices only one or a few conductors at a time, while the system 100 deices all three of the conductors of a segment simultaneously – in the case of spaced-conductor cables Couture requires several sequential deicing operations to clear all conductors of a cable. The system 100

also differs from that of Couture in number and position of the switches. Couture places one set of switches at one point between two ends of a section, while in system 100 the switches are placed at both section ends. Couture's system for a three-conductor line would have 3 switches, while system 100 has only 2 switches. At least one more difference is that in case of all the system switches fail in open position, the current flow and, thus, electric-power transmission will be interrupted, while system 100 provides continuous current flow even with all the switches open, as may happen if the system fails or is damaged, for instance, by lightning. Similarly, system 100 differs from that of Shimada at least because no loop is formed and no additional current is applied to a loop.

[0061] The alternative embodiment of the system 200 for removing or preventing ice accumulation of FIG. 2 has five instead of three conductors per cable 202. In this embodiment, each switch box 204, 210 has two ganged switches 206, 207, 209 and actuator-controller 208. In this embodiment, opening of switches 206 has the consequence of increasing the effective resistance of cable 202 by a factor of twenty-five; thereby increasing self-heating of cable 102 to melt accumulated ice and retard accumulation of additional ice. In the embodiment of FIG. 2, two conductors of the five carry current in a reverse direction while three conductors carry current in a forward direction.

[0062] In the embodiment of FIG. 2, the effective length of total conductor in a segment of cable 102 is increased by a factor of five. Phase shift introduced by this increase of length will not cause significant effect on power flow in the transmission line when operated in a power grid when segments of a few miles in length are deiced since the wavelength of sixty-cycle powerline AC current is approximately three thousand miles and this will not cause significant phase shift. Further, because the length (and conductor resistance) may be increased simultaneously in all three phase-lines by operating switches in all three phases simultaneously, there should not be a significant phase shift added by deicing operations between the different-phase conductors of the transmission line.

[0063] The resistance and power dissipation increases stated above assume embodiments having equal resistance for each conductor of the cable, as is likely the case with open-air spacer-separated-conductor cables. In other embodiments, resistance of individual conductors in a cable may have differing resistances and resistance ratios achieved will vary with the actual resistances of the conductors.

[0064] An increase in self-heating of cable 102 by a factor of twenty-five may be desirable when a cable is conducting low current, but may be excessive when the cable is operating at high currents and/or has several conductors bound together instead of being spaced apart by spacers. The switch arrangement illustrated in FIG. 2 may be operated in alternative ways to produce other effective power dissipation increases, such as is illustrated in FIG. 2A.

[0065] In the embodiment of FIG. 2A, switches 206, 209 are opened to enter a deicing mode, while switch 207 is left closed. In this embodiment, assuming equal resistance per conductor, effective resistance of the cable segment is increased by a factor of five.

[0066] Similarly, in the embodiment 215 of FIG. 2B, switches 206, 207 are opened while switch 209 is left closed. In this embodiment, assuming each conductor has resistance R , the effective resistance of the cable segment is increased from one-fifth R to three R , an increase of resistance by a factor of fifteen.

[0067] Embodiments having cables with six or more conductors may have even numbers of conductors. In the six-conductor embodiment 220 of FIG. 2C, resistance of the cable segment is increased from one-sixth R to three-halves R , an increase by a factor of nine when the switches 206, 222 open. Other configurations of the system are possible, having other power increases in deice mode; for example if switch 222 is left closed while switches 206 open, resistance increases from one-sixth R to three-fourths R , an increase of four and a half.

[0068] Similarly, an alternative embodiment 250 may have seven conductors in each cable and three or four (as illustrated in FIG. 2D) switches 252, 254, 256, 258, 260, 262, 264, 266 in each switchbox 268, 270. In the embodiment of FIG. 2D, effective resistance of the cable is programmable according to which switches are open, as illustrated in Table 1, ranging up to forty-nine times the resistance of the cable with all switches closed. Note that there are additional alternatives and patterns not portrayed in Table 1. To a certain extent, the pattern of open switches can also select which conductors are heated and which are left unenergized in anti-icing operation. In an alternative embodiment, switches 266 and 252 are replaced by wire with minimal reduction in the resistance options provided. Operating modes between the minimum and maximum resistance configurations for a system are herein known as intermediate resistance modes; many of these are illustrated in Table 1. In an embodiment, a system

controller monitors current through the transmission line and determines a resistance required for deicing, selecting a deicing mode from minimum resistance, maximum resistance, and intermediate resistance modes as appropriate for the current in the transmission line. In some embodiments, the system controller may also transmit a request to an energy storage system, generation system, or network operations center that current in the transmission line be increased to provide enough current for deicing.

Switches Open	Resistance Multiplier
None	1
254, 256, 262	2.33
254, 256, 264, 262	3.5
254, 256, 258	7
252, 254, 258, 262, 264	10.5
254, 256, 258, 260	21
254, 256, 258, 260, 262	35
254, 256, 258, 260, 262, 264	49

TABLE 1

[0069] Other alternative embodiments may exist having other numbers of conductors, for example an embodiment with nine conductors in each cable and four switches in each switchbox has effective resistance that increases by a factor of up to eighty-one when the switches open.

[0070] In a particular embodiment, a transmission line system has phase cables 267 having multiple segments each of which corresponds to the schematic diagram of FIG. 2D. In this embodiment, the cables 267 have seven conductors 253, 255, 257, 259, 261, 263, 265, made of aluminum or copper, that are bound in thermal and mechanical contact to each other and to a central steel strength member 280, according to the cable cross section of FIG. 2E. The seven conductors correspond to the seven conductors of FIG. 2D. In this embodiment, the phase cables are suspended from towers and equipped with a system controller 124 in manner resembling that of FIG. 1.

[0071] In this embodiment, controller 124 monitors current through the transmission line cables. When ice is detected, the controller 124 determines a resistance increase that will provide adequate heating of the cable 267 to deice the cable, while

avoiding damage to cable 267. The controller then automatically determines a configuration of open switches for switches 252, 254, 256, 258, 260, 262, 264, 266 of switchboxes 268, 270, and transmits that configuration to switchboxes 268, 270 to cause the system to enter deicing mode for a particular cable 267 segment. Upon completion of deicing of the cable 267 segment, the switches are closed to return to normal operation.

[0072] In the event that ice is detected and deicing is desired, but cable 267 is carrying too little current to provide adequate heating for deicing even at a maximum resistance configuration of switches 252, 254, 256, 258, 260, 262, 264, 266 of switchboxes 268, 270, controller 124 may transmit a request to a grid management system to reconfigure the power grid such that enough power is carried through cable 267 to deice the cable 267. In the case of transmission lines connecting energy storage systems to the power grid, this may require that the storage system either store or release sufficient energy to deice the line.

[0073] Resistance self-heating of a transmission line is proportional to current I through the transmission line squared, times the resistance R of the line ($I^2 \cdot R$). The resistance increases of Table 1 are calculated based upon an assumption that each conductor of the cable has equal resistance. Since there may be times when current in a transmission line is quite low, there may be transmission line systems in which it is desirable to have conductors of differing resistance such that a maximum resistance increase can be significantly higher than would be accomplished with conductors of equal resistance. For example, in a variant embodiment of the embodiment of FIG. 2D, wires 263 and 265 have resistance ten times the resistance of the other, or low resistance, conductors 253, 255, 257, 259, 261. During normal operation, these conductors carry little current, and the effective resistance R is slightly less than one fifth that of the resistance of each of the low resistance conductors 253, 255, 257, 259, 261. Should all seven conductors be configured in series by closing only switches 252 and 256, the effective resistance is increased to one hundred twenty five R , with an intermediate increase to seventy R if switches 258 and 260 are closed. An assortment of other intermediate resistance increases is also available for controller 124 to select from, and may be readily calculated.

[0074] In yet another alternative embodiment, conductor 263 has resistance ten times that of each low resistance conductor 253, 255, 257, 259, 261, and conductor 265 has resistance thirty times that of each low resistance conductor 253, 255, 257, 259,

261. In this embodiment, an intermediate increase to seventy R is available, and a maximal increase to two hundred twenty five times R is available. In these embodiments, the controller 124 selects a switch configuration appropriate to provide adequate heating for deicing based upon the amount of current available in the line. This configuration is then transmitted to switchboxes 268, 270 which set their switches accordingly. The controller continues to monitor current in the transmission line, and may reconfigure switches of switchboxes 268, 270 if current changes to provide appropriate heating for deicing while avoiding excessive heating that may damage the transmission line. Controller 124 may be a separate controller or may be integrated into a switchbox 268, 270.

[0075] In an embodiment the transmission line segment 267 carries power from a solar or wind generation system having an energy storage subsystem. In this embodiment, upon entering anti-icing mode when the transmission line is carrying little or no current; controller 124 may transmit a request to the energy storage subsystem requesting that some stored energy be released over the transmission line to provide current for deicing the line.

[0076] Alternative embodiments may have additional wires, for illustration say N wires, each mutually insulated from each other in the cable. Each conductor of embodiments resembling that of FIG. 2D may be assembled from one or more of the N wires. In an embodiment having M effective conductors seen by the switchboxes, with N insulated wires in the cable, M is less than or equal to N. The number of wires in each conductor may differ between conductors; conductors having greater resistance may have fewer wires than those conductors having lower resistance.

[0077] While local power-distribution transmission lines often operate between 3,500 and 25,000 volts, many “high-tension” three-phase transmission lines operate at voltages between 60,000 and 1,200,000 volts. While embodiments having conventional construction may be suitable for use with some local distribution transmission lines, operation on high-tension transmission lines poses additional challenges.

[0078] In an embodiment (FIG. 3) particularly suited for use with high-tension transmission lines, since all components of the switchbox 204, 116, 118 operate near power-line cable 102, 202 voltage, switchbox 204, 116, 118 is attached at the cable 202, 102 end of insulators 112 and is suspended with the cable. In such an embodiment, it is

not practical to power the switchbox 204, 116, 118 from normal 115V AC power. In consequence, switchbox 204, 116, 118, 300 is powered by an internal energy store 302 such as an ultracapacitor or battery.

[0079] In most embodiments, energy store 302 is charged through charger 310 by a device selected from devices such as an inductive pickup 304 surrounding one or more conductors of cable 102, 202, a solar panel 306, or a small-value capacitor 308 to ground. Energy store 302 powers a control signal receiver 312, which is normally the only component of the switchbox 300 to consume power.

[0080] When control signal receiver 312 receives a correctly encoded “deice” command from system control 124, which may be transmitted from control 124 to receiver 312 via a high frequency carrier wave superimposed on cable 102, 202 along with the power being transmitted, optically over an optical fiber, or by radio, the receiver 312 activates electrically operated switch actuator 314 that opens high current switch or switches 316. Switch actuator 314 may incorporate a solenoid, electromagnet, or an electric motor, and may incorporate additional springs for rapid opening and closing as known in the art of electrically-operated switching devices. In an alternative embodiment, switch 316 is an electronic switch; yet another embodiment has electronic switches in parallel with electrically-operated mechanical switches.

[0081] In an embodiment, actuator 314 operates to oppose the force of a spring 318 that tends to hold switch 316 closed.

[0082] Because inadvertent opening of switches 316 on a hot summer day while operating under full load can not only cause excessive power loss, and line heating, but can cause sufficient sag as to pose hazard to persons or property on the surface, or even cause damage to cable 102; actuator 314 pulls switch 316 open by acting not against a case of switchbox 300, but through a fusible link 320 to a clamp 322 that is attached to one conductor, such as conductor 104, of cable 102 a short distance from switchbox 300. Fusible link 320 is adjacent to conductor 104, and is made of a low-melting metal or plastic such that it will break before conductor 104 reaches a temperature at which excessive sag or damage to cable 102 occurs and allow spring 118 to close switch 116. Therefore, should the system for ice removal or ice prevention fail, switches 116 fail into the closed (low resistance) condition.

[0083] An alternative embodiment, as illustrated in FIG. 3A, has advantage that commercially available contactors and/or solid-state relays may be used for switching

components of the switchboxes that may have to interrupt substantial currents. In this embodiment, control signal receiver 312 normally switches cable 102, 202 between low and high resistance conditions by activating electrically actuated contactor modules 340. Contactor modules 340 may incorporate electromechanical switching devices or, since the maximum voltage seen across the switch is far less than the operating voltage of the transmission line, solid state relay devices, or both. An advantage in using solid state relay devices in parallel with properly timed electromechanical switching is that the electromechanical switching devices provide low switching resistance for transmission line currents that may be on the order of several hundred amperes and reduce self-heating of the solid state relay devices, while the solid state relay devices may suppress any contact arcing associated with opening and closing the electromechanical devices by being closed before the electromechanical devices close, and opened after the electromechanical devices open.

[0084] In the embodiment of FIG. 3A, contactor modules 340 are connected in parallel with safety switches 342 that are closed by spring 344 whenever fusible link 320 melts due to excessive heating in the conductor 346 to which clamp 322 is fastened. This effectively overrides both the control signal receiver 312 and switches 340 when conductor 346 reaches high temperatures. This will prevent excessive dip in, or overheating damage to, cable 102, 202 in the event of failed switchboxes, but poses some risk of ice damage to cable 102, 202 at a later time – especially if left unrepaired.

[0085] In another embodiment, control signal receiver 312 monitors temperature sensed by temperature sensor 324 and closes switches 340 to return all conductors to parallel operation at a temperature indicative of successful deicing but lower than a temperature required to melt fusible link 320. In an embodiment, temperature/status transmitter 326 transmits an indication of closing of switches 340 due to high temperature to system controller 124 so that the switchbox at the other end of the conductors can also return all conductors to parallel operation. Fusible link 320 is preferably located on the conductor having the highest current when switchboxes of a line segment are in the inconsistent state of one switchbox having switches 340 open and the other switchbox having switches 340 closed.

[0086] In order to provide feedback to the system control 124, and encourage repair of failed switchboxes, a status of a sensing switch 347 ganged with safety switches

342, senses failure of fusible link 320 and transmits this information through transmitter 326 to system control 124.

[0087] In order to assist with control of the system, a temperature sensor 324 (Figures 3 and 3A) may be attached to clamp 322, temperature readings being transmitted by temperature transmitter 326 to system control 124 to indicate when, for example, deicing of a section is expected to be complete because temperature of a conductor 104 of cable 102 has significantly exceeding the freezing point of water.

[0088] Alternatively, sensor 324 can be used to maintain cable temperature at a pre-set value during de-icing or anti-icing operation. For instance, at +10°C. In doing so, the switches close when the temperature reaches the pre-set value and open when it falls below that value. That effectively reduces total energy consumed for de-icing/anti-icing, and also prevents cable overheating.

[0089] In the embodiment of FIG. 4, each cable 400 of the transmission line, which may be hundreds of miles long and traverse a variety of terrain and climate zones, is divided into sections, such as section 402 and section 404, of from one tenth to ten miles length. Each section has a first switchbox 406, 410, 414 and a second switchbox 408, 412, 416. In order to prevent excessive voltage drop in the transmission line, when it is determined that it is desirable to deice cable 102, the switchboxes 406, 408 of the first section 402 are activated to open the switches. When that section is deiced, the switches of the first section are closed and switchboxes 410, 412 of the second section are activated to open the switchboxes, and so on in sequence until all iced-over sections of the cable 400 are deiced. Similarly, division of cable 400 into sections permits deicing of those sections of the cable 400 that have been or are exposed to icing conditions, while allowing sections exposed to different weather to continue normal operation.

[0090] Limiting voltage drop by sequentially deicing sections of the line helps maintain stability of the power grid and avoids voltage drops in the transmission line that may be noticed by customers.

[0091] Figure 5 illustrates a cross section of a cable suitable for use with a single-switch-per-switchbox, three-conductor cable of the present cable deicing system. A triangular spacer 502, which may be nonconductive plastic, ceramic, or metal with rubber insulators, is attached to each conductor 504 of the cable. Attachment of spacer 502 to the conductor 504 may be by molding, gluing a cap over cable and base part of the

insulator, with screws securing a cap to an insulator base, or such other methods as known in the art of spaced-conductor cables. Each conductor 504 may be a conductive copper or aluminum shell, over an optional steel supporting center 506, or may be assembled from conductive copper or aluminum strands wrapped around a supporting center of multiple steel strands. Spacers 502 are positioned at regular distances along the cable, spacer spacing is chosen to be small enough to prevent direct electric contact between the conductors of the cable.

[0092] In the embodiment of FIG. 6, four conductors 602 are positioned by spacers 604 around a central conductor 606, each of the five conductors is of essentially equal ampacity. One, in the embodiment illustrated conductor 606, or all five conductors 602, 606 may have a steel core 608 to provide the strength needed for long spans between towers. Since all five conductors 602 carry current during deicing, all five will be deiced even if these conductors are not in thermal contact with each other.

[0093] In the embodiment of FIG. 7, a cable 700, for use as cable 102 or 202, has three (illustrated), five, seven, or nine conductors 702, 704, 706 assembled around a strength core 708 which may be stranded steel. The conductors 702, 704, 706, which may be stranded copper or aluminum, are insulated from each other and coated with an extruded plastic insulation layer 710.

[0094] With reference to Figures 5, 6, and 7, it is anticipated that the conductors 504, 602, 606, 702, 704, 706 and steel supporting cores 506, 608, 708 need not be solid; in most embodiments these are of stranded construction for flexibility and ease of installation as known in the art of transmission line cabling. The conductors and steel cores may be merged – these may be stranded conductors having multiple individual strands of conductor-coated steel, such as stranded Copperweld® (copper clad steel) wire. Further, embodiments may have larger numbers of smaller insulated wires that are grouped into the conductors herein referenced; for example a transmission line cable may have six wires grouped into three groups of two wires each for purposes of deicing according to the present invention, and where each pair of wires are treated as a conductor for deicing as heretofore described.

[0095] The principles described herein are applicable also to DC power transmission lines. While it is not possible to power switch boxes of a DC power transmission line by inductive pickup from current in the transmission line, or through a

high-voltage capacitor, other switchbox powering arrangements may be used including but not limited to a solar cell and battery arrangement.

[0096] The system herein described uses a control signal transmitted from a system controller 124 to switchboxes 300. It is considered desirable that the control signals be transmitted in encrypted form, and encoded, to prevent accidental opening of switches of the switchboxes or sabotage of the system by unauthorized persons.

[0097] In the embodiment of FIG. 8, an alternative switch configuration provides similar effect. In this embodiment of a phase 800, a cable 802 has an odd number of conductors 810, 812, 814, 816, 818 greater than three running between two switchboxes 804, 805. During normal operation, switches 806 and 807, connected in series, connect conductors 812, 814, 816, and 818 in parallel to conductor 810 and the input 820 and to the output switchbox 805, where corresponding switches are closed. When switchbox control and actuators 808 open switches 806 and 807, current is forced to flow through all five conductors 810, 812, 814, 816, 818 in series thereby causing resistive self-heating of these conductors. This configuration has effect of reducing the voltage seen across any one switch, at the expense of increasing current in the first switches (e.g. switch 806) in the series sequence.

[0098] Deicing systems for transmission lines have been proposed where each of typically three phases is conducted over a cable 900, and that cable is divided into two conductors 904, 906, as illustrated in FIG. 9 and as disclosed in PCT/US2004/27408. A switch 908 at an end of a section 910 of the cable transitions between normal operation with the two conductors 904, 906 in parallel, and deicing operation with current flow in only one 906 of the two conductors 904, 906; the one conductor 906 used during deicing sized such that resistance of the cable is high enough to produce sufficient self-heating to deice the cable and prevent further ice accumulation, while the conductor 904 that is placed in parallel during normal operation is sized to provide suitably low resistance for low losses during normal operation. At the opposite end of section 910 from the switch 908, and ahead of the switch 914 of the next section 916, the two conductors 904, 906 are electrically shorted 912 together. Except at shorts 912, the conductors 904, 906 are separated by a layer of insulation 918. In the design disclosed in PCT/US2004/27408, deicing first conductor 904 is an outer layer of the cable physically close to the ice to be removed, while normal second conductor 906 is the central bulk of the cable, and may include any core of the cable.

[0099] High-tension transmission line cables, including modified cable 1000 (FIG.10), generally have many strands 1002 of a conductor such as aluminum or copper surrounding a strength core having strands 1004 of a stronger but more resistive material such as steel, the steel serves to help support the cable allowing greater tower or pole spacing than otherwise possible. In modified cable 1000, there is an added layer of insulation 1006 that prevents electrical contact between strength core strands 1004 and conductive strands 1002.

[0100] A modified deicing system 1100 for power transmission cables, as illustrated in FIG. 11, has a cable 1102 having a steel core 1104, an insulation layer 1106, and a conductive layer 1108, the insulation layer 1106 preventing contact between steel core 1104 and conductive layer 1108; each of steel core 1104 and conductive layer 1108 are typically formed of multiple strands. Additional layers, such as an outer insulation and weather protection layer, may exist. Cable 1102 is separated into sections 1110, at one end of a section 1110 is a switchbox 1114, at the other end is a short circuit connection 1116 between steel core 1104 and conductive layer 1108.

[0101] During normal operation, switchbox 1114 maintains an electrical connection between conductive layer 1108 of each section of the cable 1102. In this normal mode, a majority of current through cable 102 pass through conductive layer 1108. To deice a section 1110 of cable 1102, a controller 1118 of the switchbox 1114 associated with that section 1110 of cable 1102 opens a switch 1120, thereby reducing or eliminating current in conductive layer 1108 and, since the cable is part of a transmission line that is continuing to conduct power, correspondingly increasing current in steel core 1104 of that section 1110.

[0102] In an alternative embodiment, as illustrated in FIG. 14 with reference to figures 7 and 1, the conductive layer has several conductors 702, 704, 706, as illustrated in FIG. 7, coupled with switchboxes similar to those of FIG. 1 or FIG. 2. The strength core 708 is electrically connected between switchboxes 1401, 1403 at each end of a segment of cable. When the switches 1402, 1404 open, effective resistance of the conductive layer 702, 704, 706 increases relative to that of the cable with closed switches, diverting more but not all current through the steel strength core 1104, 708.

[0103] In an embodiment, switchbox 1114 contains an inductor 1122. When switch 1120 opens, the inductor is placed electrically in series with the low resistance outer conductive layer 1108 of cable section 1110, this series connection of inductor 1122

and conductive layer 1108 is electrically in parallel with inner steel core 1104 of that section; in consequence some but not all current in cable 1102 is diverted through steel core 1104; the amount of this current being substantially greater than that through steel core 1104 during normal operation with switch 1120 closed.

[0104] Switchbox 1114 has powering arrangements and high-temperature override apparatus as previously described with reference to FIG. 3 and FIG. 3A.

[0105] In an alternative embodiment, as illustrated in FIG. 12, a switchbox 1200 suitable for use in place of switchbox 1114 has no switch 1120. In this embodiment, switchbox 1200 has a power input connection 1202 connected to both the outer conductive layer 1108 and inner steel core 1104 of a preceding cable section, and to a power output connection 1204 for connection to the inner steel core 1104 of the cable section 1110; in some embodiments this connection may incorporate a locally bared steel core 1104 of the cable.

[0106] The embodiment of FIG. 12 also has a coil 1206 having a few turns of high-ampacity wire, coil 1206 connected between power input connection 1202 and a second power output connection 1208 for connection to the outer conductive layer 1108 of the cable section 1110. Switchbox 1200 has an energy store 1212 with charging arrangements as previously discussed with reference to Figures 3 and 3A, and a control signal receiver 1214. When control signal receiver 1214 receives a command to deice the cable section 1110, receiver 1214 activates a motor actuator 1216 that pulls on a nonmagnetic cable 1218. Nonmagnetic cable 1218 runs over pulley 1220 to a magnetic core element 1222, activation of motor actuator 1216 draws core element 1222 into coil 1206. When core element 1222 is drawn into coil 1206, inductance of coil 1206 is increased thereby diverting a portion of current in cable 1102 through resistive inner steel core 1104

[0107] Pulley 1220 is attached to a case of switchbox 1200 through a release catch 1224, and a spring 1226 having sufficient strength to overcome solenoid attraction of core element 1222 into coil 1206 is connected to draw core element 1222 from coil 1206. When switchbox 1200 control signal receiver 1214 receives a command to discontinue deicing of cable section 1110, control signal 1214 commands motor actuator 1216 to unwind nonmagnetic cable 1218. This permits spring 1226 to draw core element 1222 from coil 1206 and return cable section 1110 to normal operation.

[0108] In the event that a fusible link, such as previously discussed with respect to fusible link 320 of FIG. 3A, melts due to excessive heating of cable section 1110, safety actuator rod 1230 is drawn into switchbox 1200 by a spring 1232. Actuator rod 1230 being drawn into switchbox 1200 triggers release catch 1224 to release pulley 1220, which allows spring 1226 to draw core element 1222 from coil 1206 and return cable section 1110 to low-impedance operation; this effectively reduces current in strength core 1104 and reduces self-heating of the cable 1102.

[0109] In an embodiment of the switchbox of FIG. 12, the switchbox incorporates circuitry such as the sensor 324 and temperature/status transmitter 326 of FIG. 3A such that system controller 124 (FIG.1) can determine when deicing is complete, whereupon system controller 124 will command switchbox 1200 to return to normal operation and commence deicing (if required) of the next cable section. In an embodiment, the control signal receiver 312 also monitors sensor 324 and attempts to return switchbox 1200 to normal operation by extracting core 1222 at a temperature lower than that required to melt fusible link 320.

[0110] In an alternative embodiment resembling that of FIG. 12, instead of a single-piece movable core 1222, a two-piece core is used as illustrated in FIG. 12A. In this embodiment, a first L-shaped core portion 1240 is fixed to the switchbox. A second L-shaped core portion 1242 is arranged such that it may be extracted from coil 1232 in a first position as shown as 1242 in FIG. 12A to give a low-inductance setting, or drawn into the coil 1232 to a second position 1244 shown by dashed lines in FIG. 12A to give a high-inductance setting. In this embodiment, first and second L-shaped core portions 1242, 1240 form a loop for magnetic flux when the second core portion 1242 is in the high-inductance position.

[0111] The embodiments of Figures 11 and 12 operate under control of a system controller 124 as previously discussed with reference to FIG. 1; in an embodiment some sections of cable are deiced as described with reference to figures 11 and 12, while some other sections are deiced as described with reference to figures 1 and 2.

[0112] The embodiment of FIG. 13 also is a system 1300 for deicing transmission line cable, in this case by heating the cable 1302 by diverting a portion of cable power through a step-up transformer (windings 1304 and 1306) and through the steel supporting strands 1308 of cable 1302. In this embodiment, steel strands 1308 are surrounded by insulation 1310, and then surrounded by stranded aluminum or copper

conductive layer 1312. Switchbox 1313 has a switch 1314 open in normal operating mode, and 1316 closed, to allow current to flow through the conductive layer 1312 unimpeded. Switchbox 1313 also has a power store 1322 and command receiver 1324 similar to and having equivalent charging circuitry to the power store 302 and command receiver 312 described in reference to FIG. 3A; as with other embodiments command receiver 1324 is in communication with system controller 124.

[0113] When it is desired to deice cable 1302, command receiver 1324 receives a command and closes switch 1314 first to establish a current path through steel supporting strands 1308; then command receiver 1324 opens switch 1316 to apply considerable current to transformer primary winding 1306. Transformer secondary winding 1304 thereupon provides power to supporting strands 1308. Transformer primary 1306 has only a few turns, and transformer core 1318 is constructed of a saturable magnetic material, such that only a small proportion of the power available in the cable is applied to the supporting strands 1308; such as 100 to 300 watts per meter of cable – in a 600 kV transmission line drawing 1000 amps, the 150 kW required to heat all three cables of one mile of line at 300 watts per meter is less than a tenth of a percent of the total power flowing through the transmission line, and voltage drop across the primary winding 1306 may be held to a low level.

[0114] As with other embodiments, the embodiment of FIG. 13 has apparatus (not shown in FIG. 13) for sensing overheating of the cable such as a fusible link and temperature sensor. When the apparatus for sensing overheating of the cable detects an overheat condition of the cable, switch 1316 or an auxiliary switch (not shown) is closed to reduce current in cable core 1308 by bypassing transformer primary 1306; as in normal operating mode bypassing primary 1306 greatly reduces current in the cable core 1308 and reduces resistive heating of the cable 1302.

[0115] Switchboxes of all embodiments herein described, such as the switchboxes of FIG. 3, 3a, 12, and 13, sense overtemperature conditions of the cable and switchboxes, as for example through temperature sensor 324, and attempt reversion from deicing to normal operation at temperatures below that required to melt fusible links such as fusible link 320. Mechanical sensing and return to low-resistance operation provided by fusible links 320 and associated apparatus is an overriding mechanical backup intended to prevent overheat damage to the transmission line and its cables should system control 124, electrical switch actuators 314, electrically actuated switches 340, 1120,

1316, motor actuator 1216, temperature sensors 324, or other components fail into the deicing mode.

[0116] Many power distribution systems already have been built with huge capital investments. It is therefore often desirable to adapt cables of existing systems to the present electrical deicing system rather than to build new distribution systems from scratch. The embodiments previously described, including those particularly described with reference to figures 2, 2B, and 8, are often adaptable to systems originally built using an odd number of parallel-connected conductors in a common cable.

[0117] The embodiments of Figures 15 and 16, while adaptable for systems of new construction, are particularly adapted to use with previously-constructed electrical distribution systems having an even number of parallel-connected conductors in existing cables.

[0118] The embodiments of Figures 15 and 16 have switchboxes 1510, 1512, 1610, 1612 at each end of a powerline cable segment. These switchboxes 1510, 1512, 1610, 1612 may have thermal safety shutdown apparatus as previously discussed with reference to FIG. 12, may have signaling and control apparatus as discussed with reference to FIG. 3 and 3A, and may be operated under control of a remote, central, controller as discussed with reference to FIG. 1.

[0119] In normal operation the embodiments illustrated in Figures 15 and 16 operate with all switches 1501, 1502, 1503, 1601, 1602, 1603, 1604 closed.

[0120] When it is necessary to deice a power line, with reference to FIG. 15, switches 1501 and 1502 are opened in deicing mode 2. This causes conductors 1515, 1517, 1519 to be operated in series, increasing the effective resistance of the cable by placing conductors 1515, 1517, 1519 in series, and throwing more than half of the current into conductor 1521. Since conductor 1521 will carry the majority of current, conductor 1521 will heat to a greater extent than under normal conditions and, to a lesser extent, conductors 1515, 1517, and 1519 will also heat.

[0121] Upon completion of deicing conductor 1521, if conductors 1515, 1517, and 1519 need further deicing, switch 1503 in switchbox 1510 may be opened. This will divert current from conductor 1521 into series-coupled conductors 1515, 1517, causing heating of those conductors and deicing of the cable. Once deicing is finished, all switches close to return the system to normal operation.

[0122] The embodiment of FIG. 15 may be expanded to other embodiments having six conductors by adding two additional switches in manner resembling switchboxes of FIG. 2A with an additional conductor 1521 and switch 1503. The embodiment may be expanded to handle eight conductors either by paralleling the conductors in pairs, and operating with switchboxes as in FIG. 15, or by using switches to couple seven of the conductors in series during deicing in by adding two additional switches in manner resembling switchboxes of FIG. 2D with an additional conductor 1521 and switch 1503.

[0123] An alternative embodiment illustrated in FIG. 16 operates in a first deicing mode by opening switches 1601, 1602, and 1603. This puts conductors 1615, 1617, and 1619 in series, thereby increasing effective resistance of the cable segment and causing self-heating and deicing of conductors 1615, 1617, and 1619. This embodiment and mode may be extrapolated to six, eight, and higher numbers of conductors by adding switches to couple the additional conductors in series with conductors 1615, 1617, 1619 during deicing, and in parallel during normal operation, using techniques similar to those illustrated in Figures 2A and 2D.

[0124] The embodiment of FIG. 16 operates in a second deicing mode to deice conductor 1621 by closing switch 1603 and opening switches 1601, 1602, and 1604. Deicing of conductor 1621 and conductors 1615, 1617, 1619 may be performed in either order. Once deicing is completed, all switches 1601, 1602, 1603, 1604 close to return the cable to normal, low-resistance, operation.

[0125] The embodiment of FIG. 15 will conduct current even if all switches of the switchboxes are destroyed, this may provide a failsafe operation in damaged systems.

[0126] An alternative embodiment illustrated in FIG. 17 has two groups of three conductors each, a first group with conductors 1717, 1719, 1715, and a second group with conductors 1735, 1737, and 1739. Switchboxes 1710, 1712 are configured such that in a normal mode all switches of the switchboxes are closed, causing current to flow in all conductors in parallel. In a first deicing mode, switches 1703, 1702, 1701 open and 1741, 1745 remains closed, causing current to flow through the first conductor group with conductors 1717, 1719, 1715 in series with no current in the second conductor group. In a second deicing mode, switches 1741, 1701, 1742, 1703 open and 1743, 1745 close causing current to flow through the second conductor group with conductors 1735, 1737, and 1739 in series, with no current in the first conductor group. In a third deicing

mode, for use when the transmission line is lightly loaded, switches 1741 and 1742 close, with switch 1702, 1745, 1701, 1703 open to electrically couple five of the conductors in series, and in a fourth deicing mode, also for use when the transmission line is more lightly loaded than the first and second deicing modes, switches 1743 and 1742 close with remaining switches open to electrically couple a different five of the conductors in series.

[0127] In operation, the system operates in normal mode, with all switches of both switchboxes 1710, 1712 closed, until such time as it is necessary to deice the section of the transmission line. A controller, not shown in FIG. 17, then determines whether low resistance deicing of deicing modes 1 and 2 are sufficient, or whether high resistance deicing of modes 3 and 4 are required. The controller then activates modes 1 or 3 for a time sufficient to remove ice from the conductors, then modes 2 or 4 for a sufficient time to remove ice from the conductors, then returns the system to normal mode operation. In an alternative embodiment, the controller may return the system to normal mode for a time after modes 1 or 3 and before modes 2 or 4 to allow equalization of conductor temperature.

[0128] The system illustrated in FIG. 17 can be extrapolated to other even numbers of conductors, where the conductors are divided into two or more groups having an odd number of conductors in each group, and where at least one conductor of each group differs from conductors of other groups.

[0129] The present document describes systems and methods for deicing power transmission lines, including systems and methods designated as follows:

[0130] A system designated A for deicing and anti-icing operations of AC and DC power transmission lines having at least one section of cable for transmission of power in the transmission line with at least a first, a second, and a third conductor; wherein the first, second, and third conductor are mutually electrically insulated along the length of a section but are connected at ends of the section to form a series serpentine path of at least three conductors connected in series. The system also has at least a first switch at a first end of the section of cable, and at least a second switch at a second end of the section of cable, the first and second switches operable such that the first, second, and third conductor are connected in parallel in a normal mode and operate in series in a first anti-icing mode, and wherein the transmission line further comprises at least a fourth conductor carrying no current in the first anti-icing mode

[0131] A system designated C incorporating the system designated A wherein at least one switch further has a switching device and a switch controller, wherein the switching device and controller are electrically isolated from ground, and wherein the switch is controlled by control signals from an anti-icing system controller at another location.

[0132] A system designated D incorporating the system designated A or C, wherein the cable further comprises a fifth and a sixth conductor, and wherein there is a third switch at the first end of the cable for coupling the fifth and sixth conductors to the first conductor, and a fourth switch at the second end of the cable for coupling the third and fourth conductors to the sixth conductor, and wherein the third and fifth conductors are electrically coupled near the fourth switch, and the fourth and sixth conductors are electrically coupled near the third switch.

[0133] A system designated E incorporating the system designated A, C, or D wherein the system further comprises a controller for monitoring current in the transmission line and determining when anti-icing is required, and for determining a switch configuration for anti-icing operation based upon the current in the transmission line.

[0134] A system designated F incorporating the system designated A, C, D or E wherein a conductor selected from the group consisting of the second conductor, the third conductor, the fifth conductor and the sixth conductor has a resistance substantially greater than a resistance of the first conductor.

[0135] A system designated G for anti-icing operation of power transmission lines has at least one cable having at least two sections, wherein each section comprises at least a first, a second, and a third conductor; wherein the first, second, and third conductor are mutually insulated; a first switch for coupling the second and third conductors to the first conductor at a first end of the cable, the second and third conductors being electrically coupled near the first switch; a second switch for coupling the first and second conductors to the third conductor at a second end of the cable, the first and second conductors being electrically coupled near the second switch; and wherein the third conductor of the first section is connected to the first conductor of the second section; and a system controller for simultaneously opening the first and second switches of each section to increase resistance of the at least one cable by placing the first, second, and

third conductors in series for anti-icing operation of the cable of that section, and wherein the system controller is capable of sequentially opening switches of sections.

[0136] The system designated A, C, D, E, F, or G further comprising apparatus for sensing overheating of at least one conductor of the cable, and for placing the first, second, and third conductors in parallel to reduce resistance of the cable upon sensing overheating.

[0137] A system designated B comprising the system designated A, C, D, E, F, or G wherein in a second deicing mode the switches are configured to permit current flow through the sixth conductor and not through at least one other conductor.

[0138] A switchbox designated H for switching conductors of a transmission line cable between a parallel configuration and a series configuration, the switchbox comprising: an energy storage device for providing power to the switchbox; apparatus for charging the energy storage device; a control signal receiver for receiving switch operation commands, the control signal receiver powered from the energy storage device; at least one switch for determining current flow through at least one conductor of the cable, the switch electrically actuated under control of the control signal receiver; and apparatus for overriding the control signal receiver and placing the cable conductors in a parallel configuration if a high temperature is detected on a conductor of the cable.

[0139] A system designated I for deicing of a cable of a power transmission line, the cable comprising N conductors, where N is an odd integer larger than one, where each of the N conductors are electrically insulated from the other conductors the system comprising: a first and a second switchbox, wherein the first switchbox is coupled to a first end of the cable and the second switchbox is coupled to a second end of the cable; wherein each switchbox has at least $(N-1)/2$ switches; wherein in a first mode the switches of the switchboxes connect all N conductors of the cable in parallel, and in a second mode the switches of the switchboxes connect all N conductors in series to increase cable resistance for effective deicing operations; and a system controller for placing the switchboxes in the first mode for normal operation and in the second mode for deicing the cable.

[0140] A system designated J for anti-icing operation of a cable of a power transmission line, the cable comprising a resistive strength core and at least one conductor, the strength core being electrically insulated from the at least one conductor the system further comprising: a switchbox for diverting sufficient current from the

conductor through the resistive strength core for anti-icing operation of the cable in a first operating mode, and wherein a majority of the current passes through the conductor in a second operating mode.

[0141] A system designated K having the system designated J wherein the switchbox places an inductance electrically in series with the conductor during the first operating mode, the strength core being electrically in parallel with the series combination of inductor and conductor.

[0142] A system designated L incorporating the system designated J or K wherein the switchbox places an inductance electrically in series with the conductor during the first operating mode by inserting a magnetic core material into a coil, and wherein the magnetic core material is removed from the coil during the second operating mode.

[0143] A system designated M comprising the system designated J, K, or L, wherein the switchbox further comprises apparatus for switching between the first and the second operating mode under command of an external system controller, apparatus for sensing an overheat condition of the cable, and apparatus for reducing current in the resistive strength core when an overheat condition is detected.

[0144] The system of designated M wherein the switchbox comprises a transformer, the transformer having a secondary coupled to the strength core during deicing.

[0145] The system designated J, K, L, or M, wherein the cable has a strength-reinforcement conductor of higher electrical resistance and mechanical strength than the N conductors of the cable; wherein the strength-reinforcement conductor is electrically insulated from other conductors along the length of a section, but is connected at the first section end to a first conductor of the N conductors and at the second end of the section to an Nth conductor of the N conductors; and wherein opening of switches in the switchboxes increases the effective electrical resistance of the N conductors between the switchboxes such that a larger current is diverted into the strength-reinforcement conductor to deice it.

[0146] A system designated N for anti-icing of power transmission lines comprising: at least one section of cable for transmission of power in the transmission line comprising at least a first, a second, and a third conductor; wherein the first, second, and third conductor are mutually electrically insulated; at least a first switch at a first end

of the section of cable, and at least a second switch at a second end of the section of cable, the first and second switches operable such that the first, second, and third conductor are capable of being connected in at least a low resistance configuration, an intermediate resistance configuration, and a high resistance configuration; and a system controller for determining when anti-icing operation is required, for selecting an appropriate anti-icing configuration from the intermediate and high resistance configurations, and for setting the switches into the anti-icing configuration when anti-icing operation is required, and into the low resistance configuration when anti-icing operation is not required.

[0147] A method designated P for deicing a section of a cable of a power transmission line, the cable comprising a plurality of conductors extending between a first switchbox and a second switchbox, the section of cable having a normal operating mode wherein the plurality of conductors are electrically in parallel, the method comprising: detecting ice accumulation on the section of the cable; configuring switches of the switchboxes to couple a plurality of the conductors of the cable electrically in series thereby placing the section of cable in a first deicing mode having a deicing mode resistance greater than a resistance of the section of cable in the normal operating mode; allowing a current flowing in the section of cable to resistively heat the section of cable to deice the section of cable; reconfiguring switches of the switchboxes to couple a plurality of the conductors of the cable electrically in series thereby placing the section of cable in a second deicing mode, and reconfiguring the switches of the switchboxes to return the section of cable to the normal operating mode, wherein the plurality of cables coupled electrically in series in the second deicing mode differs from the plurality of cables electrically coupled together in series in the first deicing mode.

[0148] A method designated Q comprising the method designated P further comprising: monitoring the current flowing in the section of cable to determine a deicing mode appropriate for the current.

[0149] The method designated P or Q further comprising transmitting a message to request an increase in the current flowing in the section of cable when current in the cable is insufficient for deicing.

[0150] The method designated P or Q wherein a first conductor of the plurality of cables has a resistance substantially different from a resistance of a second conductor of the plurality of cables.

[0151] The method designated P or Q wherein the transmission line is configured to transmit power to electric vehicles.

[0152] The method designated P or Q wherein the cable comprises an odd number of conductors, wherein a number of conductors coupled electrically in series in the first deicing mode is an odd number, and wherein a number of conductors coupled electrically in series in the second deicing mode is an odd number.

[0153] The method designated P or Q wherein the plurality of conductors electrically coupled in series in the first deicing mode differing from the plurality of conductors electrically coupled in series in the second deicing mode means that at least one conductor electrically coupled in series to carry current in the first deicing mode is coupled to carry no current in the second deicing mode;

[0154] A system designated R for deicing of a cable of a power transmission line, the cable comprising N conductors, where N is an even integer larger than one, where each of the N conductors are electrically insulated from the other conductors the system comprising: a first and a second switchbox, wherein the first switchbox is coupled to a first end of the cable and the second switchbox is coupled to a second end of the cable; wherein in a first mode the switches of the switchboxes connect all N conductors of the cable in parallel, and in a second mode the switches of the switchboxes a first odd number M of the conductors in series to increase cable resistance for effective deicing operations; and a system controller for placing the switchboxes in the first mode for normal operation and in the second mode for deicing the cable.

[0155] The system designated R wherein in a third mode the switches of the switchboxes connect a second odd number P of the conductors in series to increase cable resistance for effective deicing operations, the P conductors including at least one conductor not included in the M conductors.

[0156] While the forgoing has been particularly shown and described with reference to particular embodiments thereof, it will be understood by those skilled in the art that various other changes in the form and details may be made without departing from the spirit and hereof. It is to be understood that various changes may be made in adapting the description to different embodiments without departing from the broader concepts disclosed herein and comprehended by the claims that follow.

CLAIMS

What is claimed is:

1. A system for deicing and anti-icing operations of power transmission lines comprises:

at least one section of cable for transmission of power in the transmission line, comprising at least a first, a second, and a third conductor; wherein the first, second, and third conductor are mutually electrically insulated along the length of a section but are connected at ends of the section to form a series serpentine path of at least three conductors connected in series;

at least a first switch at a first end of the section of cable, and at least a second switch at a second end of the section of cable, the first and second switches operable such that the first, second, and third conductor are connected in parallel in a normal mode and operate in series in a first anti-icing mode;

and wherein the transmission line further comprises at least a fourth conductor carrying no current in the first anti-icing mode.

2. The system of claim 1 wherein at least one switch further comprises a switching device and a switch controller, wherein the switching device and controller are electrically isolated from ground, and wherein the switch is controlled by control signals from an anti-icing system controller at another location.

3. The system of claim 1, wherein the cable further comprises a fifth and a sixth conductor, and wherein there is a third switch at the first end of the section of cable for coupling the fifth and sixth conductors to the first conductor, and a fourth switch at the second end of the section of cable for coupling the third and fourth conductors to the sixth conductor, and wherein the third and fifth conductors are electrically coupled near the fourth switch, and the fifth and sixth conductors are electrically coupled near the third switch.

4. The system of claim 3 wherein connections for power transmission through the cable are made to the first conductor at the first switch, and to the fifth conductor at the second switch.

5. The system of claim 3 wherein the system further comprises a controller for monitoring current in the transmission line and determining when anti-icing is required, and for determining a switch configuration for anti-icing operation based upon the current in the transmission line.

6. The system of claim 3 wherein a conductor selected from the group consisting of the second conductor, the third conductor, the fourth conductor and the fifth conductor has a resistance substantially greater than a resistance of the first conductor.

7. The system of claim 5 wherein at least one switch further comprises a switching device and a controller, wherein the switching device and controller are electrically isolated from ground, wherein the switch is controlled by control signals from the system controller, and wherein the system controller is located at a location remote from the at least one switch.

8. The system of claim 3, 4, 5, 6, or 7 wherein in a second deicing mode the switches are configured to apply current through the sixth conductor and not through at least one other conductor.

9. A system for anti-icing operation of power transmission lines comprises:
at least one cable having at least two sections, wherein each section comprises:
at least a first, a second, and a third conductor; wherein the first, second, and third conductor are mutually insulated;
a first switch for coupling the second and third conductors to the first conductor at a first end of the section, the second and third conductors being electrically coupled near the first switch;
a second switch for coupling the first and second conductors to the third conductor at a second end of the section, the first and second conductors being electrically coupled near the second switch; and
wherein the third conductor of the first section is connected to the first conductor of the second section; and
a system controller for simultaneously opening the first and second switches of each section to increase resistance of the at least one cable by placing the first, second, and third conductors in series for anti-icing operation of the

cable of that section, and wherein the system controller is capable of sequentially opening switches of sections.

10. The system of claim 8 or 9 further comprising apparatus for sensing overheating of at least one conductor of the cable, and for placing the first, second, and third conductors in parallel to reduce resistance of the cable upon sensing overheating.

11. A system for deicing of a cable of a power transmission line, the cable comprising N conductors, where N is an even integer larger than one, where each of the N conductors are electrically insulated from the other conductors, the system comprising:

a first and a second switchbox, wherein the first switchbox is coupled to a first end of the cable and the second switchbox is coupled to a second end of the cable;

wherein in a first mode the switches of the switchboxes connect all N conductors of the cable in parallel, and in a second mode the switches of the switchboxes a first odd number M of the conductors in series to increase cable resistance for effective deicing operations; and

a system controller for placing the switchboxes in the first mode for normal operation and in the second mode for deicing the cable.

12. The system of claim 11 wherein in a third mode the switches of the switchboxes connect a second odd number P of the conductors in series to increase cable resistance for effective deicing operations, the P conductors including at least one conductor not included in the M conductors.

13. The system of claim 12, wherein the cable has a strength-reinforcement conductor of higher electrical resistance and mechanical strength than the N conductors of the cable; wherein

the strength-reinforcement conductor is electrically insulated from other conductors along the length of a section, but is connected at the first section end to a first conductor of the N conductors and at the second end of the section to an Nth conductor of the N conductors; and

wherein opening of switches in the switchboxes increases the effective electrical resistance of the N conductors between the switchboxes such that a larger current is diverted into the strength-reinforcement conductor to deice it.

14. A system for anti-icing of power transmission lines comprises:
at least one section of cable for transmission of power in the transmission line comprising at least a first, a second, and a third conductor; wherein the first, second, and third conductor are mutually electrically insulated;
at least a first switch at a first end of the section of cable, and at least a second switch at a second end of the section of cable, the first and second switches operable such that the first, second, and third conductor are capable of being connected in at least a low resistance configuration, an intermediate resistance configuration, and a high resistance configuration; and
a system controller for determining when anti-icing operation is required, for selecting an appropriate anti-icing configuration from the intermediate and high resistance configurations, and for setting the switches into the anti-icing configuration when anti-icing operation is required, and into the low resistance configuration when anti-icing operation is not required.

15. A method for deicing a section of a cable of a power transmission line, the cable comprising a plurality of conductors extending between a first switchbox and a second switchbox, the section of cable having a normal operating mode wherein the plurality of conductors are electrically in parallel, the method comprising:

detecting ice accumulation on the section of the cable;
configuring switches of the switchboxes to couple a first plurality of the conductors of the cable electrically in series thereby placing the section of cable in a first deicing mode having a deicing mode resistance greater than a resistance of the section of cable in the normal operating mode;
configuring switches of the switchboxes to couple a second plurality of the conductors of the cable electrically in series thereby placing the section of cable in a second deicing mode having a deicing mode resistance greater than a resistance of the section of cable in the normal operating mode;
wherein at least one conductor electrically coupled in series to carry current in the first deicing mode carries no current in the second deicing mode;
allowing a current flowing in the section of cable to resistively heat the section of cable to deice the section of cable; and

reconfiguring the switches of the switchboxes to return the section of cable to the normal operating mode.

16. The method of claim 15 wherein the switches in the switchboxes have at least a first configuration corresponding to the normal operating mode, a second configuration corresponding to the first deicing mode having a first resistance between switchboxes, and a third configuration corresponding to the second deicing mode having a second resistance between switchboxes; the method further comprising:

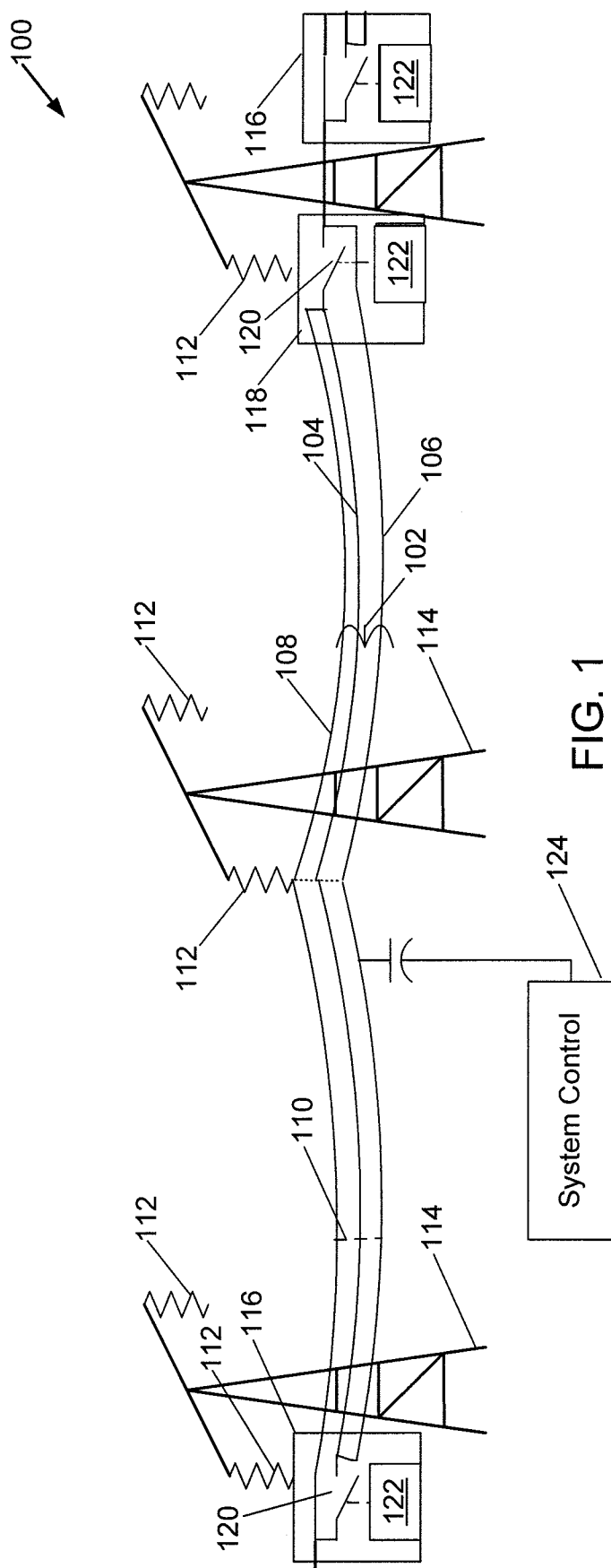
monitoring the current flowing in the section of cable to determine a deicing mode appropriate for the current.

17. The method of claim 16 further comprising transmitting a message to request an increase in the current flowing in the section of cable when current in the cable is insufficient for deicing.

18. The method of claim 16 wherein a first conductor of the plurality of conductors has a resistance substantially different from a resistance of a second conductor of the plurality of conductors.

19. The method of claim 16 wherein the transmission line is configured to transmit power to electric vehicles.

20. The method of claim 16 wherein the cable comprises an odd number of conductors, wherein a number of conductors coupled electrically in series in the first deicing mode is an odd number, and wherein a number of conductors coupled electrically in series in the second deicing mode is an odd number.



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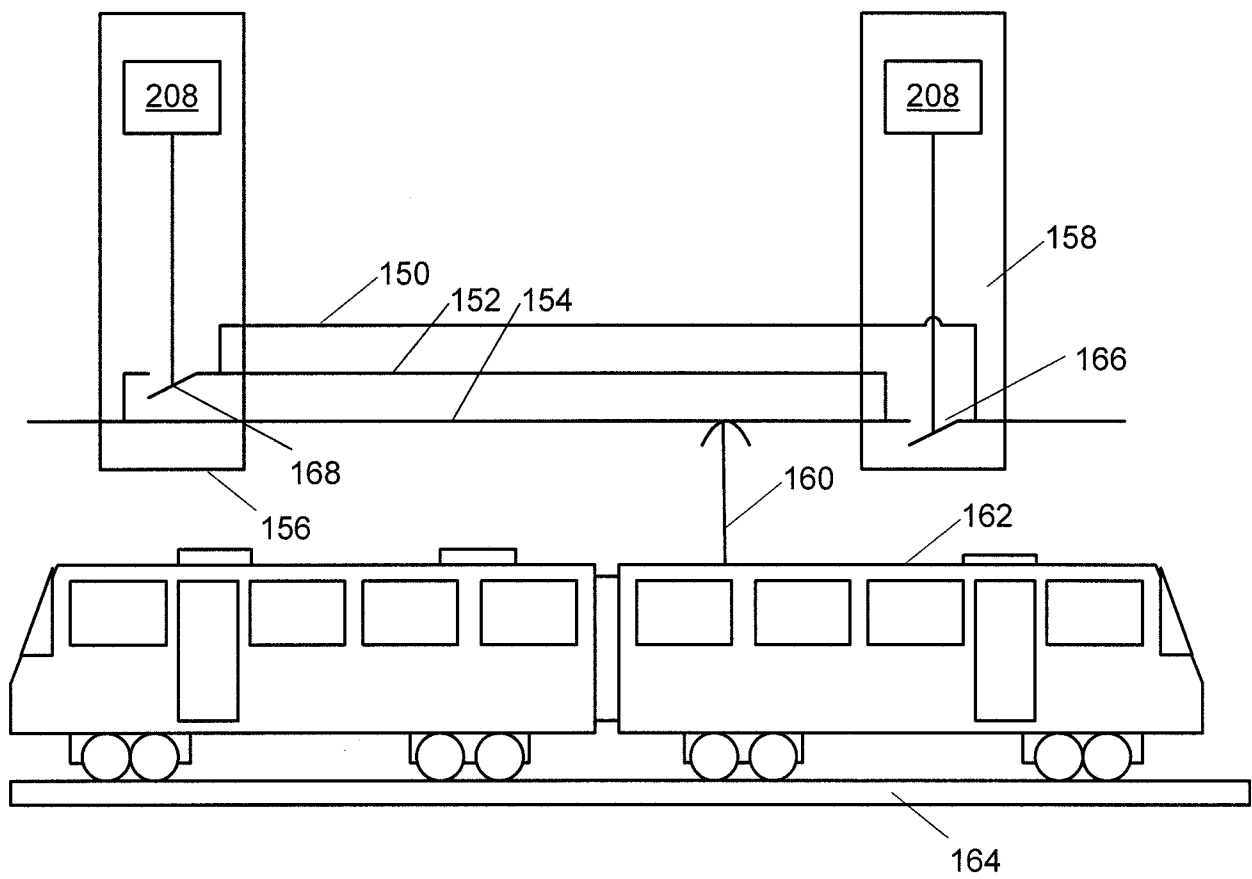


FIG. 1A

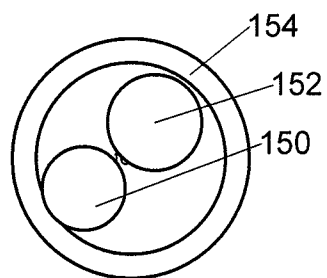
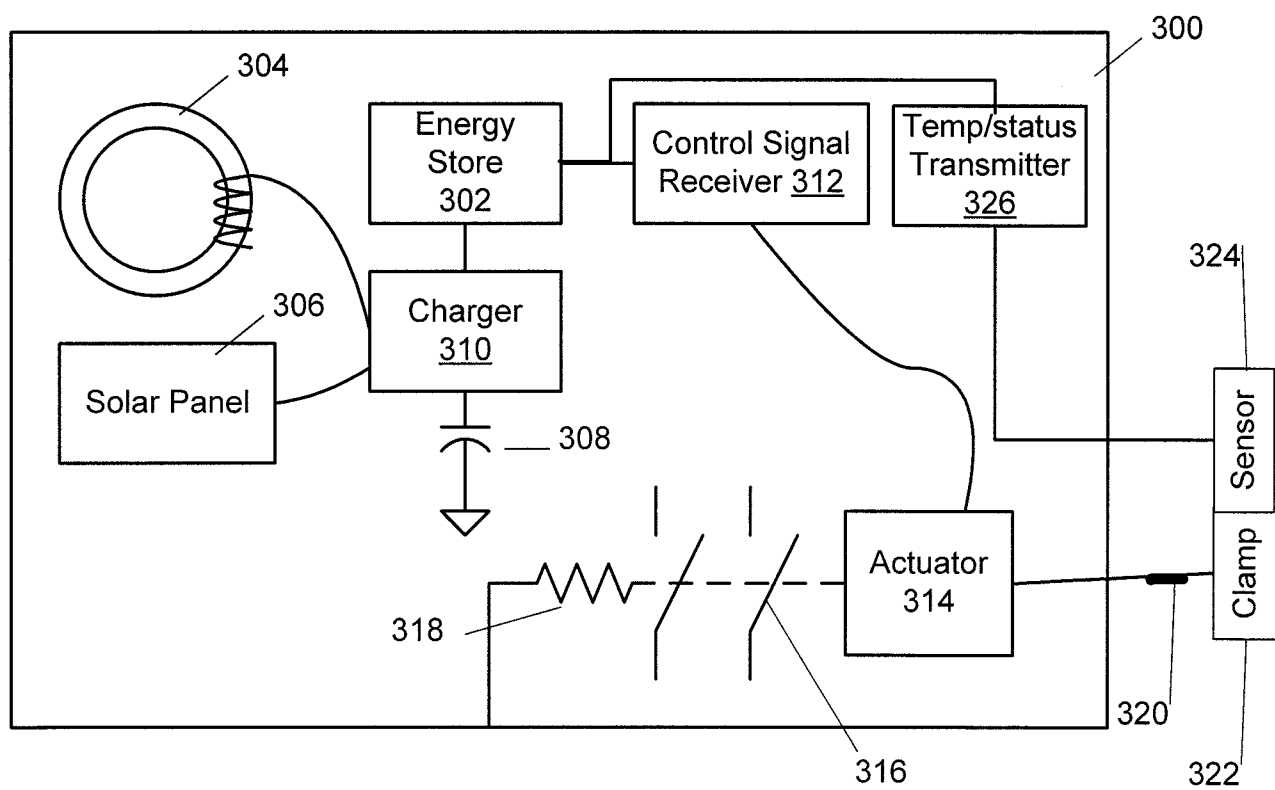
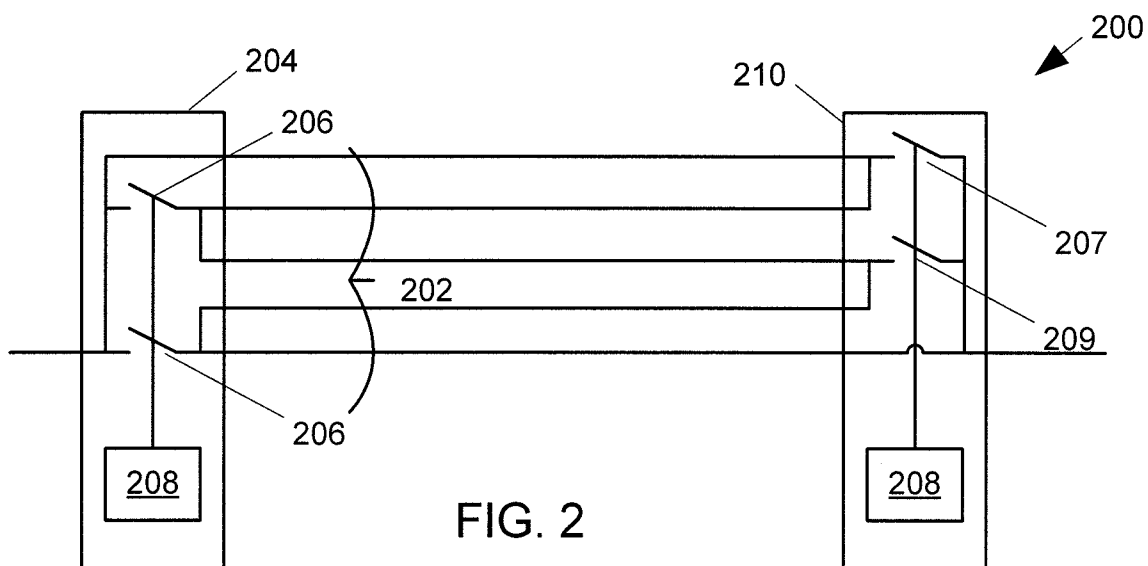
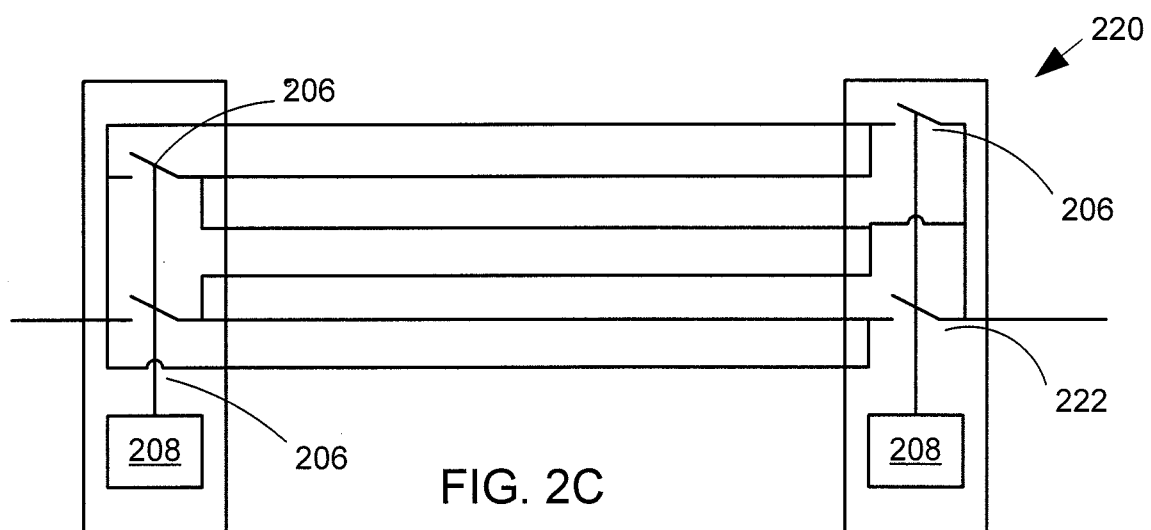
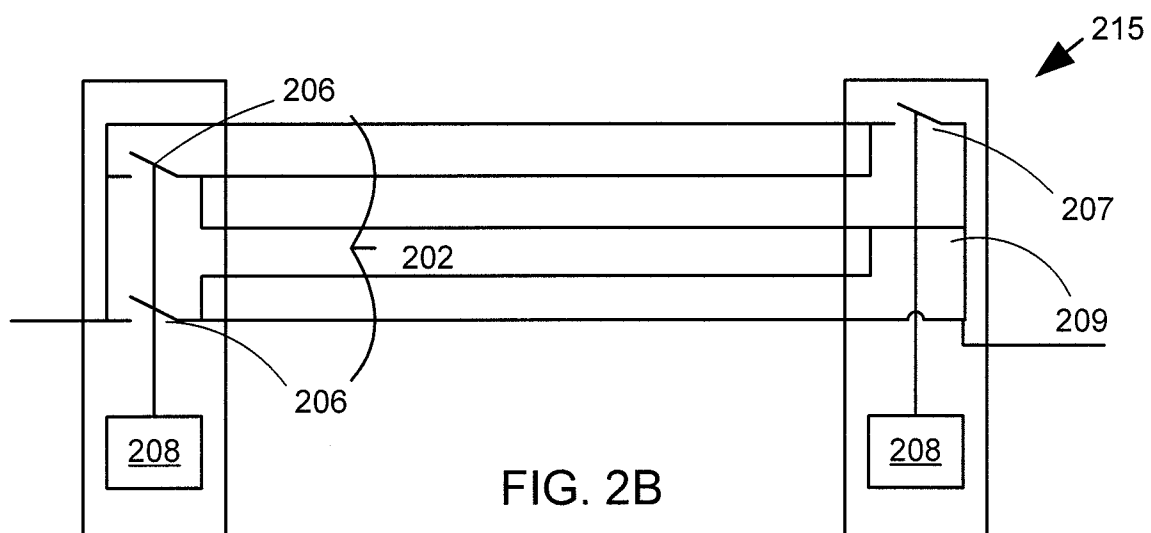
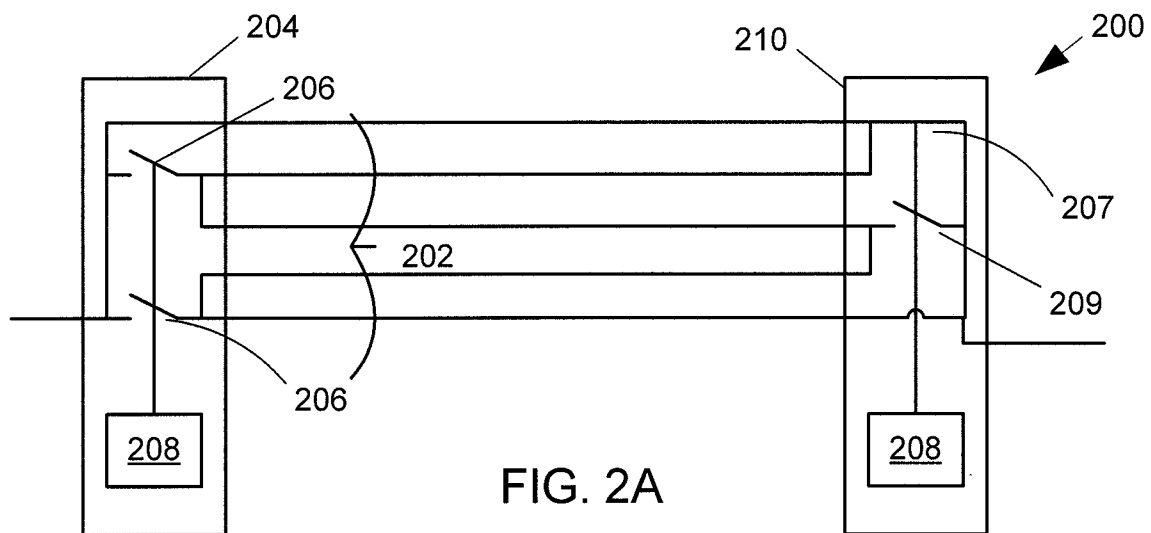


FIG. 1B

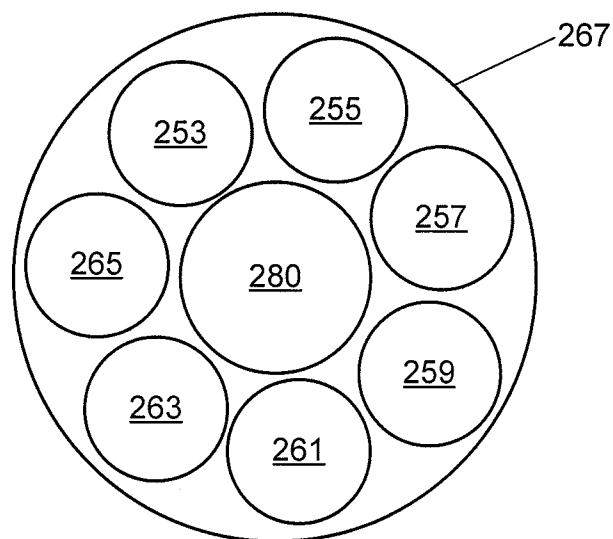
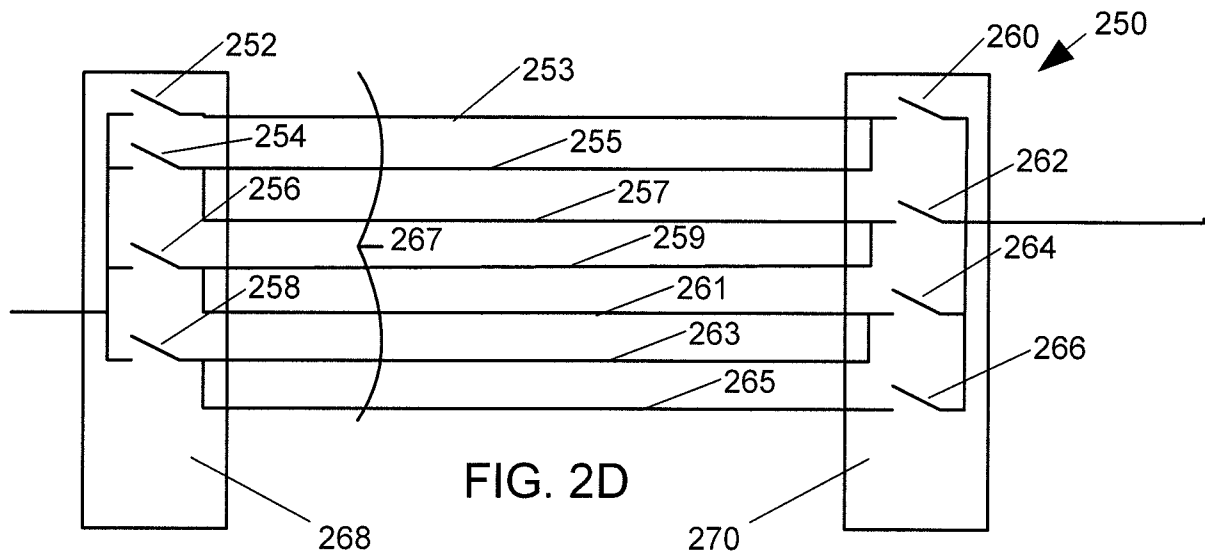
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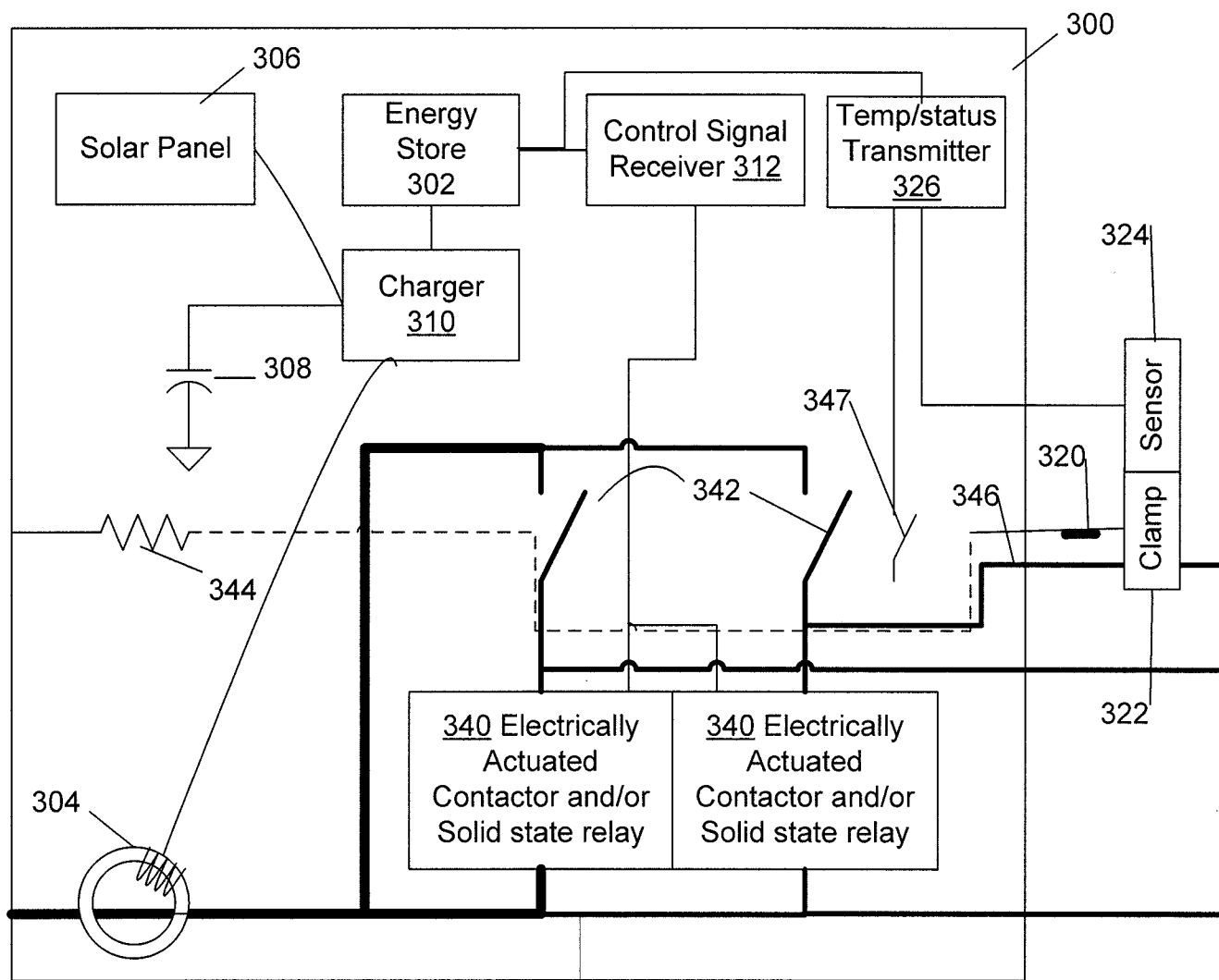


FIG. 3A

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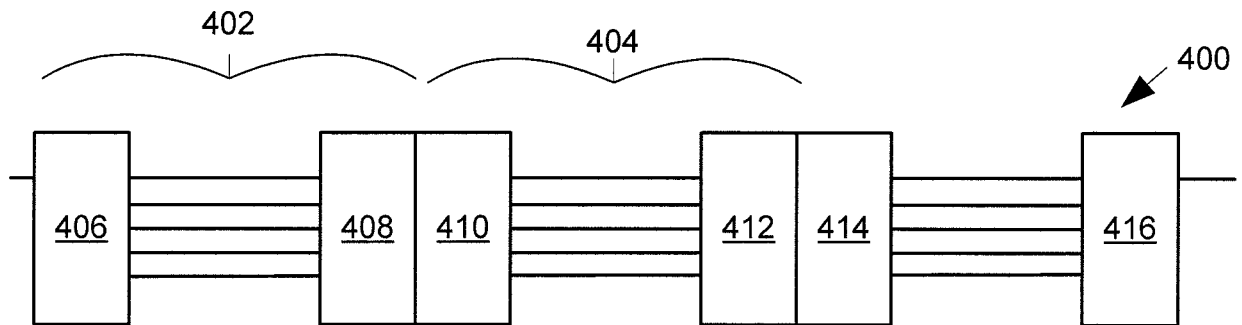


FIG. 4

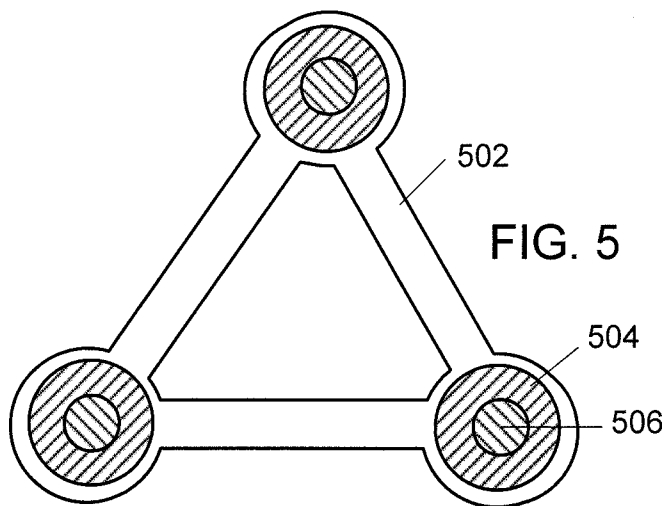


FIG. 5

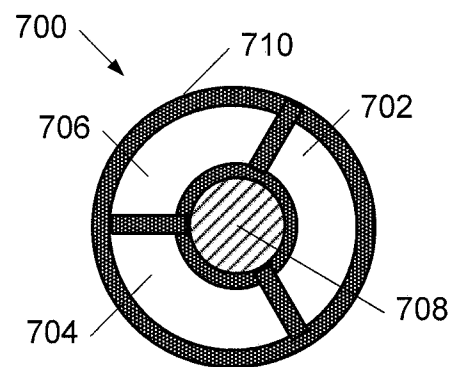


FIG. 7

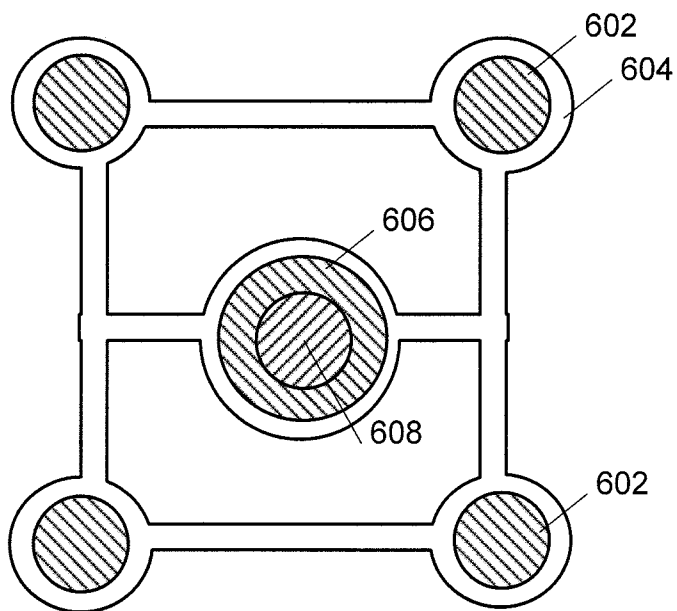
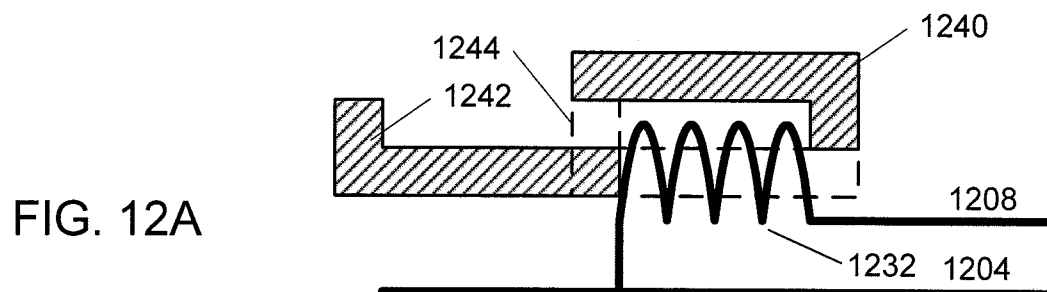
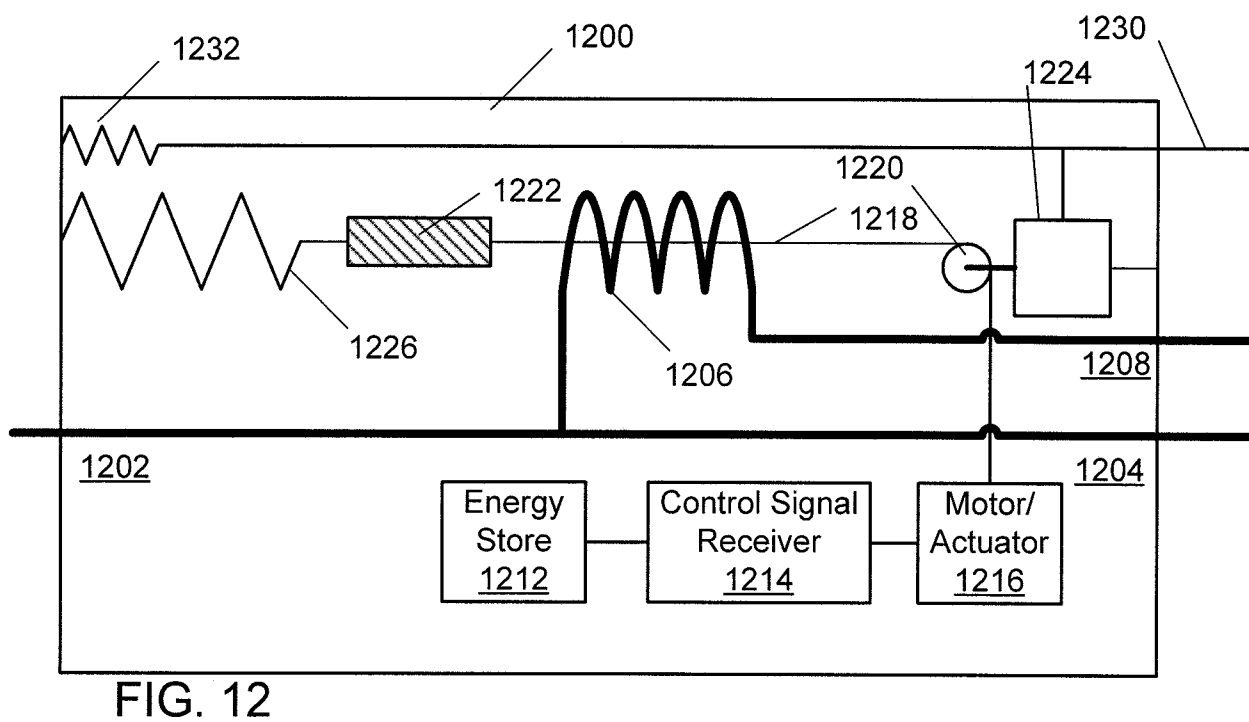
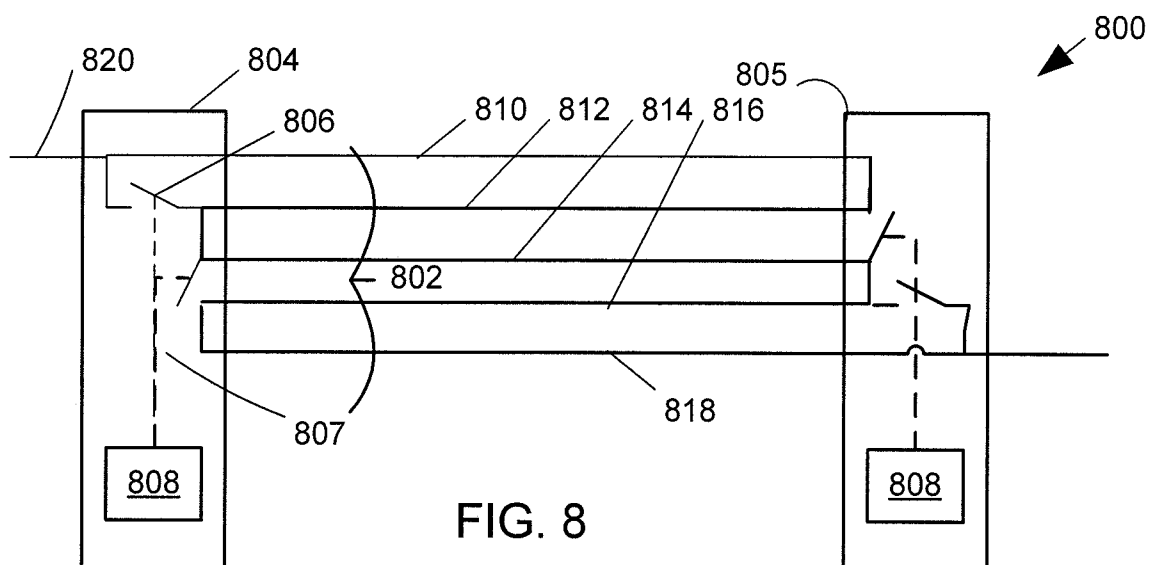


FIG. 6

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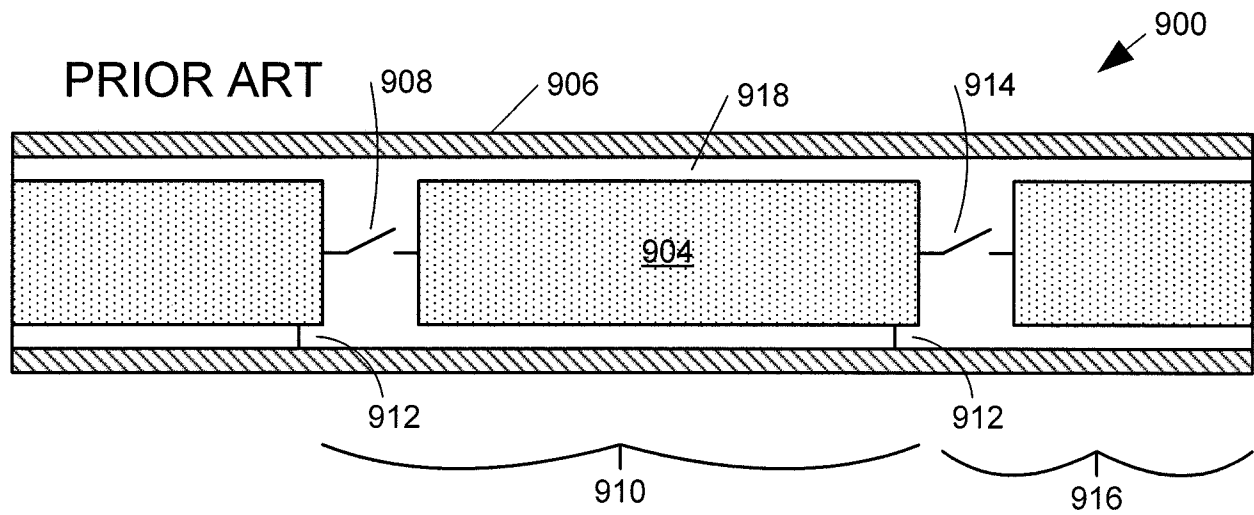


FIG. 9

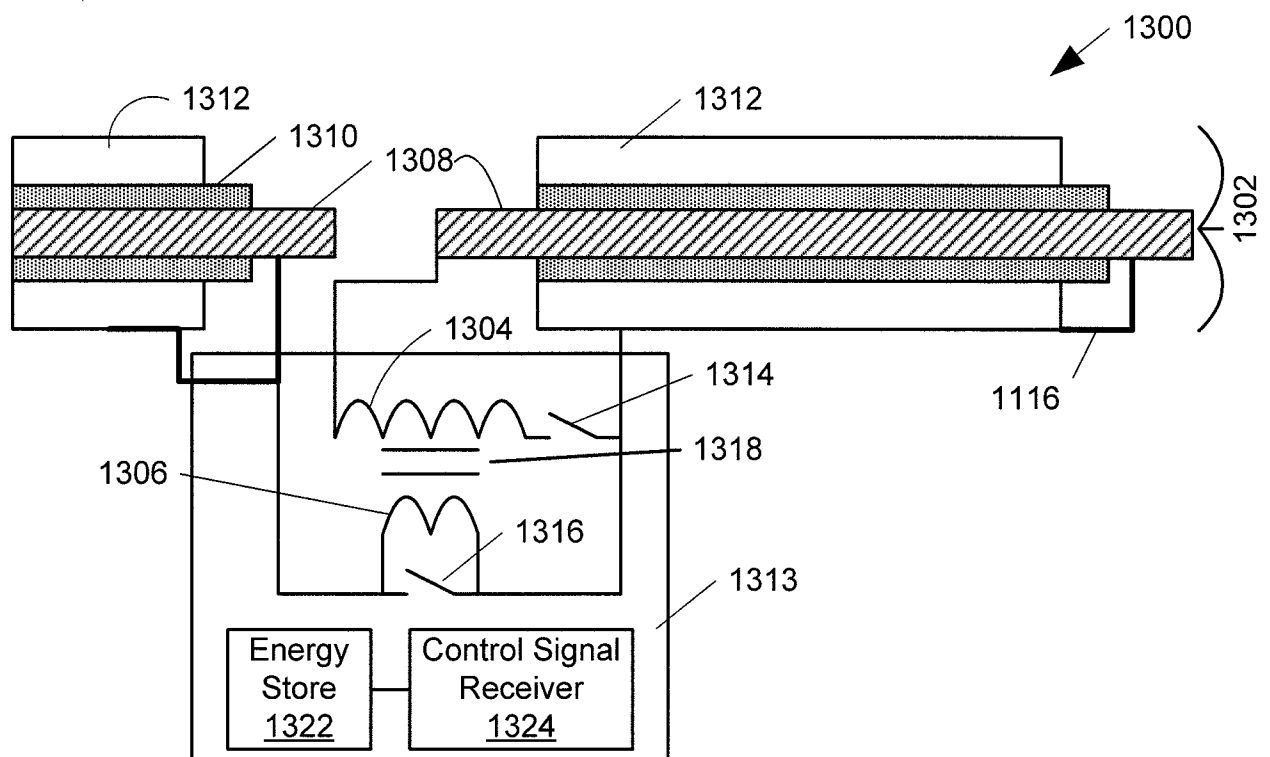


FIG. 13

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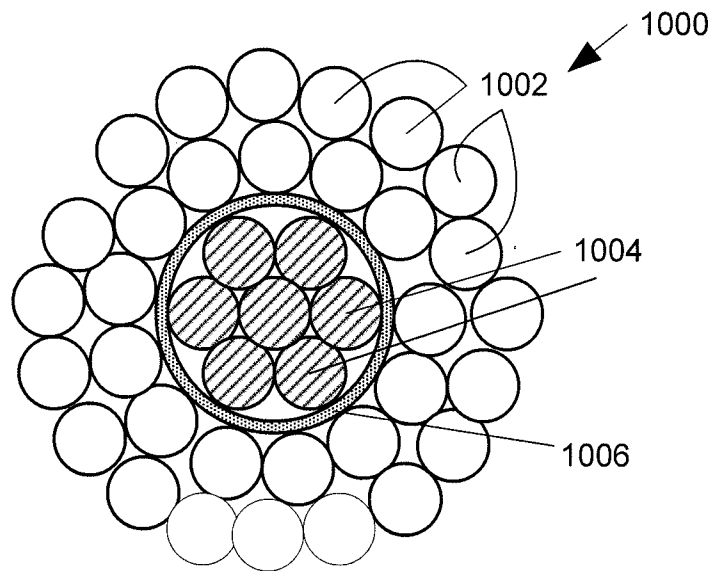


FIG. 10

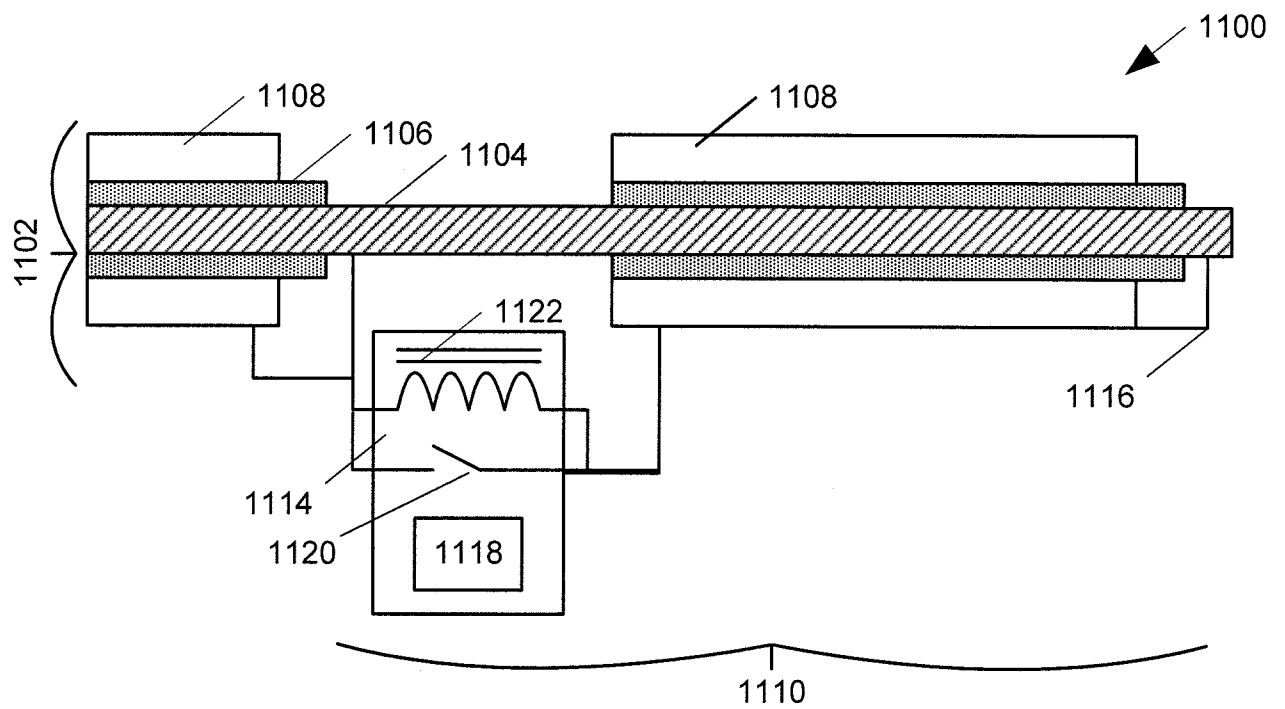


FIG. 11

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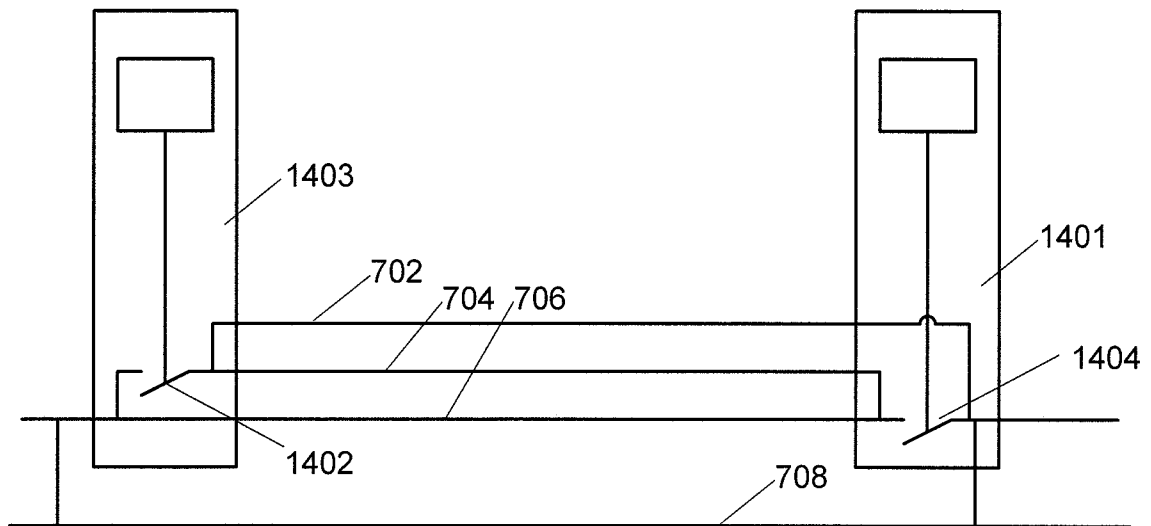


FIG. 14

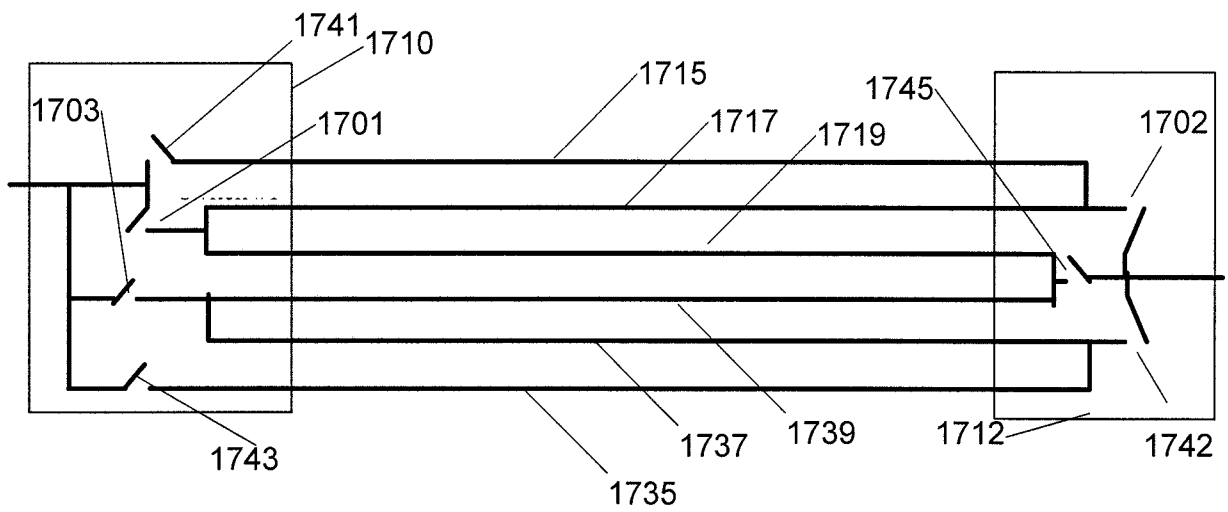


FIG. 17

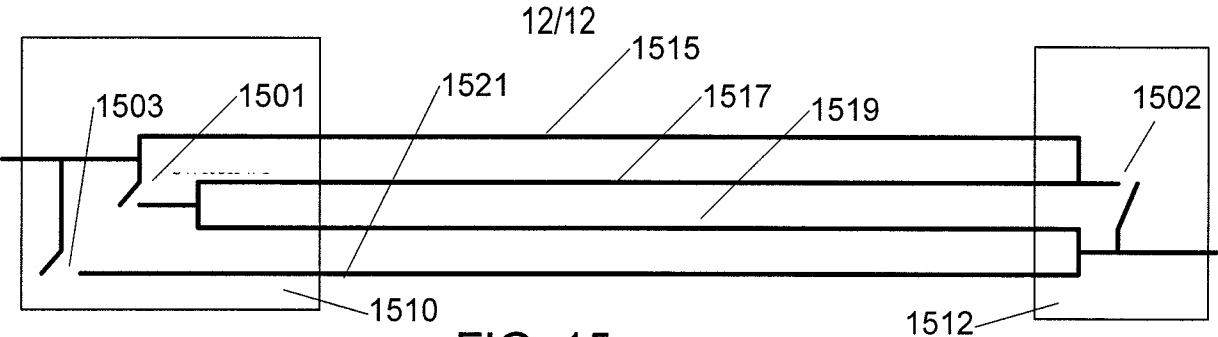


FIG. 15

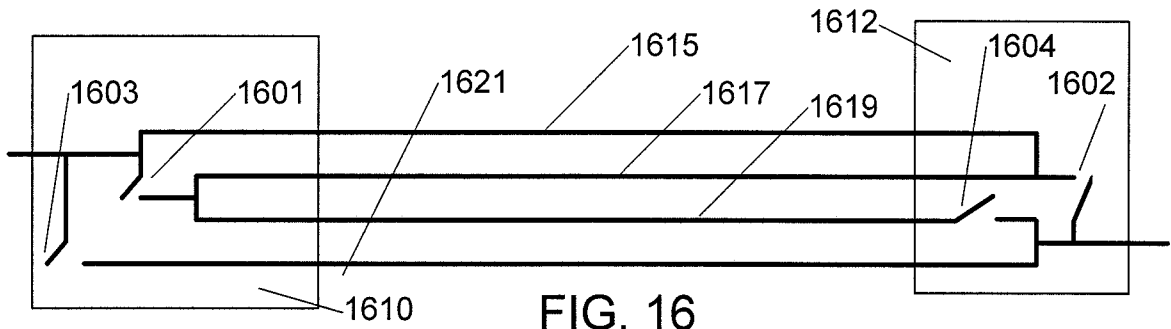


FIG. 16