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(54) Title: SELECTING PARTICULAR TRANSISTORS IN AN ELECTRIC VEHICLE TO BE ACTIVATED/DEACTIVATED IN RESPONSE TO CURRENT CONDITIONS TO IMPROVE MILEAGE AND RESPONSE OF ELECTRIC VEHICLE

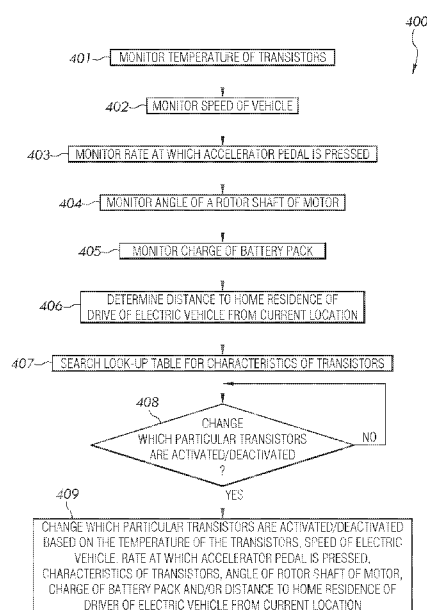


FIG. 4

(57) Abstract: A method, system and computer program product for optimizing the performance of an electric vehicle. An electronic controller controlling the operation of hub motors monitors the temperature of transistors in the electric vehicle, monitors the speed of the electric vehicle and monitors the rate at which an accelerator pedal is pressed. Furthermore, the electronic controller searches a look-up table containing the characteristics (e.g., switching characteristics) of the transistors. The electronic controller then determines whether there should be a change in the particular transistors that are activated/deactivated based on the temperature of the transistors, the speed of the electric vehicle, the rate at which the accelerator pedal is pressed and the characteristics of the transistors. In this manner, the performance of the electric vehicle is optimized since the transistors that are currently activated are those that would be most efficient to operate at that moment based on the current operating condition.

SELECTING PARTICULAR TRANSISTORS IN AN ELECTRIC VEHICLE TO BE
ACTIVATED/DEACTIVATED IN RESPONSE TO CURRENT CONDITIONS TO IMPROVE
MILEAGE AND RESPONSE OF ELECTRIC VEHICLE

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This application claims priority to U.S. Provisional Patent Application Serial No. 62/198,494, entitled "Selecting Particular Transistors in an Electric Vehicle to be Activated/Deactivated in Response to Current Conditions to Improve Mileage and Response of Electric Vehicle," filed July 29, 2015, which is incorporated by reference herein in its entirety.

TECHNICAL FIELD

[0002] The present invention relates generally to electric vehicles, and more particularly to selecting particular transistors in an electric vehicle to be activated/deactivated in response to current operating conditions to improve mileage and response of electric vehicle.

BACKGROUND

[0003] An electric vehicle, also referred to as an electric drive vehicle, uses one or more electric motors or traction motors for propulsion. An electric vehicle may be powered through a collector system by electricity from off-vehicle sources, or may be self-contained with a battery or generator to convert fuel to electricity.

[0004] There are several types of electric vehicles (e.g., golf carts, electric rickshaws, electric scooters, Neighborhood Electric Vehicles (NEVs)). For example, a plug-in electric vehicle (PEV) is any motor vehicle that can be recharged from any external source of electricity, such as wall sockets, and the electricity stored in the rechargeable battery packs drives or contributes to drive the wheels. PEV is a subcategory of electric vehicles that includes all-electric or battery electric vehicles (BEVs), plug-in hybrid vehicles (PHEVs), and electric vehicle conversions of hybrid electric vehicles and conventional internal combustion engine vehicles. Another type of electric vehicle is a hybrid vehicle. A hybrid electric vehicle combines a conventional (usually fossil fuel-powered) powertrain with some form of electric propulsion.

[0005] Some of the advantages of EVs over vehicles with internal combustion engines (ICEs) include energy efficiency. Electric vehicles convert about 59%-62% of the electrical energy from the grid to power at the wheels, whereas, conventional gasoline vehicles only convert about

17%-21% of the energy stored in gasoline to power at the wheels. Furthermore, EVs emit no tailpipe pollutants, although the power plant producing the electricity may emit them. Additionally, electric motors provide quiet, smooth operation and stronger acceleration and require less maintenance than ICEs.

[0006] EVs do, however, face significant battery-related challenges, such as limited driving range. Most EVs can only travel about 100-200 miles before recharging, whereas, gasoline vehicles can travel over 300 miles before refueling. Furthermore, fully recharging the battery pack can take 4 to 8 hours. Even a "quick charge" to 80% capacity can take 30 minutes.

[0007] If, however, the mileage of the electric vehicle could be improved, then EVs could travel a further (longer) distance before recharging thereby requiring less frequent recharges.

[0008] Furthermore, while the response of the electric vehicle to the driver's demands is good, such as responding when the driver presses down the acceleration pedal to accelerate, there could still be improvement.

[0009] Hence, current electric vehicles are deficient in terms of mileage and responding to the driver's demands.

SUMMARY

[0010] In one embodiment of the present invention, a method for optimizing a performance of an electric vehicle comprises monitoring a temperature of a plurality of transistors of the electric vehicle. The method further comprises monitoring a speed of the electric vehicle. The method additionally comprises monitoring a rate at which an accelerator pedal is pressed. Furthermore, the method comprises searching one or more look-up tables containing characteristics of the plurality of transistors. Additionally, the method comprises changing, by a processor, which particular transistors are activated or deactivated in the electric vehicle based on the temperature of the plurality of transistors, the speed of the electric vehicle, the rate at which the accelerator pedal is pressed and the characteristics of the plurality of transistors.

[0011] Other forms of the embodiment of the method described above are in a system and in a computer program product.

[0012] The foregoing has outlined rather generally the features and technical advantages of one or more embodiments of the present invention in order that the detailed description of the present invention that follows may be better understood. Additional features and advantages of the present invention will be described hereinafter which may form the subject of the claims of the present invention.

BRIEF DESCRIPTION OF THE DRAWINGS

[0013] A better understanding of the present invention can be obtained when the following detailed description is considered in conjunction with the following drawings, in which:

[0014] Figure 1 illustrates an embodiment of the present invention of an electric vehicle;

[0015] Figure 2 illustrates an embodiment of the present invention of an electronic controller of the electric vehicle;

[0016] Figure 3 illustrates the electronic controller controlling the switching of the transistors in accordance with an embodiment of the present invention;

[0017] Figure 4 is a flowchart of a method for optimizing the performance of the electric vehicle in accordance with an embodiment of the present invention;

[0018] Figure 5 is a flowchart of a method for mapping the torque and speed of a motor to the characteristics of transistors in accordance with an embodiment of the present invention;

[0019] Figure 6 is a plot illustrating the relationship between the hysteresis band, the reference current and the switching frequency of transistor in accordance with an embodiment of the present invention;

[0020] Figure 7 is a graph illustrating the total losses in comparison to the torque and speed of a motor for four different transistors with an input voltage of 24 volts in accordance with an embodiment of the present invention;

[0021] Figure 8 is a graph further illustrating the behavior of the different switches in relation to the torque and speed of the motor as shown in Figure 7 for four different transistors with an input voltage of 24 volts in accordance with an embodiment of the present invention; and

[0022] Figure 9 illustrates the current operating point and the next operating point in connection with a graph of the torque versus the speed of a motor in accordance with an embodiment of the present invention.

DETAILED DESCRIPTION

[0023] As discussed in the Background section, obtaining adequate mileage is one of the biggest challenges for electric vehicles. As discussed herein, through better power management, mileage is improved thereby improving the efficiency of the electric vehicle. Furthermore, as discussed herein, the principles of the present invention also allow the electric vehicle to provide a better response to the driver's demand.

[0024] While the following discusses the present invention in connection with electric automobiles, the principles of the present invention may be applied to other electric vehicles, such as rail vehicles, surface and underwater vessels, electric aircraft, electrically powered space vehicles, electric golf carts, electric rickshaws, electric scooters and Neighborhood Electric Vehicles (NEVs). A person of ordinary skill in the art would be capable of applying the principles of the present invention to such implementations. Further, embodiments applying the principles of the present invention to such implementations would fall within the scope of the present invention.

[0025] Referring now to the Figures, Figure 1 is an embodiment of the present invention of an electric vehicle 100. As illustrated in Figure 1, electric vehicle 100 includes wheels 101A-101D. Wheels 101A-101D may collectively or individually be referred to as wheels 101 or wheel 101, respectively. Each wheel 101A-101D is driven by a respective electric hub motor 102A-102D, respectively. Electric hub motors 102A-102D may collectively or individually be referred to as electric hub motors 102 or electric hub motor 102, respectively. Electric hub motors 102 are connected to an electric battery pack 103, the main long term energy store of electric vehicle 100, and are powered by electric power supplied by the battery pack 103. Furthermore, in one embodiment, as illustrated in Figure 1, electric vehicle 100 may include an electric motor 104 (e.g., switched reluctance motor) coupled to an electric generator 105. Alternatively, in another embodiment, a small internal combustion engine ("ICE") may be used in addition to electric motor 104 or instead of electric motor 104 and can be operated to provide electric power to top up battery pack 103.

[0026] An electronic controller 106 (or simply referred to as "controller" 106) is connected to hub motors 102 and controls operation of hub motors 102. Electronic controller 106 is also connected to battery pack 103 so that controller 106 can monitor the state of charge of battery

pack 103. In one embodiment, electronic controller 106 is connected to generator 105 and electric motor 104 to control operation thereof. In one embodiment, electronic controller 106 contains circuitry for controlling the switching of transistors/ switches, such as but not limited to metal-oxide-semiconductor field-effect transistors (MOSFETs) and insulated-gate bipolar transistors (IGBTs), and it is designed in such a way as to optimize the performance of the system with respect to the motor and drive topology being used. In one embodiment, the goal of the present invention is to minimize the switching and conduction losses, minimize the ringing and driver losses while simultaneously reducing the EMI noise and spikes due to transients in the circuitry.

[0027] Furthermore, Figure 1 illustrates a brake pedal position sensor 107 which is connected to electronic controller 106. Brake pedal position sensor 107 is used to detect the position of the brake pedal.

[0028] Figure 1 further illustrates an accelerator pedal position sensor 108 which is connected to electronic controller 106. Accelerator pedal position sensor 108 indicates the position of the accelerator pedal as well as the rate at which the accelerator pedal is pressed by the driver of electric vehicle 100.

[0029] Additionally, Figure 1 illustrates wheel sensors 109A-109D which are used to send pulses to electronic controller 106 to determine the speed of vehicle 100. Sensors 109A-109D may collectively or individually be referred to as sensors 109 or sensor 109, respectively. Alternatively, a rotation sensor may be mounted in the transmission to deliver a series of electronic pulses whose frequency corresponds to the (average) rotational speed of the driveshaft, and therefore the vehicle's speed. The principles of the present invention are not to be limited in scope in the manner of determining the speed of vehicle 100. The scope of the present invention is to include any means for determining the speed of vehicle 100.

[0030] Furthermore, electric vehicle 100 includes a sensor 110 connected to hub motors 102 and electric motor 104. Sensor 110 is used for monitoring the angle of the rotor shaft of a motor (e.g., hub motor 102, electric motor 104), such as in the embodiment of hub motor 102/electric motor 104 being a switched reluctance motor.

[0031] In one embodiment, vehicle 100 can operate with regenerative braking, i.e., the motors 102, 104 can switch to operate as generators to slow the vehicle by converting kinetic energy of the vehicle into electrical energy, which can be used to top up battery pack 103.

[0032] Electronic controller 106 may be an electronic control unit (ECU) and other control electronics, such as microprocessors, voltage regulators, switches, integrated and non-integrated circuits, transistors, relays, control logic, volatile and non-volatile memory, and other electronic components suitable for performing the control algorithms discussed herein. In particular, in one embodiment, electronic controller 106 includes at least a processing component (e.g., microprocessor) and a memory for storing a program for improving the efficiency of operation of electric vehicle 100 to improve mileage as well as improving the response of electric vehicle 100 to the driver's demands as discussed below in connection with Figure 2.

[0033] Figure 2 illustrates an embodiment of the present invention of electronic controller 106 (Figure 1). Referring to Figure 2, controller 106 includes a processor 201 and a memory 202. Memory 202 is used to store software and data for execution by processor 201 to carry out various operations of electronic controller 106. In one embodiment, memory 202 is configured to store a program for improving the efficiency of operation of electric vehicle 100 to improve mileage as well as improving the response of electric vehicle 100 to the driver's demands as discussed below.

[0034] As further illustrated in Figure 2, electronic controller 106 further includes a Global Positioning System (GPS) receiver 203 for determining its current position as well as determining a distance from its current location to the location of the home residence of the driver (previously provided to electronic controller 106 by the user, such as the driver of electric vehicle 100).

[0035] Furthermore, as illustrated in Figure 2, electronic controller 106 includes a communications adapter 204 for enabling controller 106 to communicate with other systems.

[0036] Additionally, as illustrated in Figure 2, a look-up table 205 may be stored in memory 202, where look-up table 205 is used to store the characteristics (e.g., switching characteristics, voltage ratings, current ratings) of the transistors, such as the transistors of electronic controller 106 and the transistors of the motor drives, such as hub motors 102 or electric motor 104. Information, such as the power rating of the transistors, may be stored in look-up table 205.

Such information may be used to determine the safe operating region for the transistors with respect to the various driving and operating conditions. Furthermore, such information may be used by electronic controller 106 to identify a threshold temperature at which the amount of power consumed by the transistor exceeds a desirable amount of power consumption. In such a case, such a transistor may be deactivated and another transistor may be activated to replace the operation of the deactivated transistor. In one embodiment, look-up table 205 stores the characteristics of the various transistors used and also the performance maps of the circuitry, its behavior and performance in relation to the various operating conditions. A further description of the use of look-up table 205 is provided further below in connection with Figure 4.

[0037] The present invention may be a system, a method, and/or a computer program product. The computer program product may include a computer readable storage medium (or media) having computer readable program instructions thereon for causing a processor to carry out aspects of the present invention.

[0038] The computer readable storage medium can be a tangible device that can retain and store instructions for use by an instruction execution device. The computer readable storage medium may be, for example, but is not limited to, an electronic storage device, a magnetic storage device, an optical storage device, an electromagnetic storage device, a semiconductor storage device, or any suitable combination of the foregoing. A non-exhaustive list of more specific examples of the computer readable storage medium includes the following: a portable computer diskette, a hard disk, a random access memory (RAM), a read-only memory (ROM), an erasable programmable read-only memory (EPROM or Flash memory), a static random access memory (SRAM), a portable compact disc read-only memory (CD-ROM), a digital versatile disk (DVD), a memory stick, a floppy disk, a mechanically encoded device such as punch-cards or raised structures in a groove having instructions recorded thereon, and any suitable combination of the foregoing. A computer readable storage medium, as used herein, is not to be construed as being transitory signals *per se*, such as radio waves or other freely propagating electromagnetic waves, electromagnetic waves propagating through a waveguide or other transmission media (e.g., light pulses passing through a fiber-optic cable), or electrical signals transmitted through a wire.

[0039] Computer readable program instructions described herein can be downloaded to respective computing/processing devices from a computer readable storage medium or to an

external computer or external storage device via a network, for example, the Internet, a local area network, a wide area network and/or a wireless network. The network may comprise copper transmission cables, optical transmission fibers, wireless transmission, routers, firewalls, switches, gateway computers and/or edge servers. A network adapter card or network interface in each computing/processing device receives computer readable program instructions from the network and forwards the computer readable program instructions for storage in a computer readable storage medium within the respective computing/processing device.

[0040] Computer readable program instructions for carrying out operations of the present invention may be assembler instructions, instruction-set-architecture (ISA) instructions, machine instructions, machine dependent instructions, microcode, firmware instructions, state-setting data, or either source code or object code written in any combination of one or more programming languages, including an object oriented programming language such as Smalltalk, C++ or the like, and conventional procedural programming languages, such as the "C" programming language or similar programming languages. The computer readable program instructions may execute entirely on the user's computer, partly on the user's computer, as a stand-alone software package, partly on the user's computer and partly on a remote computer or entirely on the remote computer or server. In the latter scenario, the remote computer may be connected to the user's computer through any type of network, including a local area network (LAN) or a wide area network (WAN), or the connection may be made to an external computer (for example, through the Internet using an Internet Service Provider). In some embodiments, electronic circuitry including, for example, programmable logic circuitry, field-programmable gate arrays (FPGA), or programmable logic arrays (PLA) may execute the computer readable program instructions by utilizing state information of the computer readable program instructions to personalize the electronic circuitry, in order to perform aspects of the present invention.

[0041] Aspects of the present invention are described herein with reference to flowchart illustrations and/or block diagrams of methods, apparatus (systems), and computer program products according to embodiments of the invention. It will be understood that each block of the flowchart illustrations and/or block diagrams, and combinations of blocks in the flowchart illustrations and/or block diagrams, can be implemented by computer readable program instructions.

[0042] These computer readable program instructions may be provided to a processor of a general purpose computer, special purpose computer, or other programmable data processing apparatus to produce a machine, such that the instructions, which execute via the processor of the computer or other programmable data processing apparatus, create means for implementing the functions/acts specified in the flowchart and/or block diagram block or blocks. These computer readable program instructions may also be stored in a computer readable storage medium that can direct a computer, a programmable data processing apparatus, and/or other devices to function in a particular manner, such that the computer readable storage medium having instructions stored therein comprises an article of manufacture including instructions which implement aspects of the function/act specified in the flowchart and/or block diagram block or blocks.

[0043] The computer readable program instructions may also be loaded onto a computer, other programmable data processing apparatus, or other device to cause a series of operational steps to be performed on the computer, other programmable apparatus or other device to produce a computer implemented process, such that the instructions which execute on the computer, other programmable apparatus, or other device implement the functions/acts specified in the flowchart and/or block diagram block or blocks.

[0044] The flowchart and block diagrams in the Figures illustrate the architecture, functionality, and operation of possible implementations of systems, methods, and computer program products according to various embodiments of the present invention. In this regard, each block in the flowchart or block diagrams may represent a module, segment, or portion of instructions, which comprises one or more executable instructions for implementing the specified logical function(s). In some alternative implementations, the functions noted in the block may occur out of the order noted in the figures. For example, two blocks shown in succession may, in fact, be executed substantially concurrently, or the blocks may sometimes be executed in the reverse order, depending upon the functionality involved. It will also be noted that each block of the block diagrams and/or flowchart illustration, and combinations of blocks in the block diagrams and/or flowchart illustration, can be implemented by special purpose hardware-based systems that perform the specified functions or acts or carry out combinations of special purpose hardware and computer instructions.

[0045] As discussed in the Background section, some of the advantages of EVs over vehicles with internal combustion engines (ICEs) include energy efficiency. Electric vehicles convert about 59%-62% of the electrical energy from the grid to power at the wheels, whereas, conventional gasoline vehicles only convert about 17%-21% of the energy stored in gasoline to power at the wheels. Furthermore, EVs emit no tailpipe pollutants, although the power plant producing the electricity may emit them. Additionally, electric motors provide quiet, smooth operation and stronger acceleration and require less maintenance than ICEs. EVs do, however, face significant battery-related challenges, such as limited driving range. Most EVs can only travel about 100-200 miles before recharging, whereas, gasoline vehicles can travel over 300 miles before refueling. Furthermore, fully recharging the battery pack can take 4 to 8 hours. Even a "quick charge" to 80% capacity can take 30 minutes. If, however, the mileage of the electric vehicle could be improved, then EVs could travel a further distance before recharging thereby requiring less frequent recharges. Furthermore, while the response of the electric vehicle to the driver's demands is good, such as responding when the driver presses down the acceleration pedal to accelerate, there could still be improvement. Hence, current electric vehicles are deficient in terms of mileage and responding to the driver's demands.

[0046] The principles of the present invention provide a means for improving the efficiency of operation of the electric vehicle to improve mileage as well as improving the response of the electric vehicle to the driver's demands by efficiently utilizing transistors as discussed below in connection with Figures 3-9. Figure 3 illustrates the electronic controller controlling the switching of the transistors. Figure 4 is a flowchart of a method for optimizing the performance of an electric vehicle. Figure 5 is a flowchart of a method for mapping the torque and speed of a motor to the characteristics of transistors. Figure 6 is a plot illustrating the relationship between the hysteresis band, the reference current and the switching frequency of transistor. Figure 7 is a graph illustrating the total losses in comparison to the torque and speed of a motor for four different transistors with an input voltage of 24 volts. Figure 8 is a graph further illustrating the behavior of the different switches in relation to the torque and speed of the motor as shown in Figure 7 for four different transistors with an input voltage of 24 volts. Figure 9 illustrates the current operating point and the next operating point in connection with a graph of the torque versus the speed of a motor.

[0047] Referring to Figure 3, Figure 3 illustrates electronic controller 106 (Figures 1 and 2) controlling the switching of the transistors in accordance with an embodiment of the present invention. As illustrated in Figure 3, electronic controller 106 and the motors of electric vehicle 100, such as hub motors 102 and electric motor 104, include switch matrices 301A, 301B (identified as “switch matrix 1” and “switch matrix 2,” respectively, in Figure 3). Switch matrices 301A, 301B may collectively or individually be referred to as switch matrices 301 or switch matrix 301. While Figure 3 illustrates two switch matrices 301, the principles of the present invention are not to be limited in scope to a particular number of switch matrices 301. Electric vehicle 100 may include any number of switch matrices 301 that would be required to perform the operation of electric vehicle 100.

[0048] Each switch matrix 301 includes a series of transistors. For example, switch matrix 1 301A includes transistors 302A-302D (identified as “Q1a-Q1d,” respectively, in Figure 3) connected in parallel. In another example, switch matrix 2 301B includes transistors 302E-302H (identified as “Q2a-Q2d,” respectively, in Figure 3) connected in parallel. Transistors 302A-302H may collectively or individually be referred to as transistors 302 or transistor 302, respectively. While Figure 3 illustrates that each matrix 301 includes four transistors 302, the principles of the present invention are not to be limited in scope to having switch matrix 301 include a particular number of transistors 302. Each matrix 301 may include any number of transistors 302 that would be required to perform the operation of electric vehicle 100.

[0049] As will be discussed herein, the particular activation/deactivation of transistors 302 based on the current operating conditions will be performed by electronic controller 106 thereby improving the efficiency of operation of vehicle 100 as well as improving the response of the vehicle 100 to the driver's demands. In one embodiment, each transistor 302 is activated or deactivated based on the biasing of the transistor, i.e., controlling the values of the input voltage to transistor 302 by switch drive circuit 303 of electronic controller 106.

[0050] Furthermore, as illustrated in Figure 3, electric vehicle 100 includes one or more temperature sensors 304 (in electronic controller 106 as well as in the motors outside of electronic controller 106, such as in hub motors 102 and electric motor 104, which are connected to electronic controller 106) configured to monitor the temperature of each of the transistors 302. As discussed herein, when the temperature of a transistor 302 exceeds a threshold temperature

for that given transistor (such as provided in a look-up table for that transistor), then electronic controller 106 may deactivate that transistor 302 and activate another transistor 302.

[0051] Referring now to Figure 4, Figure 4 is a flowchart of a method 400 for optimizing the performance of electric vehicle 100 (Figure 1) in accordance with an embodiment of the present invention.

[0052] Referring to Figure 4, in conjunction with Figures 1-3, in step 401, electronic controller 106 monitors the temperature of transistors 302, such as via temperature sensor 304. In this manner, as discussed below, electronic controller 106 may identify those transistors 302 with a temperature that exceeds a threshold temperature based on the transistor's characteristics stored in look-up table 205. When a transistor 302 exceeds such a threshold temperature, its operational efficiency is diminished. Temperature affects the characteristics (e.g., AC and DC characteristics) of transistors. An increase in temperature of the transistor may cause thermal runaway or increase the leakage current which increases power consumption and if sufficiently large can cause complete failure. Furthermore, an increase in temperature may increase the collector current thereby increasing the power dissipated by the transistor. As a result, knowing the characteristics of transistors 302, including its power rating, will aid electronic controller 106 in determining whether such a transistor 302 should be activated/deactivated ("activated/deactivated," as used herein, means activated or deactivated) in light of the current conditions (e.g., rate at which the accelerator pedal is pressed).

[0053] In step 402, electronic controller 106 monitors the speed of electric vehicle 100, such as via the pulses provided by wheel sensors 109.

[0054] In step 403, electronic controller 106 monitors the rate at which the accelerator pedal is pressed, such as via accelerator pedal position sensor 108.

[0055] In step 404, electronic controller 106, such as in the case where hub motor 102 or electric motor 104 is a switched reluctance motor, monitors the angle of the rotor shaft of hub motor 102 or electric motor 104. Such information may be used by electronic controller 106 to determine the actual timing of activating or deactivating particular transistors 302. In one embodiment, the angle of the rotor shaft of hub motor 102 or electric motor 104 is monitored in step 404 for switched reluctance motors. In an alternative embodiment, the current state of the operation of

the motor/rotor position of the motor is monitored in step 404 for various other types of motors, such as brushless DC electric motor or an induction motor.

[0056] In step 405, electronic controller 106 monitors the charge of battery pack 103.

[0057] In step 406, electronic controller 106 determines the distance to the home residence of the driver of electric vehicle 100 from its current location. As discussed above, electronic controller 106 may include a GPS receiver 203 thereby allowing electronic controller 106 to determine its current position as well as to determine the distance from its current location to the location of the home residence of the driver (previously provided to electronic controller 106 by the user, such as the driver of electric vehicle 100).

[0058] In step 407, electronic controller 106 searches look-up table 205 for the characteristics (e.g., switching characteristics, voltage ratings, current ratings) of transistors 302. As discussed above, information, such as the power rating of transistors 302, may be stored in look-up table 205. Such information may be used to determine the temperatures at which transistor 302 can operate safely or when transistor 302 is overheating. Furthermore, such information may be used by electronic controller 106 to identify a threshold temperature based on the current operating conditions and comparing them against the look-up table characteristics of transistors 302 at which the power loss of one set of transistors 302 may be compared to a different set. In such a case, such a transistor 302 may be deactivated and another transistor 302 may be activated to replace the operation of the deactivated transistor 302. Furthermore, look-up table 205 stores characteristics that indicate whether transistor 302 has a low current and a high voltage rating (i.e., such transistors 302 operate better at low current and high voltage) or vice-versa. Such a rating may be used by electronic controller 106 to determine which transistors 302 should be activated based on the current operating condition. For example, in the scenario where the driver has increased the rate at which the accelerator pedal is pressed, then electronic controller 106 would select those transistors 302 which have a high current rating to handle such a situation since a high current is required to accelerate electric vehicle 100. In another example, in the scenario where the rate at which the accelerator pedal is constant, electronic controller 106 would select those transistors 302 having a high voltage and a low current rating characteristic to handle such a situation since a low current is only required to maintain a constant speed of electric vehicle 100. In this manner, the performance of electric vehicle 100 is optimized since

the transistors 302 that are currently activated are those that would be most efficient to operate (less heat generated) at that moment based on the current operating condition. As a result, mileage will improve for electric vehicle 100. Furthermore, by utilizing those transistors 302 that are most efficient to operate based on the current operating condition (e.g., increase in rate at which the accelerator pedal is pressed), the response of electric vehicle 100 to the driver's demands is improved. That is, electric vehicle 100 will respond more quickly and appropriately in response to the driver's demands.

[0059] In step 408, a determination is made by electronic controller 106 as to whether there should be a change in which particular transistors 302 are activated/deactivated. It is noted that steps 401-408 may be continuously implemented by electronic controller 106 to continuously determine in real time as to whether there should be a change in which particular transistors 302 are activated/deactivated in order to improve the efficiency and drivability of electric vehicle 100. In one embodiment, such a determination is made based on the information obtained from steps 401-407, namely, the temperature of transistors 302, the speed of electric vehicle 100, the rate at which the accelerator pedal is pressed, the characteristics of transistors 302, the angle of the rotor shaft of the motor, the charge of battery pack 103 and/or the distance to the home residence of the driver of electric vehicle 100 from its current location.

[0060] If there should not be a change in which particular transistors 302 are activated/deactivated, then electronic controller 106 continues to determine whether there should be a change in which particular transistors 302 are activated/deactivated in step 408.

[0061] If, however, there should be a change in which particular transistors 302 are activated/deactivated based on the temperature of transistors 302, the speed of electric vehicle 100, the rate at which the accelerator pedal is pressed, the characteristics of transistors 302, the angle of the rotor shaft of the motor (e.g., hub motor 102, electric motor 104), the charge of battery pack 103 and/or the distance to the home residence of the driver of electric vehicle 100 from its current location, then, in step 409, electronic controller 106 changes which particular transistors 302 are activated/deactivated.

[0062] For example, in response to the rate at which the accelerator pedal is pressed, electronic controller 106 may increase the number of transistors 302 activated. Furthermore, as discussed

above, electronic controller 106 may select those transistors 302 which exhibit a high current rating characteristic to be activated.

[0063] In another example, electronic controller 106 may activate those transistors 302 having a low current and a high voltage rating in response to a constant speed of electric vehicle 100.

[0064] In a further example, electronic controller 106 may replace a deactivated transistor 302 after it has been deactivated a threshold number of times thereby ensuring that transistors 302 continue to perform efficiently thereby ensuring that electric vehicle 100 continues to efficiently operate.

[0065] In another example, electronic controller 106 may activate/deactivate transistors 302 at a time based on the angle of the rotor shaft of the motor (e.g., hub motor 102, electric motor 104).

[0066] In a further example, electronic controller 106 may determine which particular transistors 302 to be activated/deactivated based on the current charge of battery pack 103 and the distance to the home residence of the driver of electric vehicle 100. For instance, if the battery power is low and the distance to the home residence of the driver of electric vehicle 100 is a short distance, then those transistors 302 which exhibit a low current and a high voltage rating characteristic would be activated over those transistors 302 that exhibit a high current rating characteristic.

[0067] As a result, electronic controller 106 of the present invention provides better power management thereby improving the mileage and efficiency of electric vehicle 100. Furthermore, the principles of the present invention allow electric vehicle 100 to provide a better response to the driver's demands.

[0068] While the foregoing discusses the present invention as utilizing particular parameters, such as the characteristics of transistors 302 obtained from look-up table 205, the present invention may utilize other parameters, such as the torque and speed of a motor (e.g., hub motor 102, electric motor 104), to more accurately determine which transistors 302 to activate/deactivate as discussed below in connection with Figure 5.

[0069] Figure 5 is a flowchart of a method 500 for mapping the torque and speed of a motor (e.g., hub motor 102, electric motor 104) to the characteristics of transistors 302 in accordance with an embodiment of the present invention.

[0070] Referring to Figure 5, in conjunction with Figures 1-4, in step 501, electronic controller 106 sets the current as a function of the torque and speed from the motor specification sheet.

[0071] In step 502, electronic controller 106 defines the hysteresis band (range of current to be utilized) and a battery voltage based on user priority.

[0072] In step 503, electronic controller 106 approximates the motor phase by a variable inductor and the load by different current references.

[0073] In step 504, electronic controller 106 calculates and sets the frequency of the upper and the lower transistor 302 through the simulation of the motor for the given hysteresis band.

[0074] Based on the reference current, which is defined by electronic controller 106 based on the current operating conditions, the user priority, the properties of the system stored in look-up table 205, etc., the selected transistors 302 are activated/deactivated at such frequencies to keep the actual current within a certain range, commonly referred to as a hysteresis band, around a reference current. As a result, the driver of electric vehicle 100 will experience a smoother ride by controlling the torque ripple (referring to a periodic increase or decrease in output torque as the motor shaft rotates).

[0075] Figure 6, as discussed below, is a plot illustrating the relationship between the hysteresis band, the reference current and the switching frequency of transistor 302 in accordance with an embodiment of the present invention.

[0076] Different transistors 302 have different operating region “sweet spots” on the torque speed curve. Figure 7 is a graph illustrating the total losses (watts) in comparison to the torque (newton meters) and speed (revolutions per minute) of a motor (e.g., hub motor 102) for four different transistors 302 with an input voltage of 24 volts in accordance with an embodiment of the present invention. Figure 8 is a graph further illustrating the behavior of the different switches in relation to the torque (newton meters) and speed (revolutions per minute) of a motor (e.g., hub motor 102) as shown in Figure 7 for four different transistors 302 with an input voltage of 24 volts in accordance with an embodiment of the present invention.

[0077] As illustrated in Figures 7 and 8, on different regions of the torque and speed of operation, different switches 302 have different losses. By knowing the losses of transistors 302, electronic controller 106 will be able to better determine which transistors 302 should be

activated/deactivated at a given time based on the current operating conditions of electric vehicle 100. In particular, based on the user priority of maximizing efficiency, improving response (rate of change of torque with time) and minimizing torque ripple for ride comfort, electronic controller 106, based on the current operating conditions and the look-up table 205 data, sets the operating point of the system and decides which transistors 302 to activate/deactivate and the switching strategy/logic to be used.

[0078] To go from one point on the torque speed curve (the current operating point) to a different point on the curve, there exist multiple combinations of the various control parameters to reach from one point to the other. The selected parameters are based on the current operating conditions and the requirements of the user (user priority) as illustrated in Figure 9, which illustrates the current operating point (point P) and the next operating point (point Q) in connection with a graph of the torque versus the speed of a motor in accordance with an embodiment of the present invention.

[0079] As illustrated in Figure 9, point P may represent the current operating point and point Q may represent the next operating point. There are numerous ways of going from point P to point Q based on the various control parameters, which are utilized by electronic controller 106 to determine which transistors 302 to be activated/deactivated at a given time.

[0080] Furthermore, while the foregoing discusses utilizing torque and speed, other control parameters may be utilized by electric controller 102 to determine which transistors 302 to be activated/deactivated, such as the battery supply voltage, which may vary based on the number of battery packs or even the number of batteries in the battery pack, or in an alternative embodiment, may vary based on bucking or boosting the voltage to various voltage levels using switches/transistors/power electronic circuits.

[0081] The descriptions of the various embodiments of the present invention have been presented for purposes of illustration, but are not intended to be exhaustive or limited to the embodiments disclosed. Many modifications and variations will be apparent to those of ordinary skill in the art without departing from the scope and spirit of the described embodiments. The terminology used herein was chosen to best explain the principles of the embodiments, the practical application or technical improvement over technologies found in the marketplace, or to enable others of ordinary skill in the art to understand the embodiments disclosed herein.

CLAIMS:

- 1 1. A method for optimizing a performance of an electric vehicle, the method comprising:
2 monitoring a temperature of a plurality of transistors of said electric vehicle;
3 monitoring a speed of said electric vehicle;
4 monitoring a rate at which an accelerator pedal is pressed;
5 searching one or more look-up tables containing characteristics of said plurality of
6 transistors; and
7 changing, by a processor, which particular transistors are activated or deactivated in said
8 electric vehicle based on said temperature of said plurality of transistors, said speed of said
9 electric vehicle, said rate at which said accelerator pedal is pressed and said characteristics of
10 said plurality of transistors.
- 1 2. The method as recited in claim 1 further comprising:
2 increasing a number of transistors activated in said electric vehicle in response to an
3 increase in said rate at which said accelerator pedal is pressed.
- 1 3. The method as recited in claim 2 further comprising:
2 selecting additional transistors to be activated in said electric vehicle with a characteristic
3 having a high current rating.
- 1 4. The method as recited in claim 1 further comprising:
2 selecting transistors to be activated in said electric vehicle with a characteristic having a
3 low current and a high voltage rating in response to a constant speed of said electric vehicle.
- 1 5. The method as recited in claim 1 further comprising:
2 selecting transistors to be activated in said electric vehicle with a characteristic having a
3 high current rating in response to an increase in said rate at which said accelerator pedal is
4 pressed.
- 1 6. The method as recited in claim 1 further comprising:

deactivating a transistor in response to a temperature of said transistor exceeding a threshold temperature based on characteristics of said transistor obtained from said one or more look-up tables.

7. The method as recited in claim 6 further comprising:

replacing said deactivated transistor in response to said transistor exceeding said threshold temperature a threshold number of times.

8. The method as recited in claim 1 further comprising:

monitoring an angle of a rotor shaft of a motor, wherein said motor is a switched reluctance motor; and

activating or deactivating one or more transistors of said plurality of transistors in said electric vehicle at a time based on said angle of said rotor shaft.

9. The method as recited in claim 1 further comprising:

monitoring a charge of a battery pack;

determining a distance to a home residence of a driver of said electric vehicle from a current location; and

changing which particular transistors are activated or deactivated in said electric vehicle based on said temperature of said plurality of transistors, said speed of said electric vehicle, said rate at which said accelerator pedal is pressed, said characteristics of said plurality of transistors, said charge of said battery pack and said distance to said home residence of said driver of said electric vehicle from said current location.

10. The method as recited in claim 1 further comprising:

mapping characteristics of said plurality of transistors to a torque and speed of one or more motors of said electric vehicle; and

changing which particular transistors are activated or deactivated in said electric vehicle based on said temperature of said plurality of transistors, said speed of said electric vehicle, said rate at which said accelerator pedal is pressed, said characteristics of said plurality of transistors and said torque and speed of one or more motors of said electric vehicle.

11. The method as recited in claim 1 further comprising:

changing which particular transistors are activated or deactivated in said electric vehicle based on said temperature of said plurality of transistors, said speed of said electric vehicle, said rate at which said accelerator pedal is pressed, said characteristics of said plurality of transistors and battery supply voltage.

12. A computer program product for optimizing a performance of an electric vehicle, the computer program product comprising a computer readable storage medium having program code embodied therewith, the program code comprising the programming instructions for:

- monitoring a temperature of a plurality of transistors of said electric vehicle;
- monitoring a speed of said electric vehicle;
- monitoring a rate at which an accelerator pedal is pressed;
- searching one or more look-up tables containing characteristics of said plurality of transistors; and

changing which particular transistors are activated or deactivated in said electric vehicle based on said temperature of said plurality of transistors, said speed of said electric vehicle, said rate at which said accelerator pedal is pressed and said characteristics of said plurality of transistors.

13. The computer program product as recited in claim 12, wherein the program code further comprises the programming instructions for:

- increasing a number of transistors activated in said electric vehicle in response to an increase in said rate at which said accelerator pedal is pressed.

14. The computer program product as recited in claim 13, wherein the program code further comprises the programming instructions for:

- selecting additional transistors to be activated in said electric vehicle with a characteristic having a high current rating.

15. The computer program product as recited in claim 12, wherein the program code further comprises the programming instructions for:

- selecting transistors to be activated in said electric vehicle with a characteristic having a low current and a high voltage rating in response to a constant speed of said electric vehicle.

1 16. The computer program product as recited in claim 12, wherein the program code further
2 comprises the programming instructions for:

3 selecting transistors to be activated in said electric vehicle with a characteristic having a
4 high current rating in response to an increase in said rate at which said accelerator pedal is
5 pressed.

1 17. The computer program product as recited in claim 12, wherein the program code further
2 comprises the programming instructions for:

3 deactivating a transistor in response to a temperature of said transistor exceeding a
4 threshold temperature based on characteristics of said transistor obtained from said one or more
5 look-up tables.

1 18. The computer program product as recited in claim 17, wherein the program code further
2 comprises the programming instructions for:

3 replacing said deactivated transistor in response to said transistor exceeding said
4 threshold temperature a threshold number of times.

1 19. The computer program product as recited in claim 12, wherein the program code further
2 comprises the programming instructions for:

3 monitoring an angle of a rotor shaft of a motor, wherein said motor is a switched
4 reluctance motor; and

5 activating or deactivating one or more transistors of said plurality of transistors in said
6 electric vehicle at a time based on said angle of said rotor shaft.

1 20. The computer program product as recited in claim 12, wherein the program code further
2 comprises the programming instructions for:

3 monitoring a charge of a battery pack;

4 determining a distance to a home residence of a driver of said electric vehicle from a
5 current location; and

6 changing which particular transistors are activated or deactivated in said electric vehicle
7 based on said temperature of said plurality of transistors, said speed of said electric vehicle, said
8 rate at which said accelerator pedal is pressed, said characteristics of said plurality of transistors,

9 said charge of said battery pack and said distance to said home residence of said driver of said
10 electric vehicle from said current location.

1 21. The computer program product as recited in claim 12, wherein the program code further
2 comprises the programming instructions for:

3 mapping characteristics of said plurality of transistors to a torque and speed of one or
4 more motors of said electric vehicle; and

5 changing which particular transistors are activated or deactivated in said electric vehicle
6 based on said temperature of said plurality of transistors, said speed of said electric vehicle, said
7 rate at which said accelerator pedal is pressed, said characteristics of said plurality of transistors
8 and said torque and speed of one or more motors of said electric vehicle.

1 22. The computer program product as recited in claim 12, wherein the program code further
2 comprises the programming instructions for:

3 changing which particular transistors are activated or deactivated in said electric vehicle
4 based on said temperature of said plurality of transistors, said speed of said electric vehicle, said
5 rate at which said accelerator pedal is pressed, said characteristics of said plurality of transistors
6 and battery supply voltage.

1 23. A system, comprising:

2 a memory unit for storing a computer program for optimizing a performance of an
3 electric vehicle; and

4 a processor coupled to the memory unit, wherein the processor is configured to execute
5 the program instructions of the computer program comprising:

6 monitoring a temperature of a plurality of transistors of said electric vehicle;

7 monitoring a speed of said electric vehicle;

8 monitoring a rate at which an accelerator pedal is pressed;

9 searching one or more look-up tables containing characteristics of said plurality of
10 transistors; and

11 changing which particular transistors are activated or deactivated in said electric
12 vehicle based on said temperature of said plurality of transistors, said speed of said electric

13 vehicle, said rate at which said accelerator pedal is pressed and said characteristics of said
14 plurality of transistors.

1 24. The system as recited in claim 23, wherein the program instructions of the computer
2 program further comprise:

3 increasing a number of transistors activated in said electric vehicle in response to an
4 increase in said rate at which said accelerator pedal is pressed.

1 25. The system as recited in claim 24, wherein the program instructions of the computer
2 program further comprise:

3 selecting additional transistors to be activated in said electric vehicle with a characteristic
4 having a high current rating.

1 26. The system as recited in claim 23, wherein the program instructions of the computer
2 program further comprise:

3 selecting transistors to be activated in said electric vehicle with a characteristic having a
4 low current and a high voltage rating in response to a constant speed of said electric vehicle.

1 27. The system as recited in claim 23, wherein the program instructions of the computer
2 program further comprise:

3 selecting transistors to be activated in said electric vehicle with a characteristic having a
4 high current rating in response to an increase in said rate at which said accelerator pedal is
5 pressed.

1 28. The system as recited in claim 23, wherein the program instructions of the computer
2 program further comprise:

3 deactivating a transistor in response to a temperature of said transistor exceeding a
4 threshold temperature based on characteristics of said transistor obtained from said one or more
5 look-up tables.

1 29. The system as recited in claim 28, wherein the program instructions of the computer
2 program further comprise:

3 replacing said deactivated transistor in response to said transistor exceeding said
4 threshold temperature a threshold number of times.

1 30. The system as recited in claim 23, wherein the program instructions of the computer
2 program further comprise:

3 monitoring an angle of a rotor shaft of a motor, wherein said motor is a switched
4 reluctance motor; and

5 activating or deactivating one or more transistors of said plurality of transistors in said
6 electric vehicle at a time based on said angle of said rotor shaft.

1 31. The system as recited in claim 23, wherein the program instructions of the computer
2 program further comprise:

3 monitoring a charge of a battery pack;

4 determining a distance to a home residence of a driver of said electric vehicle from a
5 current location; and

6 changing which particular transistors are activated or deactivated in said electric vehicle
7 based on said temperature of said plurality of transistors, said speed of said electric vehicle, said
8 rate at which said accelerator pedal is pressed, said characteristics of said plurality of transistors,
9 said charge of said battery pack and said distance to said home residence of said driver of said
10 electric vehicle from said current location.

1 32. The system as recited in claim 23, wherein the program instructions of the computer
2 program further comprise:

3 mapping characteristics of said plurality of transistors to a torque and speed of one or
4 more motors of said electric vehicle; and

5 changing which particular transistors are activated or deactivated in said electric vehicle
6 based on said temperature of said plurality of transistors, said speed of said electric vehicle, said
7 rate at which said accelerator pedal is pressed, said characteristics of said plurality of transistors
8 and said torque and speed of one or more motors of said electric vehicle.

1 33. The system as recited in claim 23, wherein the program instructions of the computer
2 program further comprise:

3 changing which particular transistors are activated or deactivated in said electric vehicle
4 based on said temperature of said plurality of transistors, said speed of said electric vehicle, said

5 rate at which said accelerator pedal is pressed, said characteristics of said plurality of transistors
6 and battery supply voltage.

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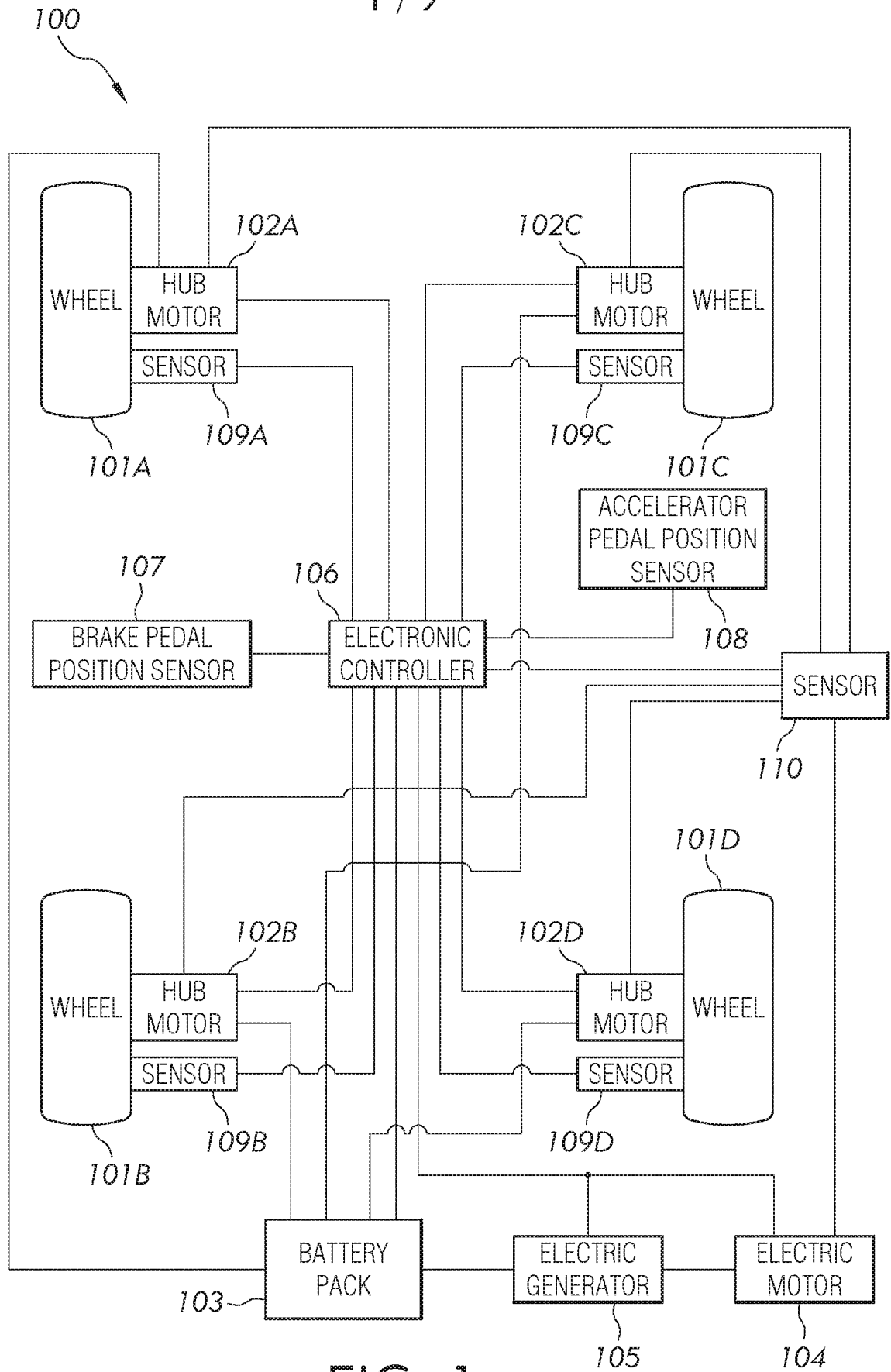


FIG. 1

2 / 9

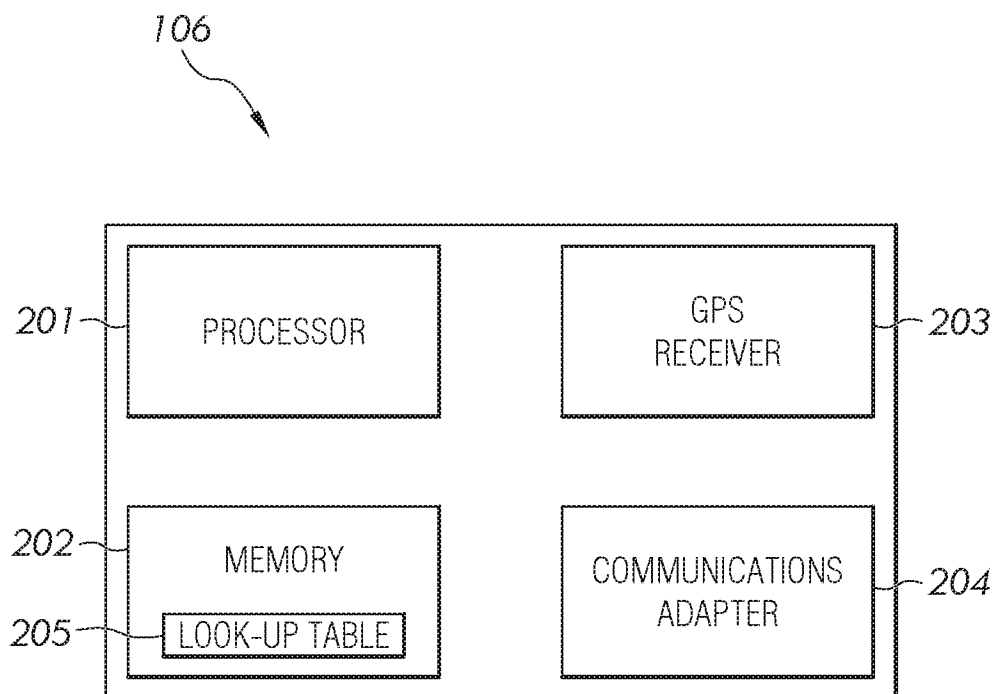


FIG. 2

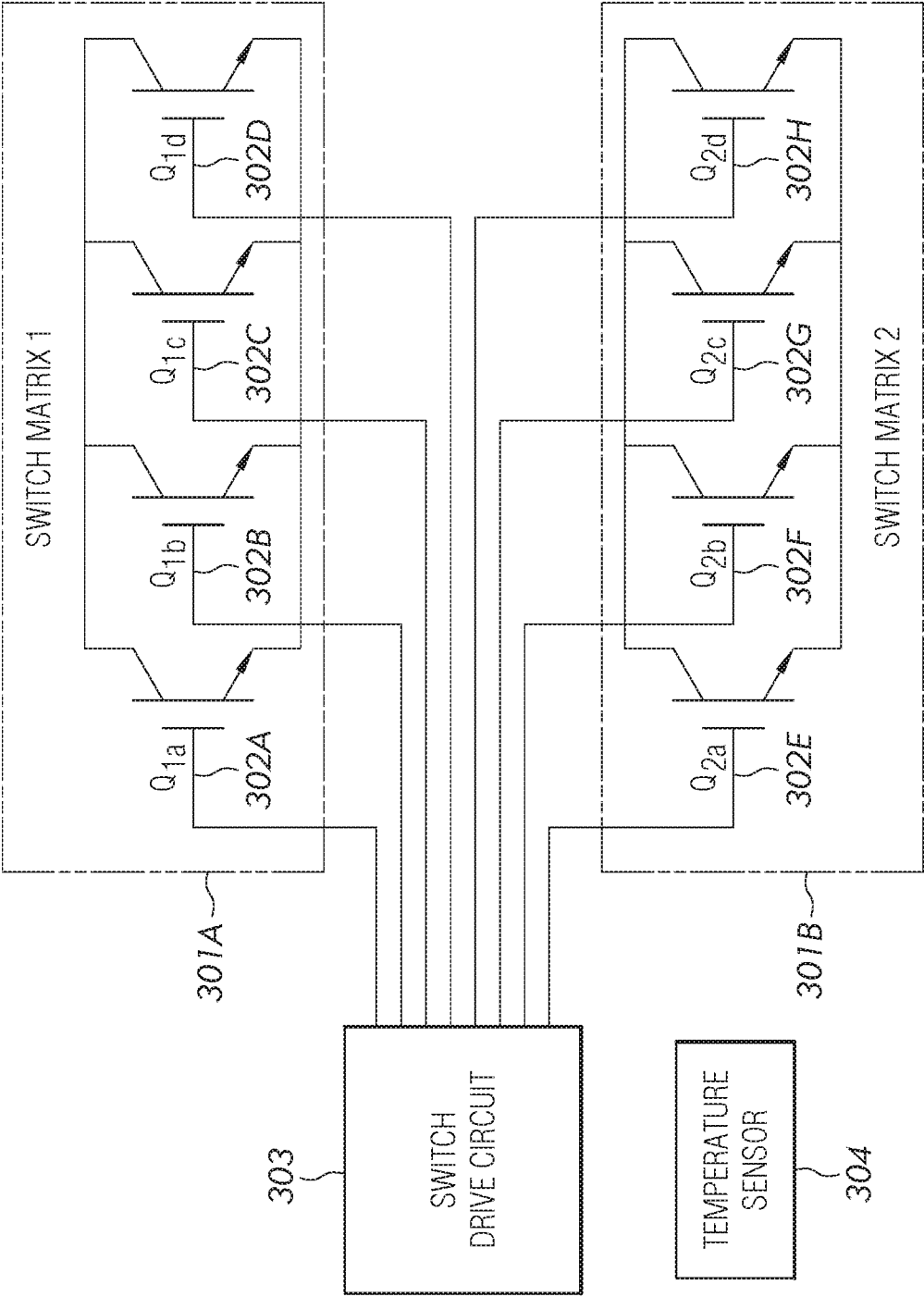


FIG. 3

4 / 9

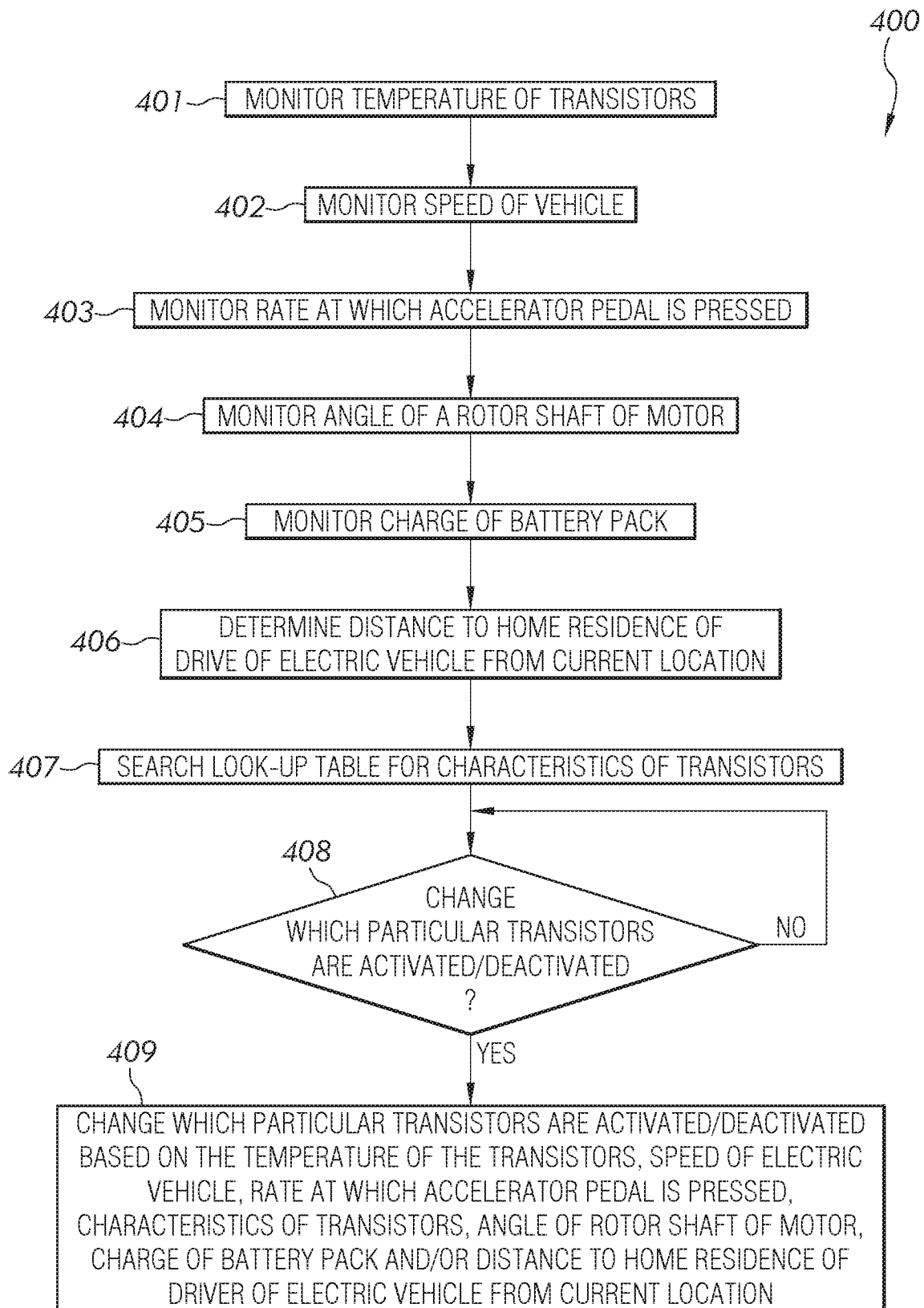


FIG. 4

5 / 9

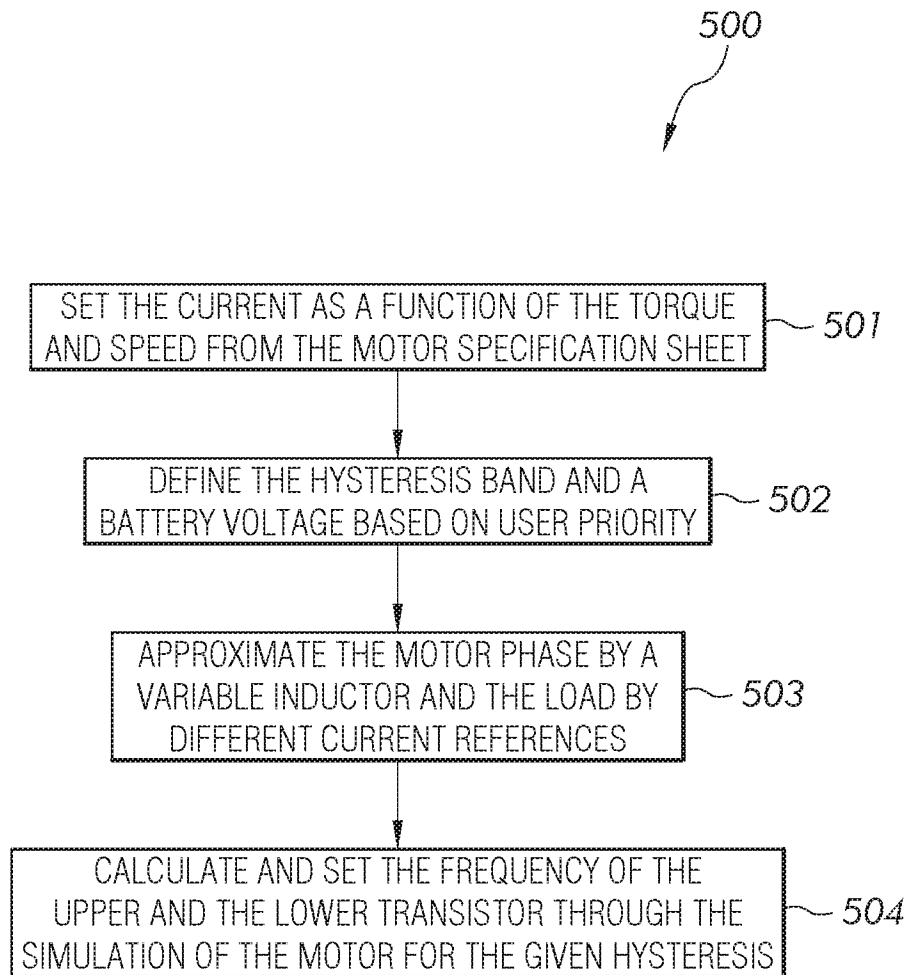


FIG. 5

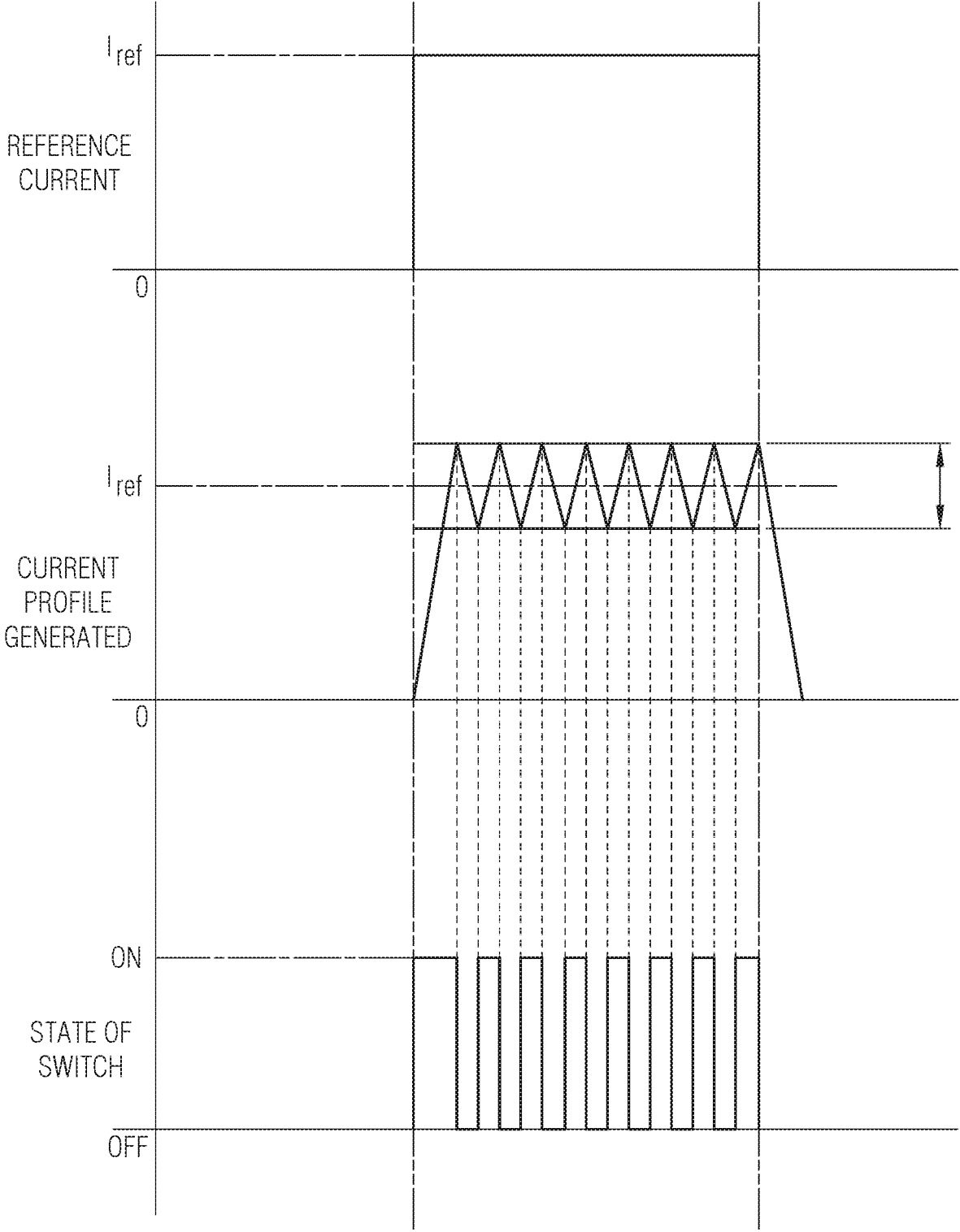


FIG. 6

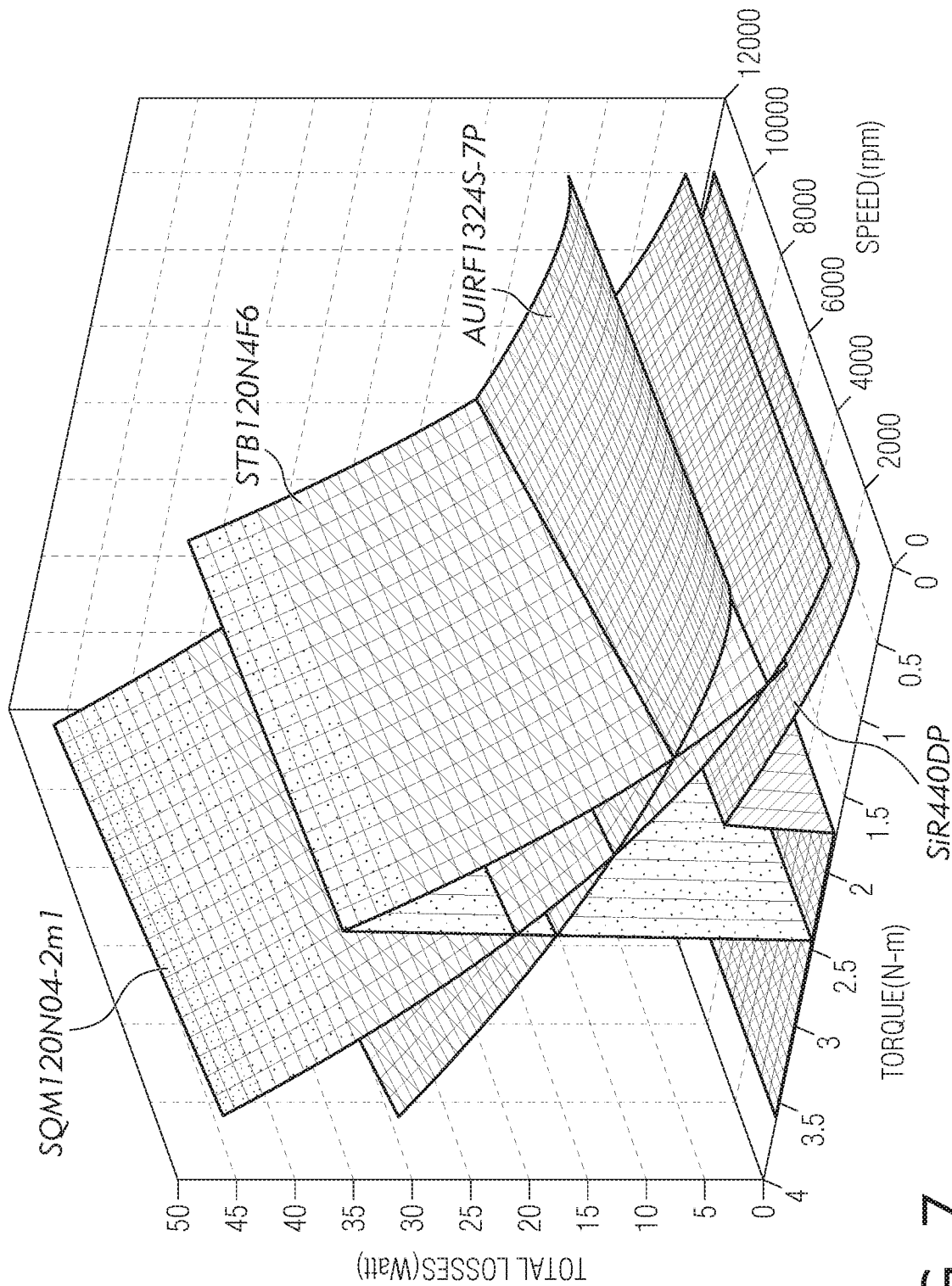


FIG. 7

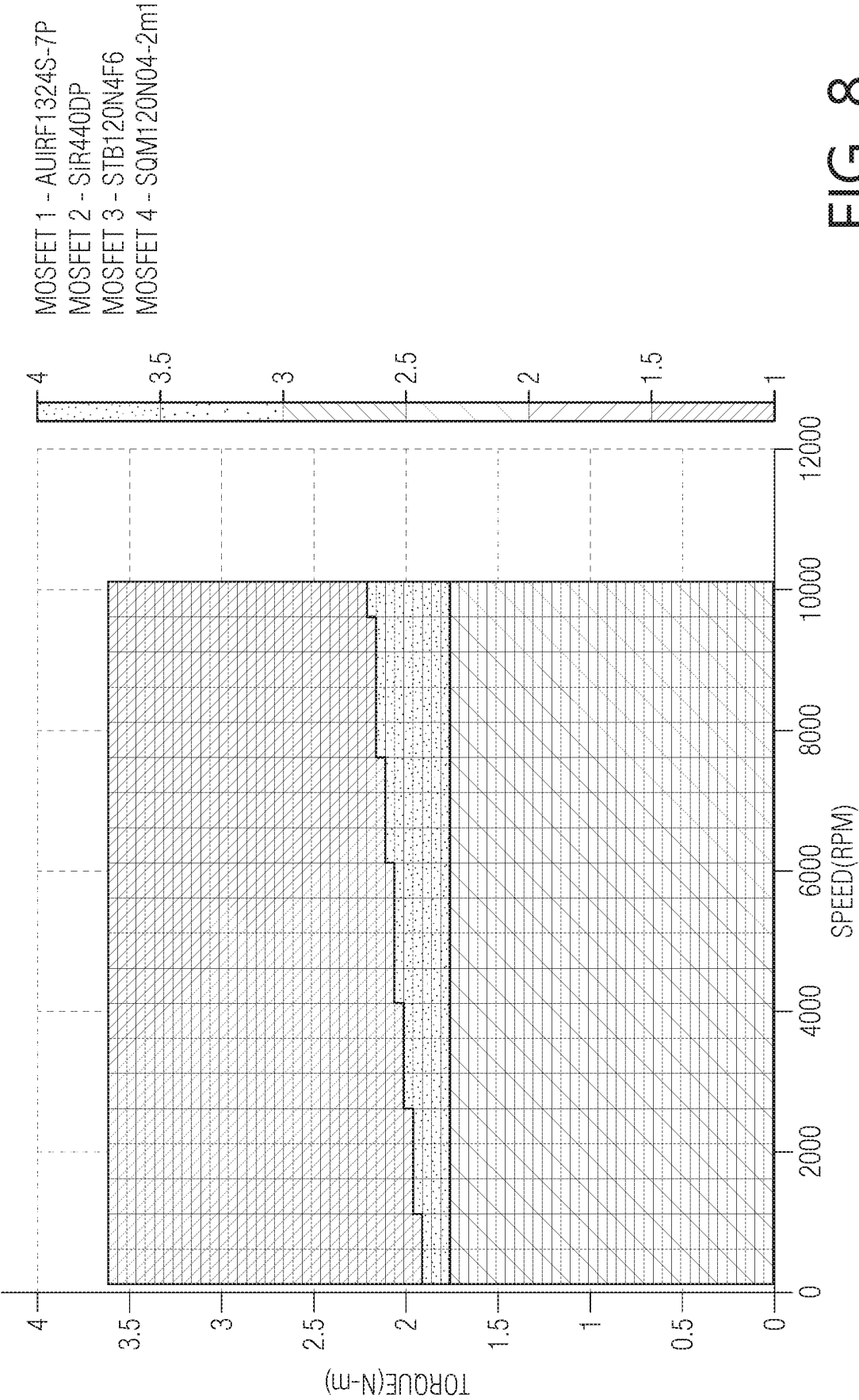


FIG. 8

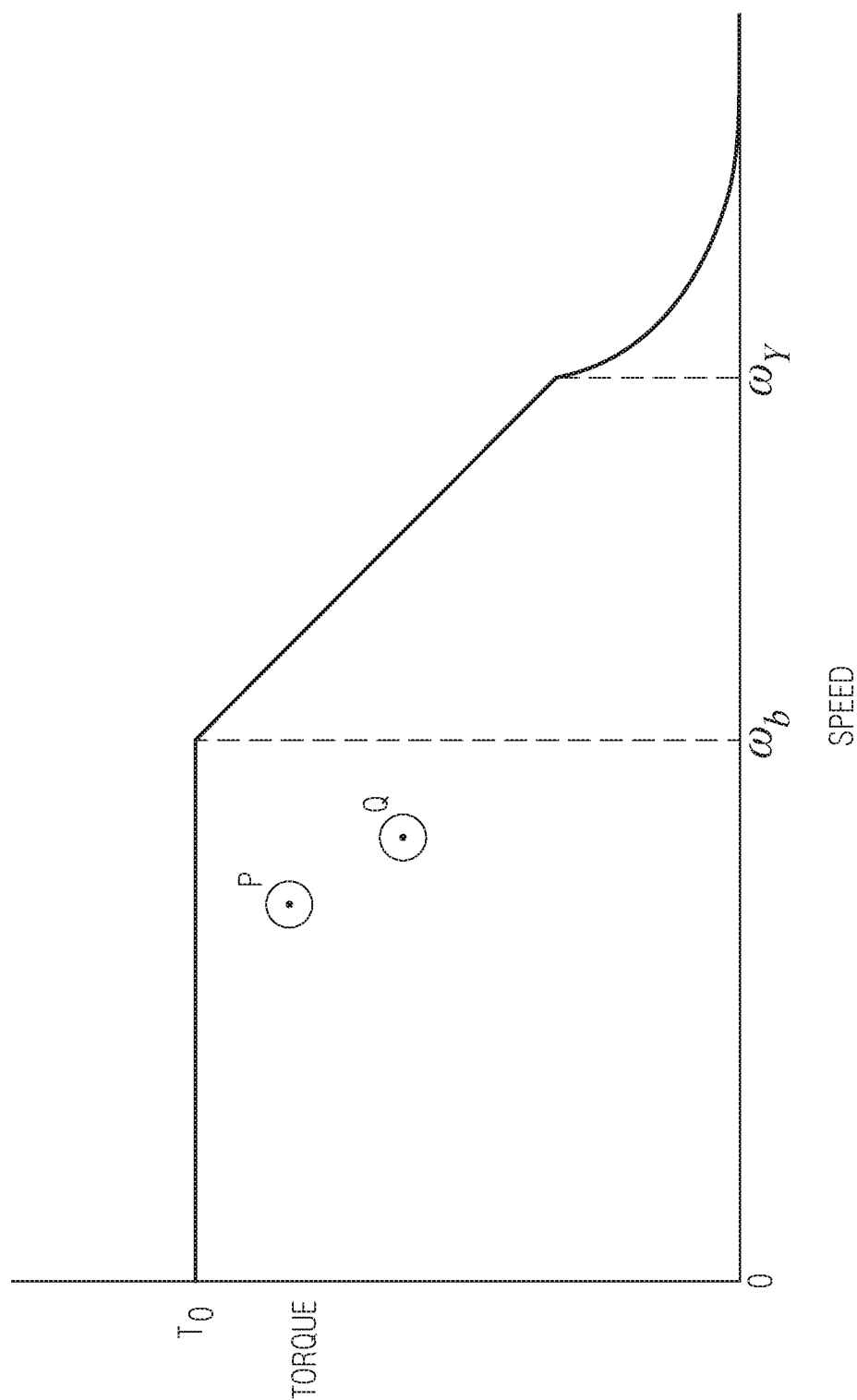


FIG. 9

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US2016/043067

A. CLASSIFICATION OF SUBJECT MATTER

IPC(8) - F02D 11/10; G06F 19/00; G06F 7/00; F02D 41/30 (2016.01)

CPC - F02D 11/105; F02D 41/1497; B60W 10/08; F16H 61/12 (2016.08)

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC - G06F 7/00; G06F 17/00; G06F 19/00; G06G 7/00; F02D 11/10; F02D 41/30

CPC - B60W 10/08; F02D 11/105; F02D 11/106; F02D 41/045; F02D 41/1497; F02D 2011/101; F16H 61/12

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

USPC - 701/22; 701/54; 701/55; 701/57; 701/61; 701/62; 701/70; 701/79; 701/84; 701/93; 701/110; 701/29.7; 701/29.1; 701/30.4; 701/31.1; 701/32.5; 701/33.4 (keyword delimited)

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

Orbit, Google Patents, Google Scholar, Google

Search terms used: electronic vehicle, ev, transistor, switch, sensor, detector, monitor, controller, processor, ecu, memory, computer, speed, velocity, gas, acceleration, pedal, temperature, heat, activate, actuate, deactivate, able, disable,

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2015/0112577 A1 (VELUSAMY et al) 23 April 2015 (23.04.2015) entire document	1-33
Y	US 4,800,974 A (WAND et al) 31 January 1989 (31.01.1989) entire document	1-33
Y	US 4,191,912 A (GERRY) 04 March 1980 (04.03.1980) entire document	3, 5, 14, 16, 25, 27
Y	US 2004/0002000 A1 (CRUCKER) 01 April 2004 (01.04.2004) entire document	4, 15, 26
Y	US 6,153,956 A (BRANECKY) 28 November 2000 (28.11.2000) entire document	8, 19, 30
Y	US 2012/0065831 A1 (ROSS et al) 15 March 2012 (15.03.2012) entire document	9, 20, 31
A	US 6,806,772 B2 (GLASER et al) 19 October 2004 (19.10.2004) entire document	1-33
A	US 2008/0300768 A1 (HIJIKATA) 04 December 2008 (04.12.2008) entire document	1-33
A	US 4,945,759 A (KROFCHALK et al) 07 August 1990 (07.08.1990) entire document	1-33
A	US 2012/0059561 A1 (NIWA et al) 08 March 2012 (08.03.2012) entire document	1-33

☐ Further documents are listed in the continuation of Box C.☐ See patent family annex.

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

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"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

15 September 2016

Date of mailing of the international search report

04 OCT 2016

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