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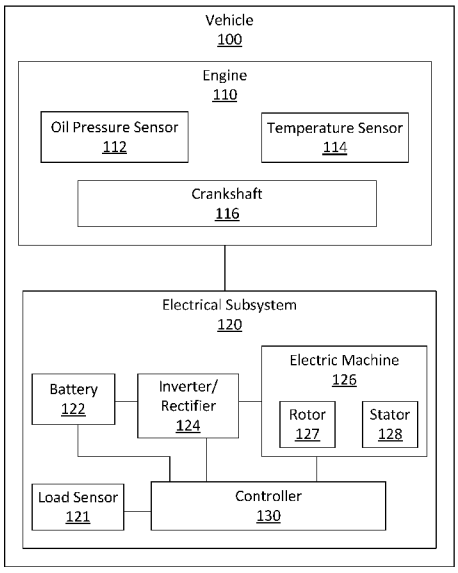

Figure 1

(57) Abstract: Systems, apparatuses, and methods are disclosed herein for controlling winding configurations of an electric machine. The apparatus includes an operation condition circuit structured to receive data indicative of an operating condition of an engine and an electric machine operatively connected to the engine, and a windings configuration circuit communicably coupled to the operation condition circuit. The windings configuration circuit is structured to selectively implementing a high torque windings mode configuration or a low torque windings mode configuration for the electric machine based at least in part on the operating condition.

ENGINE CONDITION BASED CONTROL OF STARTER/ALTERNATOR WINDING SELECTION

TECHNICAL FIELD

[0001] The present disclosure generally relates to electric machines. More particularly, the present disclosure relates to control strategies regarding selection of a windings configuration of the electric machines.

BACKGROUND

[0002] An electric machine may be used as a starter/alternator in a hybrid vehicle. The starter/alternator integrates the functions of a starter and an alternator when connected to an engine. In particular, the starter/alternator acts as a starter to crank the engine when the engine is being started. High torque is needed from the starter/alternator for cranking the engine to an idle speed. Once the engine is cranked and launched and the idle speed is reached, the starter/alternator acts as a generator powered by the engine to generate electric power for running electric loads. A mechanical transmission may help keep a starter/alternator with a single fixed winding configuration at an optimal torque region to maintain a continuous load across the operating range of the engine speed. However, a large and costly inverter is needed to output maximum electric power at the operating range of the engine speed. A scheme that improves the starter/alternator performance and reduces inverter cost is desired.

SUMMARY OF THE INVENTION

[0003] One embodiment relates to an apparatus including an operation condition circuit structured to receive data indicative of an operating condition of an engine and an electric machine operatively connected to the engine, and a windings configuration circuit communicably coupled to the operation condition circuit. The windings configuration circuit is structured to selectively implement a high torque windings mode configuration or a low torque windings mode configuration for the electric machine based at least in part on the operating condition.

[0004] Another embodiment relates to a method including receiving data indicative of an operating condition of an engine and an electric machine operatively connected to the engine, selectively implementing a high torque mode configuration and a low torque mode configuration for windings of the electric machine based at least in part on the operating condition, and operating the electric machine according to the implemented configuration of the windings.

[0005] Still another embodiment relates to a system including an electric machine operatively coupled to an engine and a controller communicably coupled to the engine and the electric machine. The electric machine is structured to operate as a starter to crank the engine during a cranking mode and as a generator powered by the engine during a generating mode for the electric machine. The controller is structured to receive data indicative of an operating condition of the engine and the electric machine, and selectively implement a high torque mode configuration or a low torque mode configuration for windings of the electric machine based at least in part on the operating condition.

[0006] These and other features, together with the organization and manner of operation thereof, will become apparent from the following detailed description when taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF DRAWINGS

[0007] FIG. 1 is a schematic diagram of a vehicle having a starter/alternator with switchable windings, according to an example embodiment.

[0008] FIG. 2(a) is a schematic diagram of a high torque mode configuration of windings of a starter/alternator, according to an example embodiment.

[0009] FIG. 2(b) is a schematic diagram of a low torque mode configuration of winding of a starter/alternator, according to an example embodiment.

[0010] FIG. 3 is a schematic diagram of the controller used with the vehicle of FIG. 1, according to an example embodiment.

[0011] FIG. 4 is a flow diagram of a method of determining between configurations of starter/alternator windings, according to an example embodiment.

DETAILED DESCRIPTION

[0012] For the purpose of promoting an understanding of the principles of the disclosure, reference will now be made to the embodiments illustrated in the drawings and specific language will be used to describe the same. It will nevertheless be understood that no limitation of the scope of the disclosure is thereby intended, any alternations and further modifications in the illustrated embodiments, and any further applications of the principles of the disclosure as illustrated therein as would normally occur to one skilled in the art to which the disclosure relates are contemplated herein.

[0013] A starter/alternator system may need to meet different performance requirements as a starter versus as an alternator. In particular, as a starter, the system may be required to provide high torque to crank an engine to an idle speed. As an alternator, the system may be desired to maintain a continuous load across an operating range of the engine speed. During normal operations, not much compromise is needed between the starter mode and the alternator mode. In some extreme situations such as cold ambient engine starts, however, the starter/alternator may need to be switched to a winding configuration different from what is used under normal situations.

[0014] Referring to the Figures generally, the various embodiments disclosed herein relate to systems and methods of determining and selecting a particular windings configuration of a starter/alternator to meet performance requirements under different situations. In one embodiment, the starter/alternator includes windings that can be switched between a high torque mode configuration and a low torque mode configuration. The high torque windings mode configuration may be selected, for example, when the starter/alternator is utilized as a starter at a low temperature. Otherwise, the low torque windings mode configuration may be selected. In other embodiments, the selection between the high torque mode configuration and the low torque mode configuration is based on multiple parameters such as but not limited to the temperature, an electric loading state of the electric machine, etc. Advantageously, the present disclosure facilitates the starter/alternator meeting different performance requirements without requiring an oversized inverter to meet the low-speed high-torque operation.

[0015] Referring now to FIG. 1, a schematic diagram of a vehicle 100 having a starter/alternator 126 with switchable windings is shown according to an example

embodiment. The vehicle 100 includes an engine 110 and an electrical subsystem 120 operatively and communicably connected to each other. For ease of explaining, other vehicle components (e.g., a transmission, final drive such as wheels, etc.) are omitted in the Figure. According to one embodiment, the vehicle 100 may be a hybrid electric vehicle (HEV), such as light duty HEVs (e.g., a sedan, golf cart, wheel chair, forklift) and heavy-duty vehicles (e.g., a front-end loader), or other types of electrical vehicles, such as a fuel electric vehicle or a plug-in HEV. It should be understood that the HEV vehicle is an example application of the system/method disclosed herein. Other applications include any vehicle/system that has a dichotomous set of requirements for the electric motors, *i.e.*, certain parts of the duty cycle require low-speed, high-torque operation while other parts require high-speed, low-torque operation. Such application include conventional vehicles with combined starter/alternator, vehicles or systems that do not have engine starting but have operating modes that could benefit from optimized electric machine operation.

[**0016**] The engine 110 may include a crankshaft 116, an oil pressure sensor 112, and a temperature sensor 114. Other engine components (e.g., gearbox, igniter, etc.) are omitted in the Figure for the ease of explaining. The engine 110 is configured to provide a mechanical force to enable one or several functionalities of the vehicle 100 as well as to drive the electrical subsystem 120. The engine 110 may be an internal combustion engine that consumes combustible fuel (e.g., gasoline, diesel fuel, natural gas, etc.) during operation in order to provide an appropriate amount of mechanical force. In operation, combustion cycles that take place in the engine 110 actuate the crankshaft 116, which in turn drives the electric machine 126 and wheels of the vehicle 100. The oil pressure sensor 112 may be any suitable sensor configured to monitor engine oil pressure in the engine 110. The temperature sensor 114 may be any suitable sensor configured to monitor temperature of engine oil, coolant, or other surrogate in the engine 110. The oil pressure sensor 112 and the temperature sensor 114 may be communicably coupled with the controller 130 and configured to generate data indicative of the detected pressure and temperature for the use of the controller 130.

[**0017**] The electrical subsystem 120 is operatively and communicably connected to the engine 110 and may assist operations of the engine 110. The electrical subsystem 120 may be used as a combination of a starter and an alternator in the vehicle 100. In particular, the electric machine 126 may act as a starter to crank the engine 110 when the engine 110 is

being started (i.e., during a cranking mode of operation). As used herein, to crank the engine 110 means to start the engine 110 by turning and accelerating the crankshaft 116 with the starter. Once the engine 110 is cranked and the idle speed is reached, the electric machine 126 may act as a generator powered by the engine 110 to generate electric power for running electric loads (i.e., a generating mode of operation). The electrical subsystem 120 may include a battery 122 and the electric machine 126 electrically connected to each other through an inverter/rectifier 124. Other electric machine components are omitted in the Figure for the ease of explaining. The battery 122 may be configured as any type of rechargeable battery and of any suitable size. That is to say, the battery 122 may be structured as any type of electrical energy storing and providing device, such as one or more capacitors (e.g., ultra capacitors, etc.) and/or one or more batteries typically used or that may be used in hybrid vehicles (e.g., Lithium-ion batteries, Nickle-Metal Hydride batteries, Lead-acid batteries, etc.). The battery 122 may be communicably coupled with the controller 130 to provide data indicative of one or more operating conditions or traits of the battery 122, such as but not limited to state of charge (SOC) of the battery 122.

[0018] The electric machine 126 may integrate the functions of a starter motor and an alternator used in conventional engine systems. In particular, when the engine 110 is being started, the electric machine 126 acts as a starter motor to crank the engine 110 through the crankshaft 116. Once the engine 110 is cranked and launched, the electric machine 126 acts as a generator powered by the engine 110 through the crankshaft 116 and generates electric power for running electric loads of the vehicle 100. The electric machine 126 may include a rotor 127 and a stator 128. The rotor 127 may be a permanent magnet or field coils structured to generate a magnetic field. The stator 128 may include three-phase windings wound on iron cores (*i.e.*, the armature windings). In other embodiments, the stator 128 may include windings of any suitable of phases and constructed of any suitable material. In some embodiments, the rotor 127 may be surrounded by the armature windings of the stator 128.

[0019] The windings of the stator 128 (the armature windings) may be electrically connected to the inverter/rectifier 124, which in turn is electrically connected to the battery 122. When the electric machine 126 operates as a starter motor, the inverter/rectifier 124 acts as an inverter to transform a direct current (DC) voltage from the battery 122 into an alternating current (AC) voltage and supplies the AC voltage to the armature windings of

stator 128. The armature windings then generate an alternating magnetic field to actuate the rotor 127, which in turn cranks the engine 110 through the crankshaft 116. When the electric machine 126 operates as a generator, the engine 110 drives the rotor 127 through the crankshaft 116. The rotor 127 then generates a moving magnetic field, which induces an AC voltage on each of the armature windings of the stator 128. The inverter/rectifier 124 acts as a rectifier to transform the AC voltage from the armature windings into a DC voltage and charges the battery 122 with the DC voltage. Depending on the type of auxiliary component that the component requires, either the electric machine 126 may supply the AC voltage or the inverter/rectifier 124 may supply the DC voltage to the auxiliary component. In this regard, the auxiliary components may include, but is not limited to, an air conditioning or cooling system, a heating system, an electric blower, lights, audio or video system, and so on.

[**0020**] The armature windings of the stator 128 may be switched between a high torque mode configuration and a low torque mode configuration. FIG. 2(a) shows an exemplary high torque mode configuration of windings – the delta (Δ)-connection; FIG. 2(b) shows an exemplary low torque mode configuration of windings – the wye (Y)-connection. As used herein, the symbol "Δ" refers to a delta connection of at least three windings, connected similar to that shown in FIG. 2(a). The symbol "Y" refers to a wye connection (also called a "star" connection) of at least three windings, connected similar to that shown in FIG. 2(b). As also used herein, a voltage difference between two ends of each winding is called a phase voltage (V_{PH}), and a voltage difference between each line connecting the armature windings to the inverter/rectifier 124 is called an AC line-to-line voltage (V_{AC}). The relationship between the phase voltage V_{PH} and the line-to-line voltage V_{AC} is:

$$V_{PH} = \begin{cases} V_{AC}, for\ \Delta - connection \\ \frac{V_{AC}}{\sqrt{3}}, for\ Y - connection \end{cases} \qquad (1)$$

[**0021**] The Δ-connection provides a higher cranking torque than the Y-connection. According to electric machine principles, the cranking torque is nearly proportional to the square value of the phase voltage (V_{PH}). As shown in equation (1), for a same V_{AC} from the inverter/rectifier 124 (*i.e.*, a same DC voltage from the battery 122), the phase voltage V_{PH} for the Δ-connection is $\sqrt{3}$ times of that for the Y-connection. The higher phase voltage provided by the Δ-connection will increase the output torque of the electric machine 120 at

cranking. At low temperatures when batteries are not fully charged, the Δ-connection may be advantageous for raising the phase voltage V_{PH} of the electric machine 120. Therefore, the engine 110 is more likely to crank and launch at low temperatures by using the Δ-connection instead of the Y-connection.

[0022] With sufficient torque, the engine 120 will crank and fire. That is to say, at this point, combustion within the engine may power the engine to thereby alleviate the need for cranking provided by the electric machine. Further, at this point, after the engine 120 fires, torque may be output from the engine 110 to the electric machine 126, which in turn supplies electric power for charging the battery 122 and running electric loads such as air conditioning system, heating system, electric blower, lights, and audio system, etc. In this state, the phase voltage V_{PH} that can be generated in the armature windings at any given engine speed determines the maximum available DC voltage that may be used to provide power to the loads at that speed. Although the power required from the engine 110 at idle or other low speeds is a relatively small amount, it is desirable to have the output voltage of the electric machine 120 as close to full loading as possible at all times. To produce a same V_{AC} to the inverter/rectifier 124 (*i.e.*, a same DC voltage for charging the battery 122), the required phase voltage V_{PH} for the Y-connection is $1/\sqrt{3}$ of that for the Δ-connection, according to equation (1). In other words, based on the available phase voltage V_{PH} when the electric machine 120 acts as a generator, the maximum V_{AC} for charging the battery 122 and running the electric loads will be increased by $\sqrt{3}$ when the Y-connection is used instead of the Δ-connection. Thus, the output power of the electric machine 126 is increased when the armature windings are switched from the Δ-connection to the Y-connection, although the phase voltage V_{PH} remains constant. This allows the output power of the electric machine 126 to be closer to 100% loading than would otherwise be possible without increasing the size of the machine. If the electric machine 126 were designed to have a single fixed armature windings configuration, a dramatic increase in the size and the cost of the inverter/rectifier 124 would be required in order to output maximum electric power at the idle speed of the engine 110.

[0023] In some embodiments, the electric machine 126 may include two sets of armature windings – one is in the high torque mode configuration (e.g., the Δ-connection) and the other is in the low torque mode configuration (e.g., the Y-connection.) According to one embodiment, the controller 130 may be structured to select between the two sets of

windings based on engine condition (e.g., the temperature, pressure, electric loading state, etc.). In other embodiments, the electric machine 126 may include one set of armature windings and the connections of the windings can be configured through switches/contactors. The controller 130 may switch the one set of windings between the high torque mode configuration and the low torque mode configuration by changing the on/off state of the switches or the contact positions of the contactors. It should be understood that the Y-connection and the Δ-connection are example configurations of the windings. Any other winding configurations that allow for two or more performance characteristics of the electric machine can be used.

[**0024**] Referring back to FIG. 1, the electrical subsystem 120 may further include a load sensor 121 for sensing the electrical load and a controller 130 communicably connected to the battery 122, the inverter/rectifier 124, the electric machine 126, and the load sensor 121. The controller 130 may further be communicably coupled with a plurality of sensors disposed throughout the vehicle 100, including but not limited to the oil pressure sensor 112 and the temperature sensor 114 disposed in the engine 110. Communication between and among the components may be via any number of wired or wireless connections. For example, a wired connection may include a serial cable, a fiber optic cable, a CAT5 cable, or any other form of wired connection. In comparison, a wireless connection may include the Internet, Wi-Fi, cellular, radio, etc. In one embodiment, a CAN bus provides the exchange of signals, information, and/or data. The CAN bus includes any number of wired and wireless connections. The controller 130 may be structured as an electronic control unit (ECU). The function and structure of the controller 130 are shown in greater detail in FIG. 3.

[**0025**] Referring now to FIG. 3, a schematic diagram of the controller 300 used with the vehicle 100 of FIG. 1 is shown according to an example embodiment. The controller 300 is shown to include a processing circuit 302 including a processor 304 and a memory 306. The processor 304 may be implemented as a general-purpose processor, an application specific integrated circuit (ASIC), one or more field programmable gate arrays (FPGAs), a digital signal processor (DSP), a group of processing components, or other suitable electronic processing components. The one or more memory device 306 (e.g., NVRAM, RAM, ROM, Flash Memory, hard disc storage, etc.) may store data and/or computer code for facilitating the various processes described herein. Thus, the one or more memory

device 306 may be communicably connected to the processor 304 and provide computer code or instructions to the processor 304 for executing the processes described in regard to the processor 304 herein. Moreover, the one or more memory devices 306 may be or include tangible, non-transient volatile memory or non-volatile memory. Accordingly, the one or more memory device 306 may include database components, object code components, script components, or any other type of information structure for supporting the various activities and information structures described herein.

[**0026**] The memory 306 is shown to include various circuits for completing the activities described herein. More particularly, the memory 306 includes an operation condition circuit 308 and a windings configuration circuit 310. The circuits are adapted to strategically control the selection of the starter/alternator windings between the high torque mode configuration and the low torque mode configuration based on the engine condition. In some embodiments, the selection may be made based on the temperature of the engine (oil, coolant, etc.) when the starter/alternator operates as a starter. In other embodiments, the selection may be made based on multiple parameters including, but not limited to, the engine temperature, the engine oil pressure, the engine speed, the ambient conditions (e.g., ambient temperature), and the electric loading of the electric machine. While various circuits with particular functionality are shown in FIG. 3, it should be understood that the controller 300 and the memory 306 may include any number of circuits for completing the functions described herein. For example, the activities of multiple circuits may be combined as a single circuit, as additional circuit with additional functionality may be included, etc. Further and while the circuits 308 and 310 are depicted as a part of the memory 306, this depiction is exemplary only. In other embodiments, the circuits 308 and 310 may be separate components relative to the memory 306. It should also be understood that the controller 300 may further control other vehicle activity beyond the scope of the present disclosure.

[**0027**] Certain operations of the controller 300 described herein include operations to interpreted and/or to determine one or more parameters. Interpreting or determining, as utilized herein, includes receiving values by any method in the art, including at least receiving values from a dataline or network communication, receiving an electric signal (e.g., a voltage, frequency, current, or PWM signal) indicative of the value, receiving a computer generated parameter indicative of the value, reading the value from a memory

location on a non-transient computer readable storage medium, receiving the value as a run-time parameter by any means known in the art, and/or by receiving a value by which the interpreted parameter can be calculated, and/or by referencing a default value that is interpreted to be the parameter value.

[0028] The operation condition circuit 308 may be structured to receive, gather, and/or acquire engine condition information indicative of various engine operating characteristics, data, or parameters such as temperature of engine oil, temperature of coolant, pressure of engine oil, engine speed, etc. In some embodiments, the operation condition circuit 308 may be structured to receive, gather, and/or acquire other operation conditions such as ambient conditions (e.g., ambient temperature), and electric loading of the electrical machine 126. In one embodiment, the operation condition circuit 308 includes communication circuitry for facilitating reception of one or more operation condition data from acquisition devices within the vehicle 100, such as the oil pressure sensor 112, the temperature sensor 114, and the load sensor 121. In other embodiments, the operation condition circuit 308 may include the engine and any data acquisition devices (e.g., oil pressure sensor 112) coupled thereto. In still other embodiments, the operation condition circuit 308 includes machine-readable content for receiving and storing the engine condition information. In yet other embodiments, the operation condition circuit 308 includes any combination of communication circuitry and machine readable content. The engine condition circuit 308 is further structured to provide the engine condition information to the windings configuration circuit 310.

[0029] The windings configuration circuit 310 is structured to receive the operation condition information from the operation condition circuit 308. In response, the windings configuration circuit 310 is structured to control the selection of windings configuration: either the high torque mode configuration or the low torque mode configuration for the windings of the electric machine 126. In some embodiments, the windings configuration circuit 310 determines that the temperature data and/or the oil pressure data received from the engine condition circuit 308 is below a predetermined threshold value and that the electric machine 126 is operating as a starter to crank the engine 110. Responsive to this determination, the windings configuration circuit 310 selects the high torque mode configuration for the windings of the electric machine 126. In some embodiments, the windings configuration circuit 310 determines that the electric machine 126 is operating as a

generator and the electrical load is below a predetermined threshold load level. Responsive to this determination, the windings configuration circuit 310 selects the high torque mode configuration for the windings of the electric machine 126. Otherwise, the low torque mode configuration is selected for the windings. In some embodiments, the windings configuration circuit 310 may include dedicated circuitry structured to control the selection of windings configuration for the electric machine 126. In other embodiments, the windings configuration circuit 310 may include machine-readable content for controlling the selection. In yet other embodiments, the windings configuration circuit 310 may include any combination of circuitry components and machine-readable content. In some embodiments, the electric machine 126 may include two sets of armature windings – one is in the high torque mode configuration (e.g., the Δ-connection) and the other is in the low torque mode configuration (e.g., the Y-connection). The windings configuration circuit 310 is structured to control selection between the two sets of windings. In other embodiments, the electric machine 126 includes one set of armature windings and the connections of the windings can be configured through switches/contactors. The windings configuration circuit 310 is structured to select between the high torque mode configuration and the low torque mode configuration by controlling the on/off state of the switches or the contact positions of the contactors.

[**0030**] By using operation condition based controls, it avoids switching the windings configuration more often than needed. For example, the windings configuration can be switched only in extreme situations, such as cold ambient engine starts. In this manner, durability of the contactors/switches will be improved. In the meantime, appropriate winding configuration is selected and the performance and efficiency of the system will be improved.

[**0031**] Referring now to FIG.4, a flow diagram of a method 400 of determining between configurations of starter/alternator windings is shown according to an example embodiment. Because the method 400 may be implemented with the controller 300 and the vehicle 100, reference may be made to one or more features of the controller 300 and the vehicle 100 to explain the method 400.

[**0032**] At process 402, data indicative of an operation condition is received. The operation condition data may include, but is not limited, a temperature of engine oil,

temperature of coolant, pressure of engine oil, electric loading of the electrical machine, etc. In some embodiments, the operation condition data may be received form detecting devices disposed throughout the vehicle 100, such as the oil pressure sensor 112 and the temperature sensor 114 disposed in the engine 110 and the load sensor 121 disposed in the electric machine 120. It shall be understood that there may be multiple oil pressure sensors and/or multiple temperature sensor disposed at different locations of the engine 110.

[**0033**] At process 404, a windings configuration is selected based on the received engine condition data. In some embodiments, the received temperature data and/or the oil pressure data is compared with a predetermined threshold value. If the temperature/oil pressure is lower than the predetermined threshold value and the starter/alternator 126 is operating as a starter to crank the engine 120, the high torque mode configuration (e.g., the Δ-connection) is selected for the windings of the electric machine 126. In some embodiments, the received data indicating the electrical load of the electric machine 126 is compared with a predetermined threshold load level. If the electrical load is lower that the predetermined threshold load level and the starter/alternator is operating as a generator, the high torque mode configuration (e.g., the Δ-connection) is selected for the windings of the electric machine 126. Otherwise, the low torque mode configuration (e.g., the Y-connection) is selected for the windings. At process 406, the electric machine is operated according to the implemented configuration of the windings.

[**0034**] It should be noted that the processes of the methods described herein may be utilized with the other methods, although described in regard to a particular method. It should further be noted that the term "example" as used herein to describe various embodiments is intended to indicate that such embodiments are possible examples, representations, and/or illustrations of possible embodiments (and such term is not intended to connote that such embodiments are necessarily extraordinary or superlative examples).

[**0035**] Example and non-limiting circuit implementation elements include sensors (e.g., coupled to the components and/or systems in FIG. 1) providing any value determined herein, sensors providing any value that is a precursor to a value determined herein, datalink and/or network hardware including communication chips, oscillating crystals, communication links, cables, twisted pair wiring, coaxial wiring, shielded wiring, transmitters, receivers, and/or transceivers, logic circuits, hard-wired logic circuits,

reconfigurable logic circuits in a particular non-transient state configured according to the circuit specification, any actuator including at least an electrical, hydraulic, or pneumatic actuator, a solenoid, an op-amp, analog control elements (springs, filters, integrators, adders, dividers, gain elements), and/or digital control elements.

[**0036**] The schematic flow chart diagrams and method schematic diagrams described above are generally set forth as logical flow chart diagrams. As such, the depicted order and labeled steps are indicative of representative embodiments. Other steps, orderings and methods may be conceived that are equivalent in function, logic, or effect to one or more steps, or portions thereof, of the methods illustrated in the schematic diagrams.

[**0037**] Additionally, the format and symbols employed are provided to explain the logical steps of the schematic diagrams and are understood not to limit the scope of the methods illustrated by the diagrams. Although various arrow types and line types may be employed in the schematic diagrams, they are understood not to limit the scope of the corresponding methods. Indeed, some arrows or other connectors may be used to indicate only the logical flow of a method. For instance, an arrow may indicate a waiting or monitoring period of unspecified duration between enumerated steps of a depicted method. Additionally, the order in which a particular method occurs may or may not strictly adhere to the order of the corresponding steps shown. It will also be noted that each block of the block diagrams and/or flowchart diagrams, and combinations of blocks in the block diagrams and/or flowchart diagrams, can be implemented by special purpose hardware-based systems that perform the specified functions or acts, or combinations of special purpose hardware and program code.

[**0038**] Many of the functional units described in this specification have been labeled as circuits, in order to more particularly emphasize their implementation independence. For example, a circuit may be implemented as a hardware circuit comprising custom VLSI circuits or gate arrays, off-the-shelf semiconductors such as logic chips, transistors, or other discrete components. A circuit may also be implemented in programmable hardware devices such as field programmable gate arrays, programmable array logic, programmable logic devices or the like.

[**0039**] Circuits may also be implemented in machine-readable medium for execution by various types of processors. An identified circuit of executable code may, for instance,

comprise one or more physical or logical blocks of computer instructions, which may, for instance, be organized as an object, procedure, or function. Nevertheless, the executables of an identified circuit need not be physically located together, but may comprise disparate instructions stored in different locations which, when joined logically together, comprise the circuit and achieve the stated purpose for the circuit.

[**0040**] Indeed, a circuit of computer readable program code may be a single instruction, or many instructions, and may even be distributed over several different code segments, among different programs, and across several memory devices. Similarly, operational data may be identified and illustrated herein within circuits, and may be embodied in any suitable form and organized within any suitable type of data structure. The operational data may be collected as a single data set, or may be distributed over different locations including over different storage devices, and may exist, at least partially, merely as electronic signals on a system or network. Where a circuit or portions of a circuit are implemented in machine-readable medium (or computer-readable medium), the computer readable program code may be stored and/or propagated on in one or more computer readable medium(s).

[**0041**] The computer readable medium may be a tangible computer readable storage medium storing the computer readable program code. The computer readable storage medium may be, for example, but not limited to, an electronic, magnetic, optical, electromagnetic, infrared, holographic, micromechanical, or semiconductor system, apparatus, or device, or any suitable combination of the foregoing.

[**0042**] More specific examples of the computer readable medium may include but are not limited to 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 portable compact disc read-only memory (CD-ROM), a digital versatile disc (DVD), an optical storage device, a magnetic storage device, a holographic storage medium, a micromechanical storage device, or any suitable combination of the foregoing. In the context of this document, a computer readable storage medium may be any tangible medium that can contain, and/or store computer readable program code for use by and/or in connection with an instruction execution system, apparatus, or device.

[0043] The computer readable medium may also be a computer readable signal medium. A computer readable signal medium may include a propagated data signal with computer readable program code embodied therein, for example, in baseband or as part of a carrier wave. Such a propagated signal may take any of a variety of forms, including, but not limited to, electrical, electro-magnetic, magnetic, optical, or any suitable combination thereof. A computer readable signal medium may be any computer readable medium that is not a computer readable storage medium and that can communicate, propagate, or transport computer readable program code for use by or in connection with an instruction execution system, apparatus, or device. Computer readable program code embodied on a computer readable signal medium may be transmitted using any appropriate medium, including but not limited to wireless, wireline, optical fiber cable, Radio Frequency (RF), or the like, or any suitable combination of the foregoing.

[0044] In one embodiment, the computer readable medium may comprise a combination of one or more computer readable storage mediums and one or more computer readable signal mediums. For example, computer readable program code may be both propagated as an electro-magnetic signal through a fiber optic cable for execution by a processor and stored on RAM storage device for execution by the processor.

[0045] Computer readable program code for carrying out operations for aspects of the present invention may be written in any combination of one or more programming languages, including an object oriented programming language such as Java, Smalltalk, C++ or the like and conventional procedural programming languages, such as the "C" programming language or similar programming languages. The computer readable program code may execute entirely on the user's computer, partly on the user's computer, as a stand-alone computer-readable 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).

[0046] The program code may also be stored in a computer readable medium that can direct a computer, other programmable data processing apparatus, or other devices to

function in a particular manner, such that the instructions stored in the computer readable medium produce an article of manufacture including instructions which implement the function/act specified in the schematic flowchart diagrams and/or schematic block diagrams block or blocks.

[**0047**] Accordingly, the present disclosure may be embodied in other specific forms without departing from its spirit or essential characteristics. The described embodiments are to be considered in all respects only as illustrative and not restrictive. The scope of the disclosure is, therefore, indicated by the appended claims rather than by the foregoing description. All changes which come within the meaning and range of equivalency of the claims are to be embraced within their scope.

WHAT IS CLAIMED IS:

1. An apparatus, comprising:

an operation condition circuit structured to receive data indicative of an operating condition of an engine and an electric machine operatively connected to the engine; and

a windings configuration circuit communicably coupled to the operation condition circuit, wherein the windings configuration circuit is structured to selectively implement a high torque windings mode configuration or a low torque windings mode configuration for the electric machine based at least in part on the operating condition.

2. The apparatus of claim 1, wherein the data includes an indication of at least one of a temperature of an engine oil, a temperature of an engine coolant, a pressure of the engine oil, an engine speed, an ambient temperature, and an electric load level of the electrical machine.

3. The apparatus of claim 1, wherein the high torque mode configuration includes a delta connection of windings of the electric machine, and wherein the low torque mode configuration includes a wye connection of the windings.

4. The apparatus of claim 1, wherein the electric machine is structured to operate as a starter to crank the engine during a cranking mode and as a generator powered by the engine during a generating mode for the electric machine.

5. The apparatus of claim 4, wherein the windings configuration circuit is further structured to selectively implement the high torque mode configuration in response to the data indicating a temperature at or lower than a predetermined threshold temperature value and the electric machine operating as the starter to crank the engine.

6. The apparatus of claim 4, wherein the windings configuration circuit is further structured to selectively implement the high torque mode configuration in response to the data indicating an engine oil pressure at or lower than a predetermined threshold engine oil pressure value and the electric machine being as the starter to crank the engine.

7. The apparatus of claim 4, wherein the windings configuration circuit is further structured to selectively implement the high torque mode configuration in response to the data indicating an electric load level of the electric machine at or lower than a

predetermined threshold load level and the electric machine being as a generator powered by the engine.

8. The apparatus of claim 4, wherein the windings configuration circuit is further structured to selectively implement the low torque mode configuration in response to the data indicating an electric load level of the electric machine higher than a predetermined threshold load level and the electric machine being as a generator powered by the engine.

9. A method, comprising:

receiving data indicative of an operating condition of an engine and an electric machine operatively connected to the engine;

selectively implementing a high torque mode configuration and a low torque mode configuration for windings of the electric machine based at least in part on the operating condition; and

operating the electric machine according to the implemented configuration of the windings.

10. The method of claim 9, wherein the data includes an indication of at least one of a temperature of engine oil, a temperature of engine coolant, a pressure of engine oil, an engine speed, an ambient temperature, and an electric loading state.

11. The method of claim 9, wherein the high torque mode configuration includes a delta connection of windings of the electric machine, and wherein the low torque mode configuration includes a wye connection of the windings.

12. The method of claim 9, wherein the electric machine includes two sets of windings, wherein one set of the windings is in the high torque mode configuration, while the other set of the windings is in the low torque mode configuration, and wherein the selectively implementing includes connecting one of the two sets of windings to the engine.

13. The method of claim 9, wherein the electric machine includes switches structured to connect the windings, and wherein the selectively implementing includes controlling on/off states of the switches so as to implement the high torque mode configuration or the low torque mode configuration for the windings.

14. The method of claim 9, wherein the electric machine includes contactors configured to connect the windings, and wherein the selectively implementing includes controlling contact positions of the contactors so as to implement the high torque mode configuration or the low torque mode configuration for the windings.

15. The method of 9, wherein the electric machine is structured to operate as a starter to crank the engine during a cranking mode and as a generator powered by the engine during generating mode.

16. The method of claim 15, wherein the selectively implementing includes implementing the high torque mode configuration in response to the data indicating a temperature at or lower than a predetermined threshold value and the electric machine operating as the starter to crank the engine.

17. The method of claim 15, wherein the selectively implementing includes implementing the high torque mode configuration in response to the data indicating an electric load level of the electric machine at or lower than a predetermined threshold load level and the electric machine being as a generator powered by the engine.

18. A system, comprising:

an electric machine operatively coupled to an engine and structured to operate as a starter to crank the engine during a cranking mode and as a generator powered by the engine during a generating mode for the electric machine; and

a controller communicably coupled to the engine and the electric machine, the controller structured to:

receive data indicative of an operating condition of the engine and the electric machine; and

selectively implement a high torque mode configuration or a low torque mode configuration for windings of the electric machine based at least in part on the operating condition.

19. The system of claim 18, wherein the data includes an indication of at least one of a temperature of engine oil, a temperature of engine coolant, a pressure of engine oil, an engine speed, an ambient temperature, and an electric loading state.

20. The system of claim 18, wherein the electric machine includes two sets of windings, wherein one set of the windings is in the high torque mode configuration, while the other set of the windings is in the low torque mode configuration, and wherein the controller is structured to selectively connecting one of the two sets of windings to the engine.

21. The system of claim 18, wherein the electric machine includes switches structured to connect the windings, and wherein the controller is structured to control on/off states of the switches so as to implement the high torque mode configuration or the low torque mode configuration for the windings.

22. The system of claim 18, wherein the electric machine includes contactors configured to connect the windings, and wherein the controller is structured to control contact positions of the contactors so as to implement the high torque mode configuration or the low torque mode configuration for the windings.

23. The system of claim 19, wherein the controller is structured to selectively implementing the high torque mode configuration in response to the data indicating a temperature at or lower than a predetermined threshold temperature value and the electric machine operating as the starter to crank the engine.

24. The system of claim 19, wherein the controller is structured to selectively implementing the high torque mode configuration in response to the data indicating an electric load level of the electric machine at or lower than a predetermined threshold load level and the electric machine being as a generator powered by the engine.

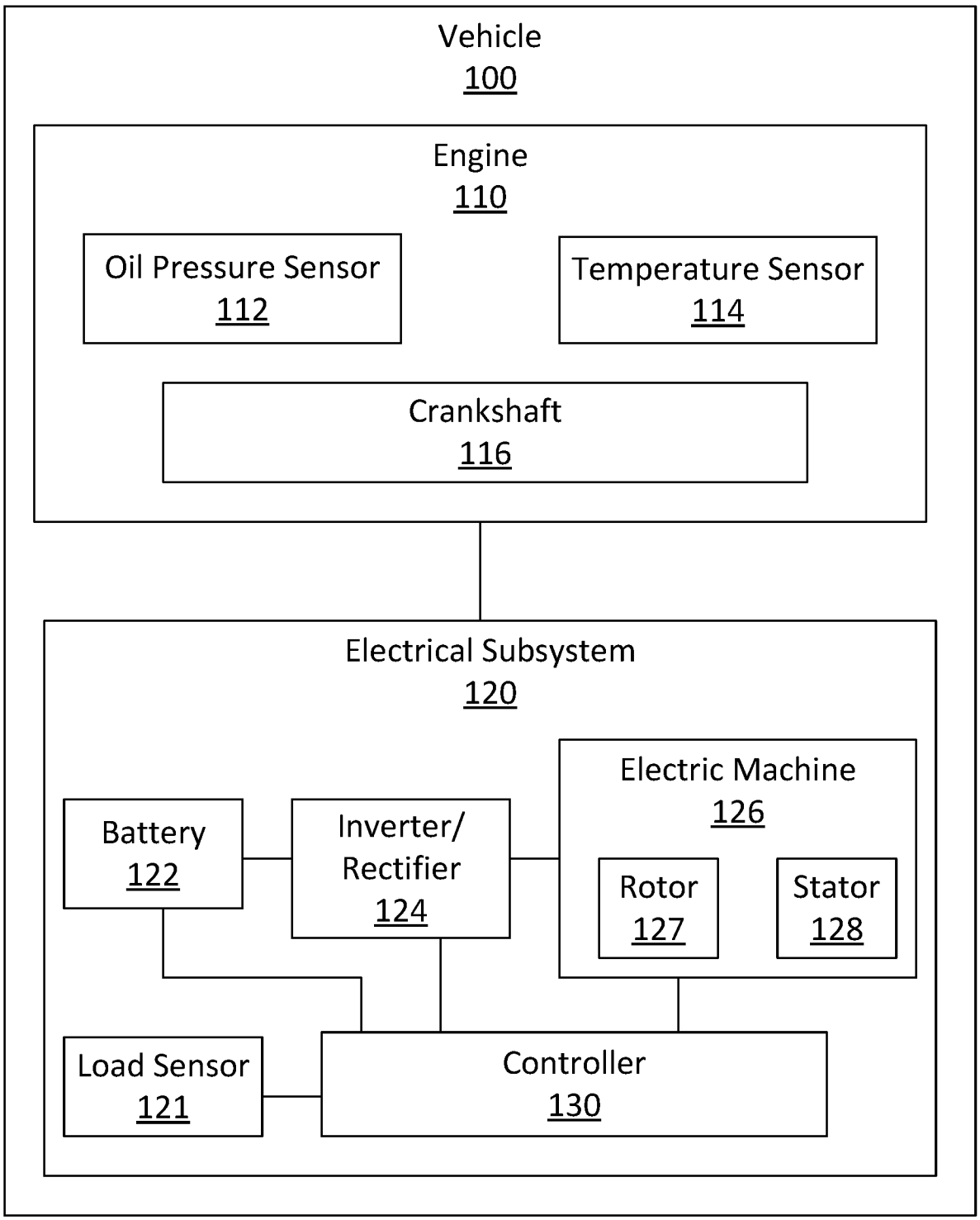
Vehicle
100
Engine
110
Oil Pressure Sensor
112
Temperature Sensor
114
Crankshaft
116
Electrical Subsystem
120
Electric Machine
126
Battery
122
Inverter/
Rectifier
124
Rotor
127
Stator
128
Load Sensor
121
Controller
130

Figure 1

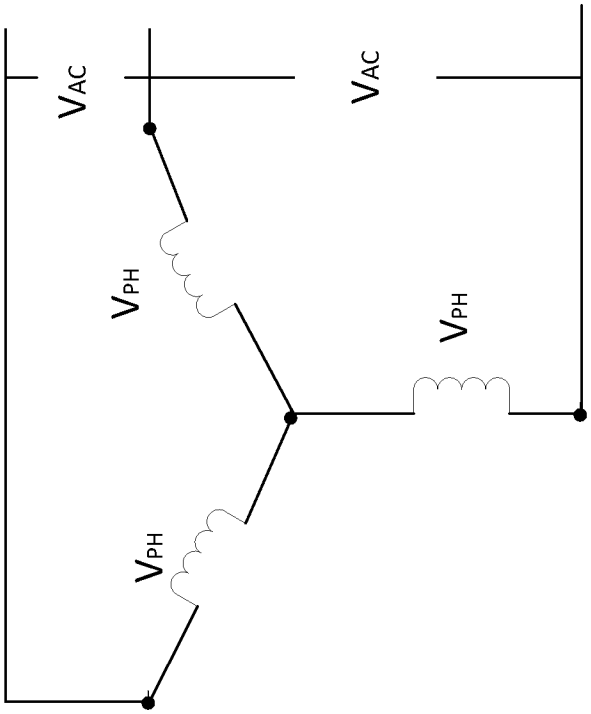

Figure 2(b)

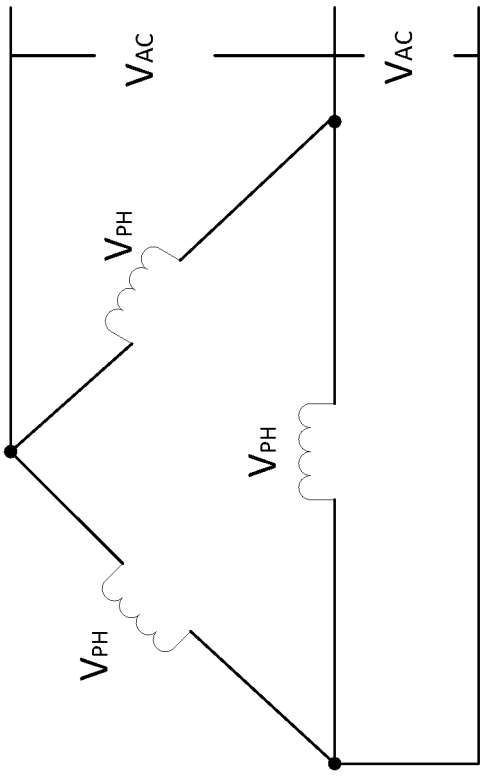

Figure 2(a)

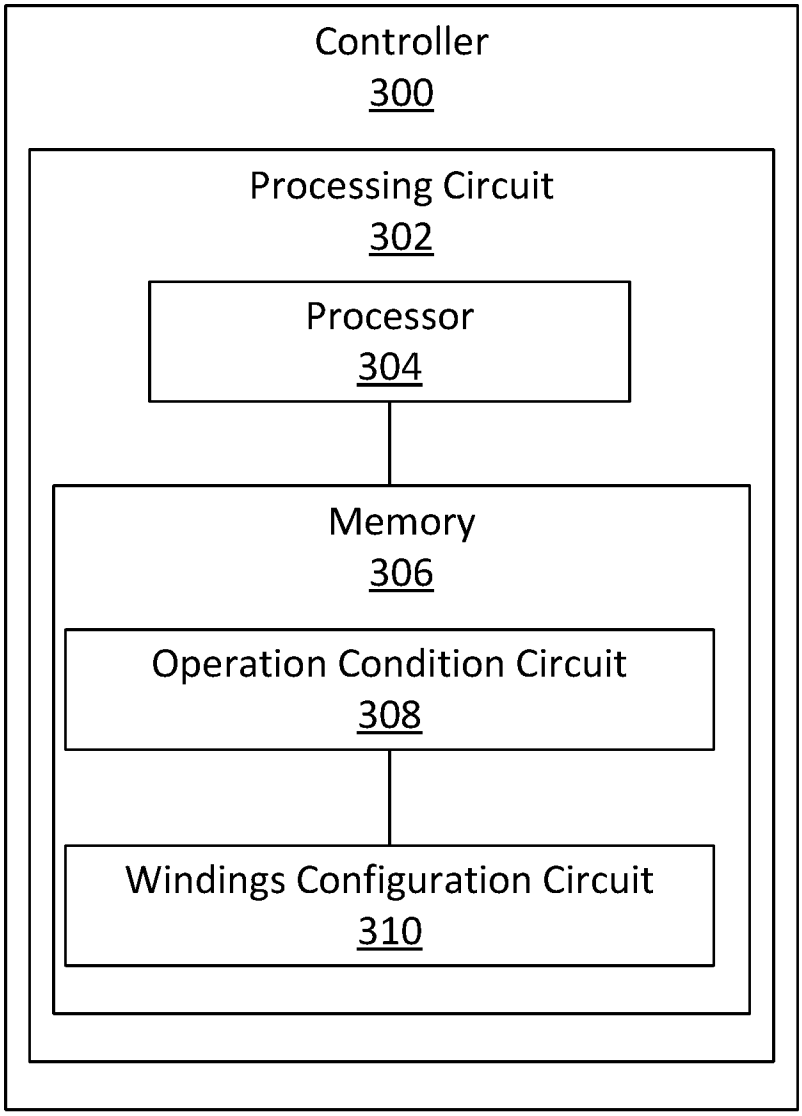
Controller
300
Processing Circuit
302
Processor
304
Memory
306
Operation Condition Circuit
308
Windings Configuration Circuit
310

Figure 3

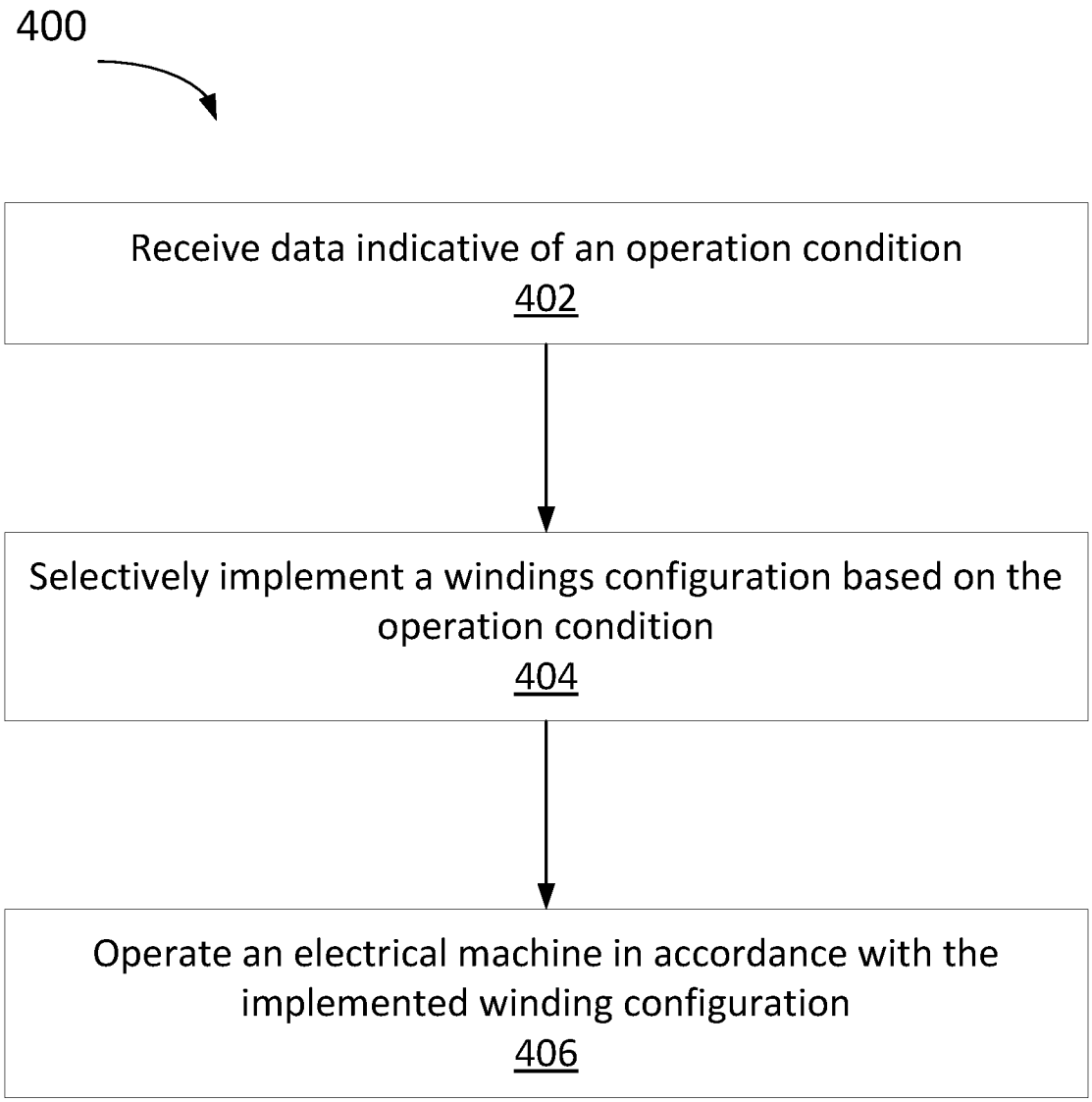
400
Receive data indicative of an operation condition
402
Selectively implement a windings configuration based on the operation condition
404
Operate an electrical machine in accordance with the implemented winding configuration
406

Figure 4

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US16/27574

A. CLASSIFICATION OF SUBJECT MATTER
IPC(8) - F02N 11/04, 11/08; H02P 1/32; H02K 3/28, 7/06 (2016.01)
CPC - F02N 11/04, 11/087; H02P 1/32; H02K 3/28, 7/06
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC(8): H02K 3/28, 7/00, 7/06, 7/118, 7/20; H02P 1/32, 4/00, 25/02; F02N 11/04, 11/08, 99/00 (2016.01)
CPC: H02K 3/28, 7/06, 7/118, 7/20; H02P 1/32, 4/00; F02N 11/003, 11/006, 11/04, 11/0859, 11/087, 2011/0896, 2300/102

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

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
PatSeer (US, EP, WO, JP, DE, GB, CN, FR, KR, ES, AU, IN, CA, INPADOC Data); Google Scholar; EBSCO Discovery Service; IP.com; Keywords: engine, motor, turbine, starter, alternator, generator, delta, wye, start, pressure, temperature, speed, load, crank, winding

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X --- Y	US 2004/0217723 A1 (CAI, W et al.) November 4, 2004; abstract; figures 1-9; paragraphs [0001, 0003, 0036, 0050, 0051]	1-11, 13-19 and 21-24 --- 12, 20
Y	US 4,947,100 A (DHYANCHAND, P et al.) August 7, 1990; figures 2 and 3; column 3, lines 49-53; column 4, lines 17-44 and 45-59	12, 20
A	EP 2 824 314 A2 (YAMAHA HATSUDOKI KABUSHIKI KAISHA) January 14, 2015; entire document	1-24
A	US 6,365,983 B1 (MASBERG, U et al.) April 2, 2002; entire document	1-24
A	US 6,153,942 A (ROSEMAN, R et al.) November 28, 2000; entire document	1-24

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

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"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
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"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	Date of mailing of the international search report
20 June 2016 (20.06.2016)	26 JUL 2016
Name and mailing address of the ISA/ Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-8300	Authorized officer Shane Thomas PCT Helpdesk: 571-272-4300 PCT OSP: 571-272-7774