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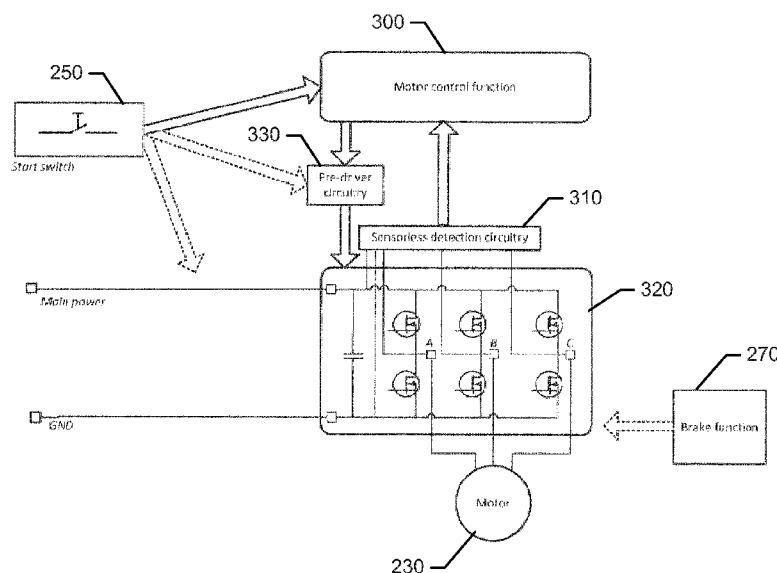


FIG. 3

(57) **Abstract:** A method of starting a BLDC motor may include maintaining all power stage transistors in an off state during a motor startup check responsive to activation of a start switch, determining, prior to motor startup, motor state information including information indicative of whether the BLDC motor is rotating and, if rotating, speed of rotation, and employing a selected one of at least two startup procedures including a first start procedure and a second startup procedure based on the motor state information.

ADAPTIVE STARTUP FOR A BLDC MOTOR

TECHNICAL FIELD

[0001] Example embodiments generally relate to outdoor power equipment and, more particularly, relate to outdoor power equipment that employs a brushless direct current (BLDC) motor with adaptive startup features.

BACKGROUND

[0002] Outdoor power equipment includes such devices as mowers, trimmers, edgers, chainsaws, blowers and the like. These devices are often used to perform tasks that inherently require the devices to be mobile. Accordingly, these devices are typically made to be relatively robust and capable of handling difficult work in hostile environments, while balancing the requirement for mobility.

[0003] Powering such devices could be accomplished in any number of ways. However, for outdoor power equipment that is intended to be mobile, and for which the emissions (i.e., in terms of noise and/or pollutants) generated by the device may also become an important consideration, electric motors are often popular choices to power such devices. Given that outdoor power equipment operates in hostile environments, a BLDC motor may be a popular choice as the electric motor for such devices.

[0004] In this regard, BLDC motors do not include a commutator and brush assembly and thus there is no ionizing sparking generated by the BLDC motor and there is no brush and commutator erosion. BLDC motors use a solid-state circuit for generating an alternating current from a DC electric power source (e.g., a battery). BLDC motors may therefore provide a longer life, reduced noise, and increased reliability relative to DC motors that employ commutators and brushes. Furthermore, BLDC motors can operate in entirely enclosed environments, so they may be isolated from dirt and debris.

[0005] Despite the advantages of BLDC motors, the fact that control circuitry must direct rotor rotation means that the position and orientation of the rotor relative to the stator coils is important. Although some BLDC motors may employ measurement of back EMF in order to determine rotor position, others may use Hall effect sensors or other such devices to determine rotor position.

BRIEF SUMMARY OF SOME EXAMPLES

[0006] Some example embodiments may therefore provide structures and methods for facilitating startup of a BLDC motor based on motor state information before startup begins.

[0007] In accordance with an example embodiment, a method of starting a BLDC motor is provided. The method may include maintaining all power stage transistors in an off state during a motor startup check responsive to activation of a start switch, determining, prior to motor startup, motor state information including information indicative of whether the BLDC motor is rotating and, if rotating, direction and speed of rotation, and employing a selected one of at least two startup procedures including a first start procedure and a second startup procedure based on the motor state information.

[0008] In another example embodiment, an apparatus including control circuitry for controlling a BLDC motor that powers a working assembly is provided. The control circuitry may be configured for maintaining all power stage transistors in an off state during a motor startup check responsive to activation of a start switch, determining, prior to motor startup, motor state information including information indicative of whether the BLDC motor is rotating and, if rotating, direction and speed of rotation, and employing a selected one of at least two startup procedures including a first start procedure and a second startup procedure based on the motor state information.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWING(S)

[0009] Having thus described the invention in general terms, reference will now be made to the accompanying drawings, which are not necessarily drawn to scale, and wherein:

[0010] FIG. 1 illustrates a perspective view of one example of outdoor power equipment that may employ a BLDC motor in accordance with an example embodiment;

[0011] FIG. 2 illustrates a block diagram of an electric powered device in accordance with an example embodiment;

[0012] FIG. 3 illustrates a block diagram of various components of an apparatus capable of executing an adaptive startup based on motor state information in accordance with an example embodiment;

[0013] FIG. 4 illustrates a block diagram of a method of executing the adaptive startup in accordance with an example embodiment;

[0014] FIG. 5 illustrates a graph of motor phase voltage according to an example embodiment; and

[0015] FIG. 6 illustrates a graph of motor phase voltage for a motor restart in accordance with an example embodiment.

DETAILED DESCRIPTION

[0016] Some example embodiments now will be described more fully hereinafter with reference to the accompanying drawings, in which some, but not all example embodiments are shown. Indeed, the examples described and pictured herein should not be construed as being limiting as to the scope, applicability or configuration of the present disclosure. Rather, these example embodiments are provided so that this disclosure will satisfy applicable legal requirements. Like reference numerals refer to like elements throughout. Furthermore, as used herein, the term “or” is to be interpreted as a logical operator that results in true whenever one or more of its operands are true. As used herein, operable coupling should be understood to relate to direct or indirect connection that, in either case, enables functional interconnection of components that are operably coupled to each other.

[0017] Some example embodiments described herein provide structures and methods for providing different startup procedures to be employed by outdoor power equipment that employs BLDC motors based on motor state information. In this regard, some example embodiments may provide for the inclusion of control circuitry in the equipment to control motor driver output based on motor state information. However, the motor state information may be determined before the startup procedure is selected so that current conditions can be considered when determining what motor driver output to generate. By providing motor startup with control over speed and torque, startup can be accomplished at any normal operating speed. Good dynamic properties may therefore be achievable since motor voltage output can be set to the correct value during startup. Selected parts of the motor driver can be inhibited or powered-off when the start switch is not pressed, without losing the ability to restart again. Furthermore, a separate brake function that is not part of the normal motor control function can be employed without inhibiting the ability to restart again.

[0018] FIG. 1 illustrates a perspective side view of an electric powered device 100 in accordance with an example embodiment. It should be appreciated that the electric powered device 100 of FIG. 1 merely represents one example of power equipment on which an example embodiment may be employed (namely a blower). However, example embodiments may also be practiced in connection with powering other device such as, for example, mowers, trimmers, edgers, chainsaws, and the like. Thus, the device 100 of FIG. 1 is merely

an example of a device that may employed a BLDC motor within a housing using a power switch and speed control to power a work assembly.

[0019] Referring to FIG. 1, the electric powered device 100 may include a housing 110 inside which various components of the blower are housed. The electric powered device 100 may further include a motor or power unit that is housed within the housing 110 for providing the driving force to power a working assembly of the electric powered device 100. In this example, the working assembly may be a fan assembly. However, in other embodiments the working assembly may be a cutting blade, cutting chain, or the like. In some embodiments, the power unit may be a BLDC motor. The BLDC motor may be operated under the control of a control unit or control circuitry and powered by a battery 140 or battery adaptor.

[0020] The battery 140 may be housed in a battery compartment of the housing 110. Power may be available for application from the battery 140 to the BLDC motor based on the position of an on/off switch 150 provided on or proximate to a handle 144. The handle 144 may include a trigger 146 that may be operated by a finger of the operator while the operator holds the handle 144. Actuation of the trigger 146 may cause power from the battery 140 to be selectively applied to the BLDC motor to control the speed of the BLDC motor. In some cases, the control unit may include interlocks, protective functions or other control mechanisms that may sense various conditions via sensors, switches or other mechanisms in order to selectively control the application of power to the BLDC motor for safety reasons and/or based on indications of user intent (e.g., via actuation of the trigger 146) and/or determinations regarding the state of the electric powered device 100 as provided by the sensors, switches or other mechanisms.

[0021] FIG. 2 illustrates a block diagram of an electric powered device 200 in accordance with an example embodiment. The device 200 could be a mower, trimmer, hedgetrimmer, edger, chainsaw, blower, and the like. As shown in FIG. 2, the device 200 may include a power source 210, a working assembly 220 and a BLDC motor 230. The BLDC motor 230 may be controlled by control circuitry 240 (which may include motor driver components). A start switch 250 may provide control for the application of power to the BLDC motor 230 and a throttle control operator 260 (e.g., trigger 146) may control the speed of the BLDC motor 230, if speed control is an option. However, it should be appreciated that the throttle control operator 260 and the start switch 250 may be the same device in some embodiments (e.g., where one discrete switch and one potentiometer are provided in one mechanical assembly, or just one discrete switch is provided).

[0022] In some embodiments, product safety requirements may dictate that certain design criteria be met. For example, design considerations may be employed to ensure that no single fault in electronics hardware can lead to a start of the product without a start command being issued by the operator. Simple and robust methods employed to realize these criteria may for example involve that the normal motor control function is inhibited when the start switch 250 (or on/off switch) is not pressed.

[0023] This principle of inhibiting parts of the motor control function may generally lead to a problem that when the start switch 250 is released, and then pressed again, the motor driver must restart the BLDC motor 230 in a proper way depending on the motor state (e.g., whether the BLDC motor 230 is rotating and, if so, at which speed and in which direction). If the restart is not adapted to the state of the BLDC motor 230, a failure to restart the BLDC motor 230 at all may occur. Alternatively, bad control of the dynamic behavior of the device during start-up may occur, and high motor current that is unfavorable may result and the BLDC motor 230 or motor driver may be damaged.

[0024] In some cases, the device 200 may further include a brake function 270 that is used to stop the BLDC motor 230 when the start switch 250 is not pressed or when a stop command has been provided in another way. The brake function 270 may be another reason why the motor control function may not have control over the motor during deceleration.

[0025] To deal with these issues, an example embodiment may be provided such that the control circuitry 240 is configured to determine motor state (e.g., whether the BLDC motor 230 is rotating and, if so, at which speed and in which direction) before startup. The control circuitry 240 may then use the motor state information to choose a startup strategy to employ. For example, the control circuitry 240 may be configured to select a normal startup procedure or, for a startup during rotation, use the state information to employ selected timing during the startup. In some cases, the normal startup procedure may include using motor position information that may be obtained via sensorless (or sensed) detection circuitry to determine motor driver output in terms of which motor phases to power (commutate). The startup procedure for situations where motor rotation is occurring may include using motor speed information obtained from the sensorless (or sensed) detection circuitry, reference speed (constant or based on user input), load conditions and acceleration profile to determine the motor driver output in terms of which voltage command (duty cycle) to employ.

[0026] FIG. 3 illustrates a block diagram of various components of an apparatus capable of executing an adaptive startup based on motor state information. FIG. 4 illustrates a block diagram of a method of executing the adaptive startup in accordance with an example

embodiment. FIG. 5 illustrates a graph of motor phase voltage according to an example embodiment. FIG. 6 illustrates a graph of motor phase voltage for a motor restart in accordance with an example embodiment.

[0027] Referring now to FIGS. 3-6, the start switch 250 may provide power to a motor control function 300 that may include processing circuitry (e.g., control circuitry 240) configured to control operation of the BLDC motor 230. The motor control function 300 may therefore employ a microprocessor, processor, control IC, FPGA or other such processing circuitry that is configured to monitor motor state information and take action based on such information for engine startup that is adaptive and based on the motor state information. In this example, sensorless detection circuitry 310 may monitor a power stage 320 that provides power control hardware for controlling operation of the BLDC 230 to determine motor state information. In some examples, the sensorless detection circuitry 310 may be configured to monitor back EMF in order to determine motor state information.

[0028] Pre-driver circuitry 330 may also be provided to interface with the power stage 320 to control commutation for startup from a stopped condition (e.g., when the rotor is not already moving). The power stage 320 may include transistors, inverters and/or other hardware that is employable to generate three phase AC power from a DC power source. The power stage 320 may control the phase timing, duty cycle, modulation and/or other characteristics of the power applied to the BLDC motor 230. As shown in FIG. 3, the start switch 250 may act as a signal input to the motor control function 300, but may also switch a critical power part of the motor driver such as by controlling power to the pre-driver circuitry 330, or controlling the application of main power itself.

[0029] In an example embodiment, the sensorless detection circuitry 310 may be configured to monitor back EMF in order to determine motor state information. As shown in FIG. 5, motor phase voltage with per-unit scaling is shown for phases A, B and C. Zero crossings are highlighted in FIG. 5 with circles. As can be appreciated from FIG. 5, the sensorless detection circuitry 310 may be configured to detect the zero crossings and identify the time between zero crossings (as indicated by T1 and T2) and/or the number of zero crossings in a given time. The frequency of zero crossing activity may be used to determine motor speed. Meanwhile, motor direction may be determined based on the order of occurrence of the zero crossings for each different phase. As such, by monitoring back EMF, the sensorless detection circuitry 310 may determine motor state information and provide such information to the motor control function 300. The motor control function 300 may then be configured to use such information to apply the method of FIG. 4.

[0030] As shown in FIG. 4, a method for control of a BLDC motor may include maintaining pre-driver circuitry inactive (to maintain all power stage transistors in an off state) during a motor startup check responsive to activation of the start switch at operation 400. At operation 410, the sensorless detection circuitry may be employed to determine motor state. As such, back EMF may be monitored (as described above) to determine whether the BLDC motor is rotating and if so, at what speed (and direction in some cases). If the BLDC motor is not rotating, or if it is rotating below a threshold (or limit) speed, then a first (or normal) start procedure may be employed at operation 420. The first start procedure may be an open loop start procedure that can be employed from a stand-still condition.

[0031] If instead the BLDC motor is determined to be rotating (or rotating above the threshold speed), a second (or restart) procedure may be employed at operation 430. The restart procedure may include determining a pulse width modulation (PWM) duty cycle to be applied to the BLDC motor based on the measured speed. In some cases a reference speed that can be a fixed nominal value or may be defined by user input may be used as a reference to which the measured speed is compared. A suitable acceleration rate and load conditions may also be factors considered for determining the PWM duty cycle to apply. The restart procedure may also include applying the calculated PWM duty cycle, activating the pre-driver circuitry and switching the correct transistors depending on the motor angle information obtained from the sensorless detection circuitry. This will enable the BLDC motor to be started with motor driver voltage output that has correct amplitude and phase for the current motor state (e.g., position and speed).

[0032] As such, the motor control function 300 may be configured to receive motor state information and perform a selected pre-programmed startup procedure based on the motor state information. In some examples, the motor control function 300 may be configured to monitor motor state information and reference a table to find pre-timing values that correspond to the motor state information. The corresponding pre-timing value for a given motor state information may then be applied. In an example case using an eight-pole motor, a typical setup may be to employ a threshold of 50 Hz frequency or 188 rpm mechanical speed as a limit regarding whether to choose to employ the first (normal) or second (restart) procedure. This may enable detection of two full electric periods of each phase during 40 ms, which would be an acceptable startup delay and may also give sufficient time to acquire startup information.

[0033] FIG. 6 shows motor phase voltage with per-unit scaling for phases A, B and C based on sinusoidal back EMF for application of a restart startup procedure. In this regard,

the zero crossings in FIG. 6 are again highlighted with circles. As mentioned above, the frequency of zero crossings can be monitored to determine whether motor rotation is occurring and at what speed. If the restart procedure is required based on motor speed, there may be a correct way to start the motor. As an example, with a falling zero crossing on phase C (circle 401), the motor should be started with voltage applied from phase A to phase C. In this commutation case, the phase A high side (+) transistor may be used together with the phase C low side transistor (-) (with duty cycle and modulation, etc.). Once started, the commutation will continue per the pattern indicated in FIG. 6 per the normal operating procedure. Given that the startup time is not critical, it can be enough to look for one pre-defined zero crossing and always start with the same phase configuration. The pre-timing angle in this example may be about 20 degrees from the zero crossing. However, other values may be selected for different types of motors. As such, pre-timing angles may be initiated based on a given motor speed for a given motor model, type or style

[0034] In some cases, it may be desirable to prescribe the same pre-timing angle for all or a range of speeds, but it should be appreciated that multiple options are available. It should also be appreciated that commutation could be provided at the zero crossings instead of at a particular angle relative to the zero crossing.

[0035] An apparatus of an example embodiment may therefore include control circuitry for controlling a BLDC motor that powers a working assembly. The control circuitry may be configured for maintaining pre-driver circuitry inactive (to maintain all power stage transistors in an off state) during a motor startup check responsive to activation of a start switch, determining, prior to motor startup, motor state information including information indicative of whether the BLDC motor is rotating and, if rotating, speed (and in some cases direction) of rotation, and employing a selected one of at least two startup procedures including a first start procedure and a second startup procedure based on the motor state information.

[0036] The apparatus (or control circuitry) of some embodiments may include additional features that may be optionally added either alone or in combination with each other. For example, in some embodiments, (1) if the BLDC motor is not rotating, or if the BLDC motor is rotating below a threshold speed, then the first start procedure is employed. The first startup procedure may include an open loop start procedure employed from a stand-still condition. In some cases, (2) if the BLDC motor is rotating, or if the BLDC motor is rotating above a threshold speed, the second procedure is employed. The second startup procedure may include determining a motor driver output for driving the BLDC motor (230) based on

the motor state information. In an example embodiment, (3) determining motor driver output may include determining a pulse width modulation (PWM) duty cycle to be applied to the BLDC motor based on measured speed. In some examples, (4) determining motor driver output may further include determining the PWM duty cycle to be applied based on comparing the measured speed to a reference speed, and based on an acceleration profile and load conditions. In some embodiments, (5) determining the PWM duty cycle to be applied may include comparing the measured speed to the reference speed where the reference speed corresponds to a predefined value. In some cases, (6) determining the PWM duty cycle to be applied may include comparing the measured speed to the reference speed where the reference speed corresponds to a user defined value.

[0037] In some embodiments, any or all of (1) to (6) may be employed in addition to the optional modifications or augmentations described below. For example, in some embodiments, determining the motor driver output may include referencing a table to find pre-timing values that correspond to the motor state information and applying pre-timing values based on the motor state information. Additionally or alternatively, determining a motor driver output may include providing commutation at zero crossings of measured phases or at a particular angle relative to the zero crossings. Additionally or alternatively, determining motor state may include utilizing sensorless detection circuitry to determine motor state based on back EMF measurements.

[0038] Many modifications and other embodiments of the inventions set forth herein will come to mind to one skilled in the art to which these inventions pertain having the benefit of the teachings presented in the foregoing descriptions and the associated drawings. Therefore, it is to be understood that the inventions are not to be limited to the specific embodiments disclosed and that modifications and other embodiments are intended to be included within the scope of the appended claims. Moreover, although the foregoing descriptions and the associated drawings describe exemplary embodiments in the context of certain exemplary combinations of elements and/or functions, it should be appreciated that different combinations of elements and/or functions may be provided by alternative embodiments without departing from the scope of the appended claims. In this regard, for example, different combinations of elements and/or functions than those explicitly described above are also contemplated as may be set forth in some of the appended claims. In cases where advantages, benefits or solutions to problems are described herein, it should be appreciated that such advantages, benefits and/or solutions may be applicable to some example embodiments, but not necessarily all example embodiments. Thus, any advantages, benefits

or solutions described herein should not be thought of as being critical, required or essential to all embodiments or to that which is claimed herein. Although specific terms are employed herein, they are used in a generic and descriptive sense only and not for purposes of limitation.

THAT WHICH IS CLAIMED:

1. A method of starting a BLDC motor (230), the method comprising:
maintaining (400) all power stage transistors in an off state during a motor startup check responsive to activation of a start switch (250);
determining (410), prior to motor startup, motor state information comprising information indicative of whether the BLDC motor (230) is rotating and, if rotating, speed of rotation; and
employing (420/430) a selected one of at least two startup procedures including a first start procedure and a second startup procedure based on the motor state information.
2. The method of claim 1, wherein if the BLDC motor (230) is not rotating, or rotating below a threshold speed, then the first start procedure is employed, the first startup procedure comprising an open loop start procedure employed from a stand-still condition (420).
3. The method of claim 1, wherein if the BLDC motor (230) is rotating or rotating above a threshold speed, the second procedure is employed, and wherein the second startup procedure comprises determining a motor driver output for driving the BLDC motor (230) based on the motor state information (430).
4. The method of claim 3, wherein determining motor driver output comprises determining a pulse width modulation (PWM) duty cycle to be applied to the BLDC motor based on measured speed (430).
5. The method of claim 4, wherein determining motor driver output further comprises determining the PWM duty cycle to be applied based on comparing the measured speed to a reference speed, and based on an acceleration profile and load conditions.
6. The method of claim 5, wherein determining the PWM duty cycle to be applied comprises comparing the measured speed to the reference speed, the reference speed corresponding to a predefined value.

7. The method of claim 5, wherein determining the PWM duty cycle to be applied comprises comparing the measured speed to the reference speed, the reference speed corresponding to a user defined value.

8. The method of any of claims 3-7, further comprising applying the calculated PWM duty cycle, activating the pre-driver circuitry and switching selected transistors depending on motor angle information obtained from the motor state information to provide the motor driver output as a motor driver voltage having selected amplitude and phase based on the motor state information.

9. The method of any of claims 3-8, wherein determining the motor driver output comprises referencing a table to find pre-timing values that correspond to the motor state information and applying pre-timing values based on the motor state information.

10. The method of any of claims 3-9, wherein determining a motor driver output comprises providing commutation at zero crossings of measured phases or at a particular angle relative to the zero crossings.

11. The method of any preceding claim, wherein determining motor state comprises utilizing sensorless detection circuitry (310) to determine motor state based on back EMF measurements.

12. The method of any preceding claim, wherein the motor state information further comprises a direction of rotation and the BLDC motor powers outdoor power equipment.

13. An apparatus (200) comprising control circuitry (240) for controlling a BLDC motor (230) that powers a working assembly (220), the control circuitry (240) being configured for:

maintaining all power stage transistors in an off state during a motor startup check responsive to activation of a start switch (250);

determining, prior to motor startup, motor state information comprising information indicative of whether the BLDC motor (230) is rotating and, if rotating, speed of rotation; and

employing a selected one of at least two startup procedures including a first start procedure and a second startup procedure based on the motor state information.

14. The apparatus (200) of claim 13, wherein if the BLDC motor (230) is not rotating, or rotating below a threshold speed, then the first start procedure is employed by the control circuitry (240), the first startup procedure comprising an open loop start procedure employed from a stand-still condition.

15. The apparatus (200) of claim 14, wherein if the BLDC motor (230) is rotating or rotating above a threshold speed, the second procedure is employed by the control circuitry (240), and wherein the second startup procedure comprises determining a motor driver output for driving the BLDC motor (230) based on the motor state information (430).

16. The apparatus (200) of claim 15, wherein the control circuitry (240) is configured to determine motor driver output via determining a pulse width modulation (PWM) duty cycle to be applied to the BLDC motor based on measured speed.

17. The apparatus (200) of claim 16, wherein the control circuitry (240) is configured to determine motor driver output further by determining the PWM duty cycle to be applied based on comparing the measured speed to a reference speed, and based on an acceleration profile and load conditions.

18. The apparatus (200) of claim 17, wherein the control circuitry (240) is configured to determine the PWM duty cycle to be applied by comparing the measured speed to the reference speed, the reference speed corresponding to a predefined value.

19. The apparatus (200) of claim 17, wherein the control circuitry (240) is configured to determine the PWM duty cycle to be applied by comparing the measured speed to the reference speed, the reference speed corresponding to a user defined value.

20. The apparatus (200) of any of claims 15-19, wherein the control circuitry (240) is further configured to apply the calculated PWM duty cycle, activating the pre-driver circuitry and switching selected transistors depending on motor angle information obtained

from the motor state information to provide the motor driver output as a motor driver voltage having selected amplitude and phase based on the motor state information.

21. The apparatus (200) of any of claims 15-20, wherein the control circuitry (240) is configured to determine the motor driver output by referencing a table to find pre-timing values that correspond to the motor state information and applying pre-timing values based on the motor state information.

22. The apparatus (200) of any of claims 15-21, wherein determining a motor driver output comprises providing commutation at zero crossings of measured phases or at a particular angle relative to the zero crossings.

23. The apparatus (200) of any of claims 13-20, wherein the control circuitry (240) is configured to determine motor state by utilizing sensorless detection circuitry (310) to determine motor state based on back EMF measurements.

24. The apparatus (200) of any of claims 13-23, wherein the motor state information further comprises a direction of rotation.

25. The apparatus (200) of any of claims 13-24, wherein the apparatus (200) is outdoor power equipment.

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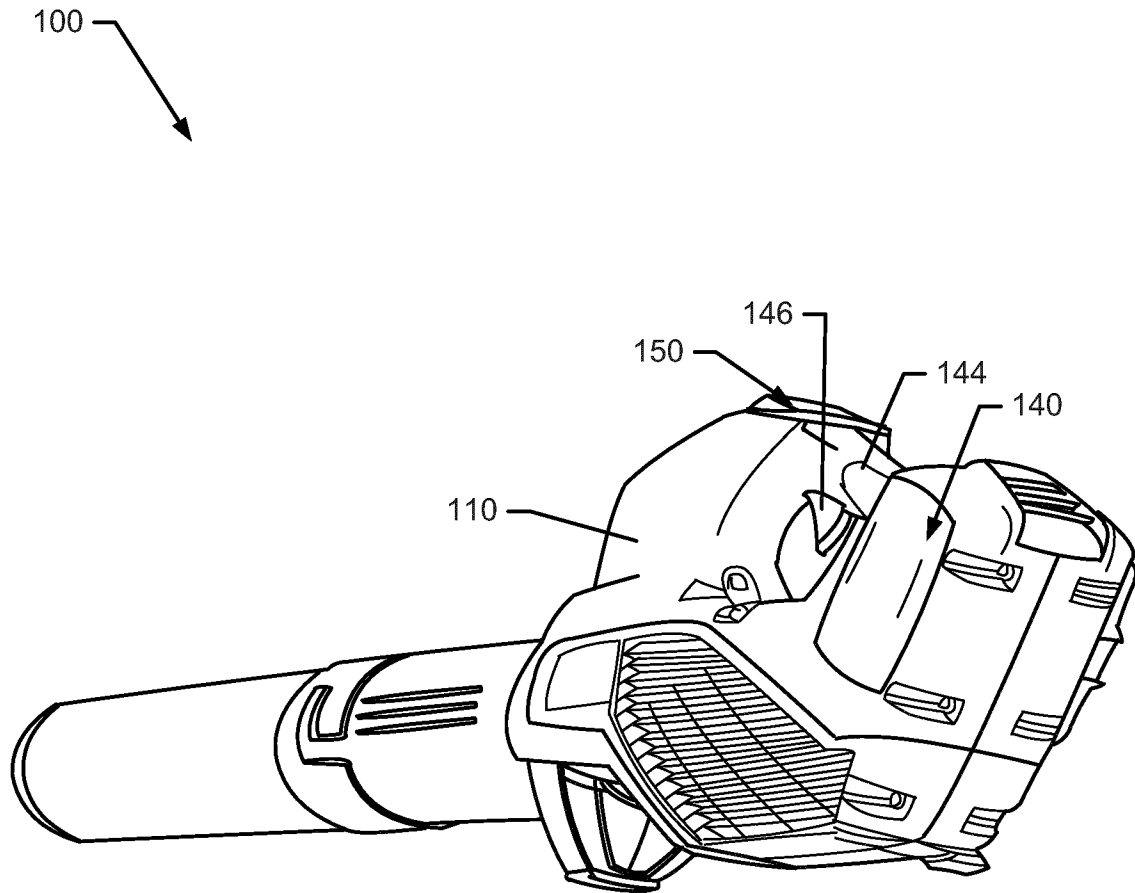


FIG. 1

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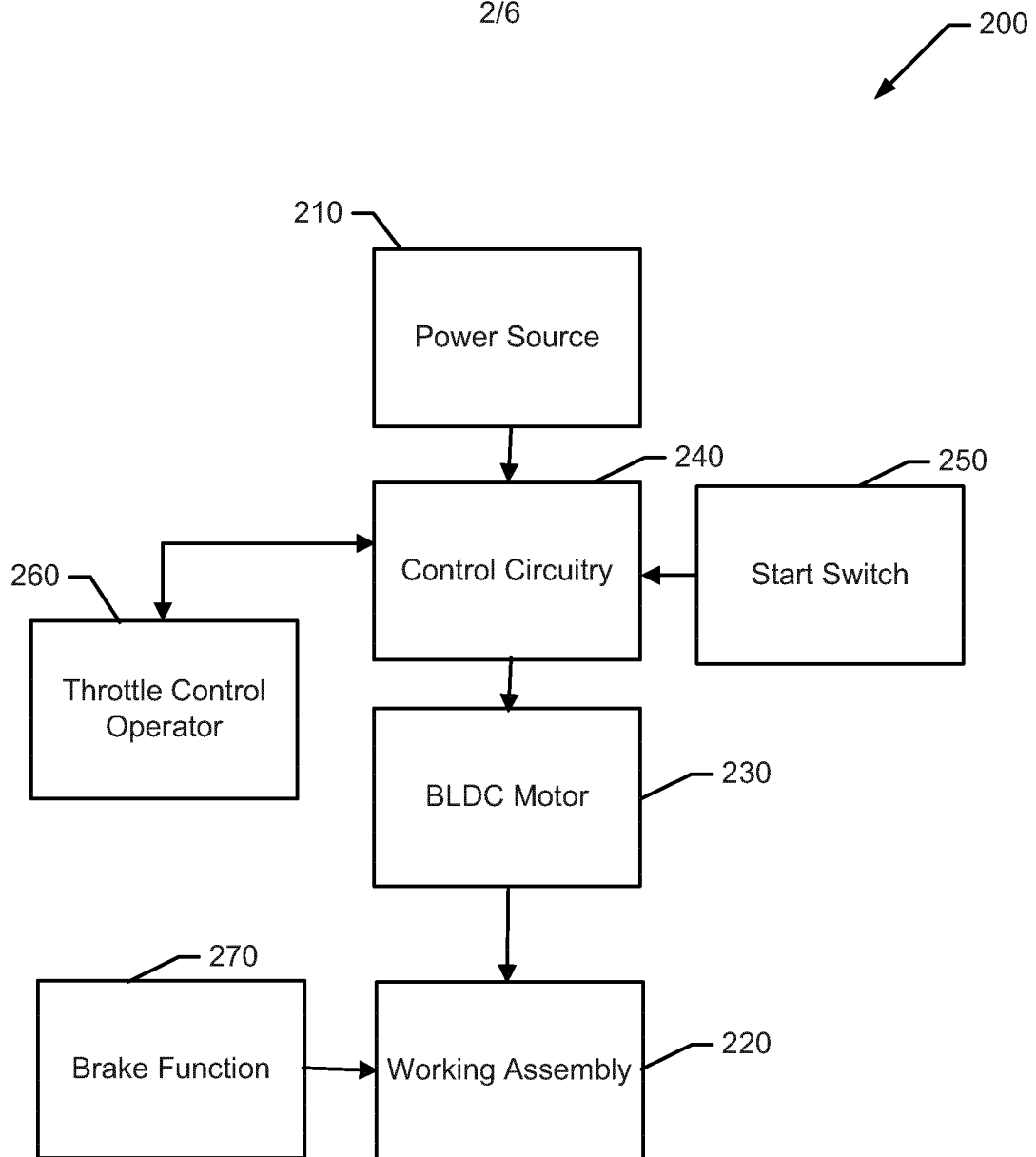


FIG. 2

3/6

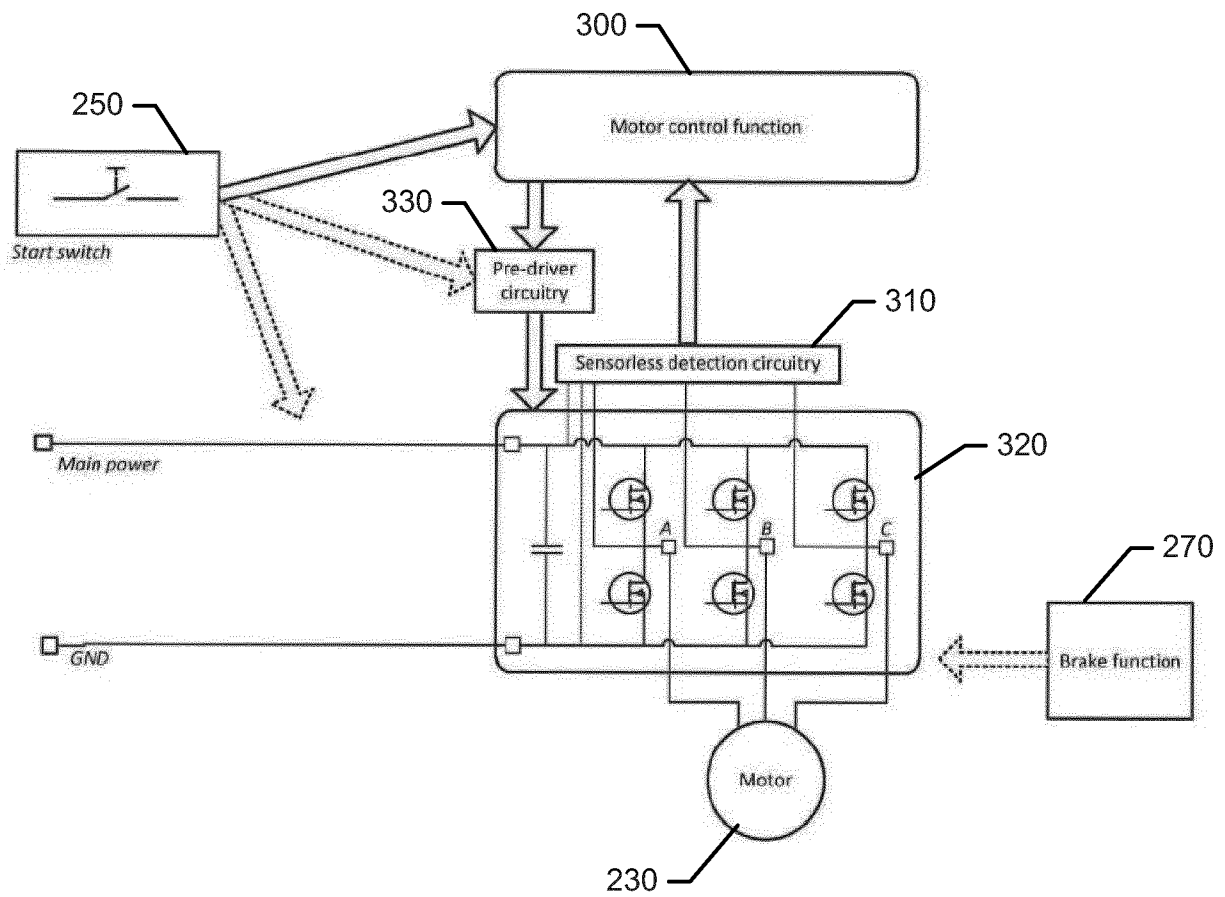


FIG. 3

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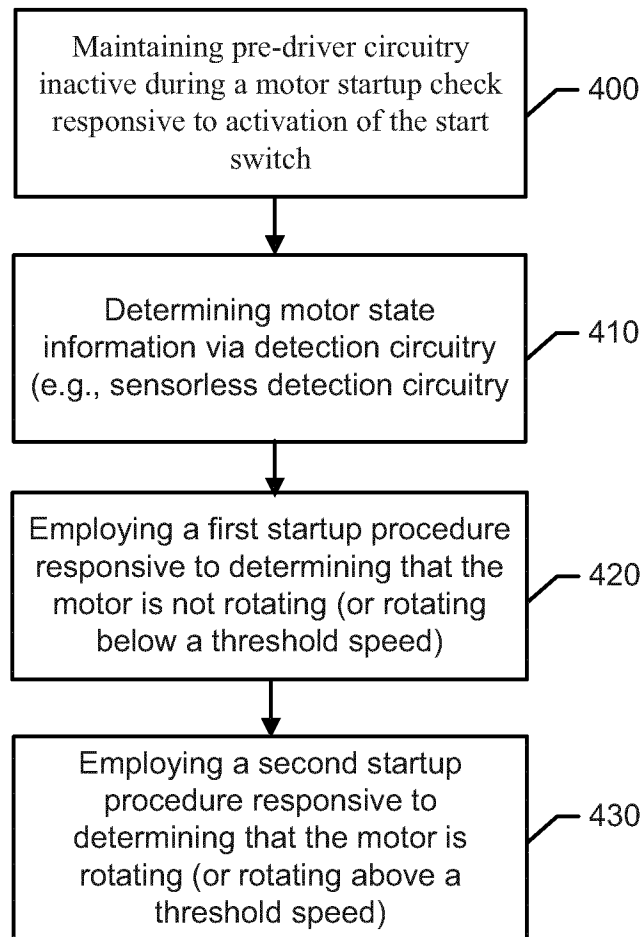


FIG. 4

5/6

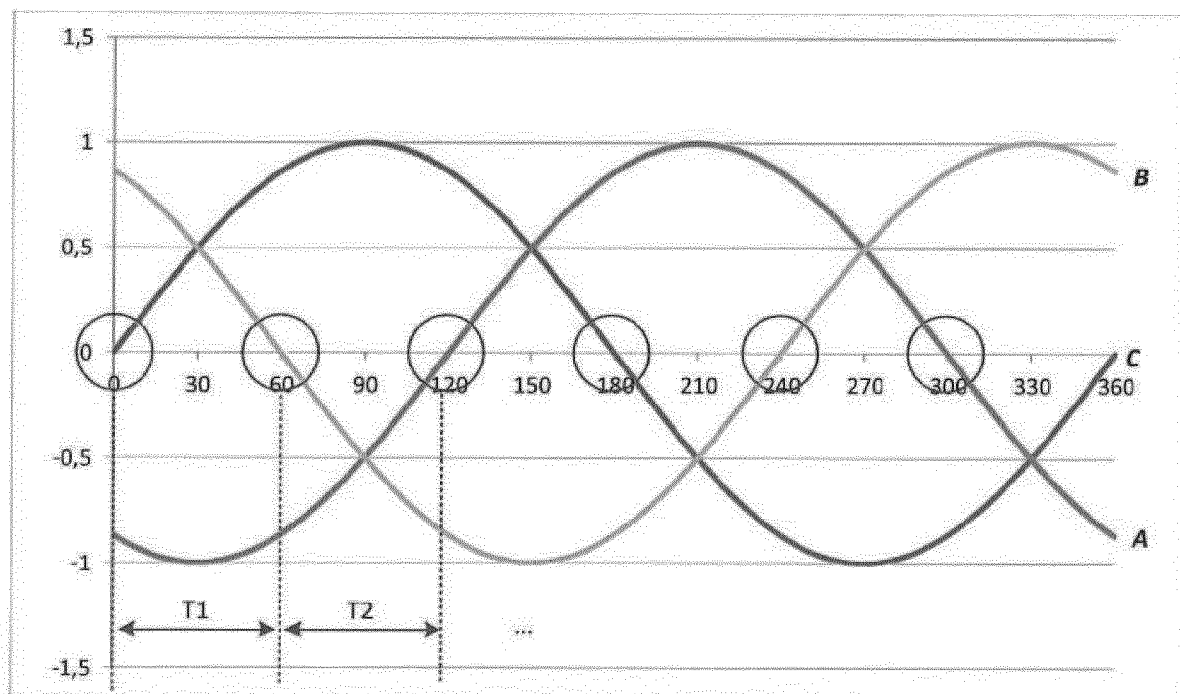


FIG. 5

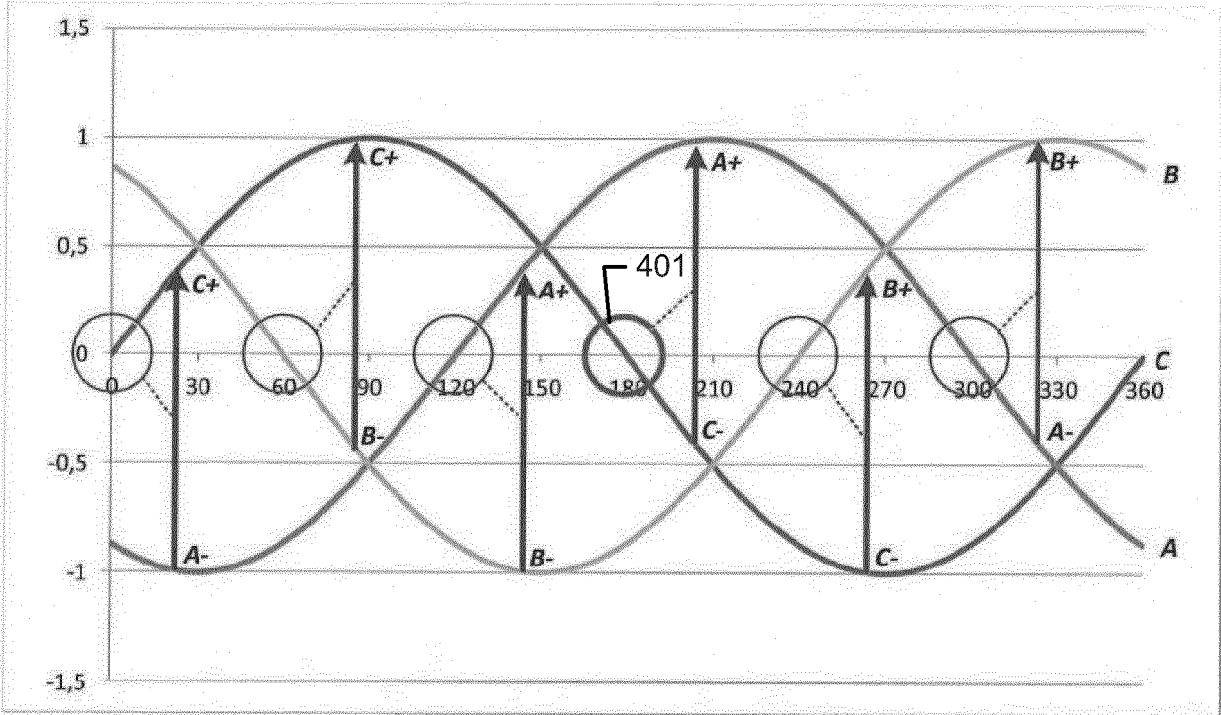


FIG. 6

INTERNATIONAL SEARCH REPORT

International application No

PCT/EP2014/059175

A. CLASSIFICATION OF SUBJECT MATTER

INV. H02P1/02 H02P6/20
ADD.

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)
H02P

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)

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y A	EP 1 406 376 A2 (SIEMENS VDO AUTOMOTIVE INC [CA]) 7 April 2004 (2004-04-07) paragraphs [0001] - [0013]; figure 4	1-3, 13-15 4-6,8, 16-18,20 7,9,12, 19,21, 24,25
X Y	----- US 2012/274249 A1 (MULLIN PAUL [US]) 1 November 2012 (2012-11-01) paragraph [0039] - paragraph [0044] ----- -/-	1-3,10, 11, 13-15, 22,23 4-6,8, 16-18,20



Further documents are listed in the continuation of Box C.



See patent family annex.

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Date of the actual completion of the international search

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INTERNATIONAL SEARCH REPORT

International application No

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C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 1 505 719 A2 (ST MICROELECTRONICS INC [US]) 9 February 2005 (2005-02-09)	1,11,13,23,24
Y	paragraph [0002] - paragraph [0019]	4-6,8,16-18,20

X	EP 2 045 907 A2 (HAMILTON SUNDSTRAND CORP [US]) 8 April 2009 (2009-04-08)	1-3,13-15
Y	paragraph [0006] - paragraph [0019]	4-6,8,16-18,20

Y	US 2006/132084 A1 (DELANGE ROBERT J [US]) 22 June 2006 (2006-06-22)	4-6,8,16-18,20
	paragraph [0010] - paragraph [0043]	

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/EP2014/059175

Patent document cited in search report		Publication date		Patent family member(s)		Publication date
EP 1406376	A2	07-04-2004	EP	1406376 A2		07-04-2004
			US	2004061467 A1		01-04-2004

US 2012274249	A1	01-11-2012	EP	2702682 A2		05-03-2014
			US	2012274249 A1		01-11-2012
			WO	2012149237 A2		01-11-2012

EP 1505719	A2	09-02-2005	EP	1505719 A2		09-02-2005
			JP	2005065491 A		10-03-2005
			US	2005030002 A1		10-02-2005

EP 2045907	A2	08-04-2009	EP	2045907 A2		08-04-2009
			US	2009091133 A1		09-04-2009

US 2006132084	A1	22-06-2006	EP	1829200 A1		05-09-2007
			US	2006132084 A1		22-06-2006
			WO	2006069069 A1		29-06-2006
