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ABSTRACT OF THE DISCLOSURE

An electric motor controller is configured to be coupled to an electric motor. The controller is also configured to control the electric motor to produce torque when direct current (DC) link voltage has a 100% voltage ripple.

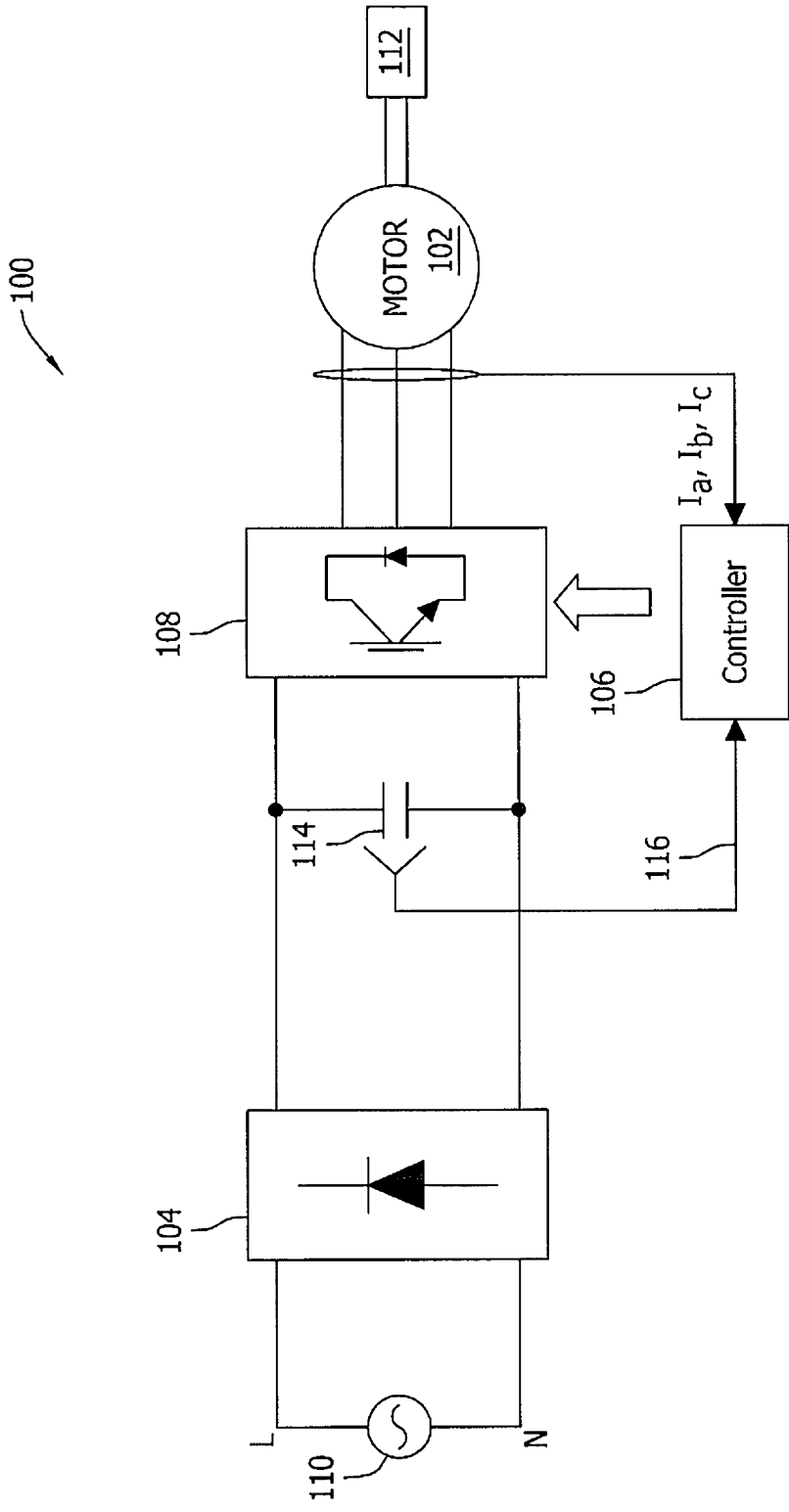


FIG. 1

METHODS AND SYSTEMS FOR CONTROLLING AN ELECTRIC MOTOR

BACKGROUND OF THE DISCLOSURE

The field of the invention relates generally to electric motors, and more specifically, to methods and systems for operating electric motors.

Typical electric motor systems include a motor controller and an electric motor. The motor controller receives power from an alternating current (AC) power supply, and applies it to a rectifier and to filter capacitors to generate a smoothed direct current (DC) voltage. The motor controller then supplies the DC voltage to the electric motor, which uses the power to drive a load.

Filter capacitors typically used in motor controllers include electrolytic capacitors with high capacitances (about 1000 μ F). The high capacitances cause the capacitors of the motor controller to be bulky and expensive. These filter capacitors necessitate a larger motor controller and may reduce the lifespan of the motor controller.

SUMMARY OF THE INVENTION

In accordance with a first aspect of the present invention, there is provided an electric motor controller configured to be coupled to an electric motor, said controller configured to increase energy transfer of the electric motor to a load when alternating current (AC) input voltage is available and to mitigate a reduction in energy transfer from the load to the electric motor to produce torque when direct current (DC) link voltage has a 100% voltage ripple.

In accordance with a second aspect of the present invention, there is provided a method of controlling an electric motor using a motor controller, the electric motor configured to be coupled to a power supply and to a load, said method comprising:
increasing energy transfer of the electric motor to the load when AC input voltage is available;

mitigating a reduction in energy transfer from the load to the electric motor to produce torque when direct current (DC) link voltage is one of approaching zero and equal to zero.

In accordance with a third aspect of the present invention, there is provided an
5 air moving system comprising:
an electric motor;
a load coupled to said electric motor; and
a controller coupled to said electric motor, said controller configured to increase
energy transfer of the electric motor to a load when alternating current (AC) input
10 voltage is available and to mitigate a reduction in energy transfer from the load to the
electric motor to produce torque when direct current (DC) link voltage is one of
approaching zero and equal to zero.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a functional diagram of a motor controller that may be used for operating an electric motor.

15 Figure 2 is a block diagram of an exemplary controller that may be used with the motor controller shown in Figure 1.

Figure 3 is an operational diagram of the exemplary motor controller shown in Figure 1, in which energy may be stored on a load coupled to an electric motor.

20 Figure 4 illustrates a graphical relationship between rail voltage, torque, and rotational speed the exemplary electric motor controller shown in Figure 1.

Figure 5 illustrates multiple performance benefits achieved by using the exemplary motor controller shown in Figure 1.

Figure 6 is a functional diagram of an exemplary embodiment of a motor controller.

25 Figure 7 is a functional diagram of an exemplary embodiment of a motor controller.

Figure 8 is a functional diagram of an exemplary embodiment of a motor controller.

Figure 9 is a flow chart of an exemplary method of operating an electric motor using the motor controller shown in Figure 1.

5 Figure 10 is a block diagram of an exemplary embodiment of the motor controller shown in Figure 1 used an air moving control system.

DETAILED DESCRIPTION OF THE DISCLOSURE

Figure 1 is a functional diagram of a motor controller 100 that may be used for operating an electric motor 102. In the exemplary embodiment, motor controller 100 includes a rectifier 104, a controller 106, and an inverter 108. Motor controller 100 is
10 coupled to a power supply 110 for receiving input power to drive electric motor 102. Electric motor 102 is coupled to and drives a load 112.

In the exemplary embodiment, power supply 110 supplies a single-phase alternating current (AC) voltage to motor controller 100. However, power supply 110 may supply three-phase AC, direct current (DC) voltage, or any other type of input
15 voltage that enables motor controller 100 to function as described herein. Rectifier 104 receives an AC input voltage from a power supply 110 and rectifies it to produce a pulsed DC voltage. Inverter 108 conditions the pulsed DC voltage, and supplies it to electric motor 102, which uses the power to drive load 112. In the exemplary
20 embodiment, inverter 108 converts the pulsed DC voltage to a three-phase AC voltage. Alternatively, inverter 108 converts the pulsed DC voltage to any type of voltage that enables motor controller to function as described herein.

In some embodiments, motor controller 100 includes a low-capacitance capacitor 114 for storing small amounts of energy when input voltage is available. Capacitor 114 may have a capacitance between about 0.1 $\mu\text{F}/\text{kW}$ and about 10 $\mu\text{F}/\text{kW}$.
25 The use of bulky, unreliable electrolytic filter capacitors in motor controller 100 is avoided. In some embodiments, capacitor 114 is configured to filter out switching frequency harmonics of electric motor 102. In other embodiments, the low-capacitance

of capacitor 114 reduces inrush input current to electric motor 102. Further, capacitor 114 facilitates motor controller 100 increasing line input power factor.

Motor controller 100 also includes a voltage sensor 116 coupled across capacitor 114. Voltage sensor 116 is configured to measure a DC link voltage being
5 output by rectifier 104. Voltage sensor 116 provides the DC link voltage measurement to controller 106 for use in controlling electric motor 102 to produce torque when DC link voltage has a 100% voltage ripple.

Figure 2 is a block diagram of an exemplary algorithm implemented by controller 106 (shown in Figure 1). Because there is no filter capacitor in motor
10 controller 100 (shown in FIG. 1), DC link voltage drops to zero each time the AC input voltage drops to zero. Typically, when DC link voltage drops to zero, also referred to as a 100% voltage ripple, regeneration and braking occur in electric motor 102, which may cause undesired effects in electric motor 102. In the exemplary embodiment, controller 106 is configured to control electric motor 102 (shown in Figure 1) to produce torque
15 when input voltage is one of approaching zero and equal to zero. More specifically, in the exemplary embodiment, controller 106 is configured to control electric motor 102 to produce torque when DC link voltage has a 100% voltage ripple.

In the exemplary embodiment, controller 106 is coupled to rectifier 104 and to inverter 108 (both shown in Figure 1). Controller 106 receives three-phase motor
20 current measurements I_a , I_b , and I_c from at least one current sensor 200, which is coupled to electric motor 102. Controller 106 includes a d-q conversion module 202, a current command generator 204, a PI controller 206, an a-b-c conversion module 208, and a modulator 210.

Current measurements I_a , I_b , and I_c are converted to a d-q reference frame by d-
25 q conversion module 202 to obtain a d-axis current I_d , related to a flux linkage component of the current and a q-axis current I_q related to a torque component of the current. I_d and I_q are sent to PI controller 206. Current command generator 204 generates a d-axis command I_d^* and a q-axis command I_q^* , which are both also sent to PI controller 206.

PI controller 206 prepares voltage values V_d and V_q to be applied to electric motor 102 such that the d-axis current value I_d and the q-axis current value I_q become equal to the d-axis current command I_d^* and the q-axis current command I_q^* . V_d and V_q are converted back to a three-phase coordinate system by a-b-c conversion module 208, which provides the three-phase voltage values V_a , V_b , and V_c to modulator 210. Modulator 210 outputs the voltage values V_a , V_b , and V_c to inverter 108 as a pulse-width-modulated (PWM) signal. Modulator 116 outputs the PWM signal with a frequency, angle, and/or duty cycle to provide suitable power to electric motor 102.

In the exemplary embodiment, controller 106 is configured to control electric motor 102 to produce torque when input voltage is one of approaching zero and equal to zero. In controlling electric motor 102, controller 106 is configured to maintain torque of electric motor 102 above a predetermined level when input voltage is zero. More specifically, in the exemplary embodiment, controller 106 is configured to control current flowing to electric motor 102 such that electric motor 102 produces torque when input voltage is one of approaching zero and equal to zero.

In one embodiment, to control current flowing to electric motor 102, controller 106 is configured to induce the flux linkage component I_d of the current to maintain the torque component I_q of the current above zero while reducing loss of energy stored in the stator windings of electric motor 102. In another embodiment, to control current flowing to electric motor 102, controller 106 is configured to induce the flux linkage component I_d of the current to maintain the torque component I_q of the current above zero while reducing torque ripple in electric motor 102. In yet another embodiment, to control current flowing to electric motor 102, controller 106 is configured to induce the flux linkage component I_d of the current to maintain the torque component I_q of the current above zero while manipulating torque harmonics to reduce audible noise in electric motor 102.

In the exemplary embodiment, controller 106 is implemented in one or more processing devices, such as a microcontroller, a microprocessor, a programmable gate array, a reduced instruction set circuit (RISC), an application specific integrated circuit (ASIC), etc. Accordingly, in this exemplary embodiment, d-q conversion module 202, current command generator 204, PI controller 206, a-b-c conversion module 208, and

modulator 210 are constructed of software and/or firmware embedded in one or more processing devices. In this manner, controller 106 is programmable, such that instructions, intervals, thresholds, and/or ranges, etc. may be programmed for a particular electric motor 102 and/or operator of electric motor 102. One or more of d-q
5 conversion module 202, current command generator 204, PI controller 206, a-b-c conversion module 208, and modulator 210 may be wholly or partially provided by discrete components, external to one or more processing devices.

Figure 3 is an operational diagram of motor controller 100 in which inertial energy may be stored on electric motor 102. Figure 4 illustrates a graphical relationship
10 between rail voltage 400, torque 402 produced by rotation of electric motor 102, and rotational speed 404 of load 112. Motor controller 100 is substantially similar to motor controller 100 (shown in Figure 1), and as such, components shown in Figures 3 and 4 are labeled with the same reference numbers used in Fig. 1.

An increase in input voltage to motor controller 100 results in an increase in
15 armature current. The increase in armature current results in an increase in torque production by electric motor 102, resulting in increased acceleration. As rotational speed of electric motor 102 increases, induced voltage on electric motor 102 also increases. As a result, current and torque gradually decrease until torque again equals the load or induced voltage equals the applied voltage. A decrease in voltage results in
20 a decrease of armature current and a decrease in torque produced by electric motor 102, causing electric motor 102 to slow down. Induced voltage may momentarily be higher than the applied voltage, causing regenerative braking in electric motor 102.

Because only a small capacitor 114 is used in motor controller 100, large amounts of voltage are not be stored on the DC link of motor controller 100. Rather, in
25 the exemplary embodiment, motor controller 100 stores energy on rotational load 112, which is coupled to a rotatable shaft (not shown) of electric motor 102. More specifically, in the exemplary embodiment, load 112 is a mechanical energy storage device. For example, in one embodiment, load 112 may be a blower and/or fan used in an air moving control system.

During operation, in the exemplary embodiment, rectifier 104 rectifies the AC line input voltage received from power supply 110 into a pulsed AC. When AC line input voltage is available (i.e., increasing in graph 400), controller 106 is configured to store energy in rotating load 112 at inertia. More specifically, when input voltage is available, the torque increases (graph 402), causing the rotational speed (graph 404) of load 112 to also increase, as is shown in Figure 4. Inertia stored on rotating load 112 is represented by the equation $\frac{J*\Delta\omega^2}{2}$, where J represents inertia of load 112 and $\Delta\omega$ represents a change in speed of load 112 with respect to time. In the exemplary embodiment, the inertia of load 112 limits speed variations of electric motor 102, which enables torque production to continue when input voltage is unavailable.

In one embodiment, while input voltage is available, processing unit also stores small amounts of voltage in capacitor 114. When the AC line input voltage approaches zero, controller 106 controls capacitor 114 to provide the stored voltage to electric motor 102. The amount of energy stored in capacitor 114 is represented by the equation $\frac{C*\Delta U^2}{2}$, where C represents a capacitance of capacitor 114 and ΔU represents a change in voltage in capacitor 114 with respect to time.

As the input voltage begins to drop, torque produced on load 112 by electric motor 102 turns into rotational speed. As AC line input voltage approaches zero, controller 106 manages energy transfer from load 112 to electric motor 102 (represented by dashed arrows). More specifically, controller 106 controls current flowing to electric motor 102 such that electric motor 102 continues producing torque when input voltage to electric motor 102 approaches zero or equals zero. To do so, controller 106 implements an algorithm (shown in Figure 2) to produce a signal that induces a flux linkage component of current to maintain a torque component of the current above zero. More specifically, controller 106 injects a negative d-axis current signal to electric motor 102 as AC line input voltage approaches zero to maintain q-axis current at a positive level. In an alternative embodiment, controller 106 also manages energy transfer from capacitor 114 to electric motor 102 (represented by dashed arrows). These energy transfers enable electric motor 102 to operate while input voltage is low or unavailable during each phase of the pulsed DC.

Figure 5 illustrates multiple performance benefits achieved by using motor controller 100 (shown in Figure 1) as opposed to using known motor controllers (not shown) using large electrolytic capacitors. Performance of known motor controller using 1000 μF electrolytic filter capacitors is represented by the line containing diamonds. Performance of motor controller 100 using a 10 μF capacitor 114 (shown in Figure 1) is represented by the line containing squares; using a 5 μF capacitor 114 is represented by the line containing triangles; and using a 1 μF capacitor 114 is represented by the line containing "X's".

Graph 500 compares power factor of electric motor 102 (shown in Figure 1) to different power levels of electric motor 102. The power factor of electric motor 102 using motor controller 100 is noticeably higher than the power factor of an electric motor using known electrolytic capacitor motor controllers, regardless of which capacitance of capacitor 114 is used.

Graph 502 compares input current to operating power of electric motor 102. Input current is inversely related to the power factor shown in graph 500. Graph 502 shows that electric motor 102 with motor controller 100 operates at the same power level, while using less input current than known motor controllers.

Graph 504 compares total harmonic distortion (THD) to electric motor 102 operating power. In the exemplary embodiment, THD using motor controller 100 is reduced by approximately 50% over THD using known motor controllers.

Graph 506 compares efficiency of electric motor 102 to operating power. Motor controller 100 does not filter the rectified AC line input voltage, so current levels in motor controller 100 are large compared to known motor controllers. Accordingly, up to about 6% efficiency may be sacrificed using motor controller 100. However, this decrease in efficiency is acceptable in some applications when compared to the increased power factor, reduced THD, and reduced size of motor controller 100.

Figure 6 is a functional diagram of an exemplary embodiment of a motor controller 600. Components of motor controller 600 that are identical to components of

motor controller 100 (shown in Figure 1) are described using the same reference characters as in Figure 1.

In the exemplary embodiment, motor controller 600 includes rectifier 104, controller 106, and inverter 108. Motor controller 600 is coupled to power supply 110 for receiving input power to drive electric motor 102. Electric motor 102 is coupled to and drives a load 112. Controller 106 implements the algorithm described in Figure 2.

In the exemplary embodiment, power supply 110 supplies a single-phase alternating current (AC) voltage to motor controller 600. However, power supply 110 may supply three-phase AC, DC voltage, or any other type of input voltage that enables motor controller 600 to function as described herein. Rectifier 104 receives an AC input voltage from power supply 110 and rectifies it to produce a pulsed DC voltage. Inverter 108 conditions the pulsed DC voltage, and supplies it to electric motor 102, which uses the power to drive load 112. In the exemplary embodiment, inverter 108 converts the pulsed DC voltage to a three-phase AC voltage. Alternatively, inverter 108 converts the pulsed DC voltage to any type of voltage that enables motor controller to function as described herein.

In the exemplary embodiment, motor controller 600 includes capacitor 114 for storing small amounts of energy when input voltage is available. Capacitor 114 has a capacitance between about $0.1 \mu\text{F}/\text{kW}$ and about $10 \mu\text{F}/\text{kW}$. The use of bulky, unreliable electrolytic filter capacitors in motor controller 600 is avoided. In some embodiments, capacitor 114 is configured to filter out switching frequency harmonics of electric motor 102. In other embodiments, the low-capacitance of capacitor 114 reduces inrush input current to electric motor 102. Further, capacitor 114 facilitates motor controller 600 increasing line input power factor. Voltage sensor 116 (shown in FIG. 1) may also be provided across capacitor 114 for measuring DC link voltage being output by rectifier 104. Voltage sensor 116 provides the DC link voltage measurement to controller 106 for use in controlling electric motor 102 to produce torque when DC link voltage has a 100% voltage ripple.

In the exemplary embodiment, motor controller 600 also includes a voltage clamping device 602 coupled across a DC link of motor controller 600. Voltage

delivered to inverter 108 may be very large due to the low-capacitance of capacitor 114, which may cause the rating of inverter 108 to be exceeded. Voltage clamping device 602 is configured to protect motor controller 600 from over-voltage conditions. In the exemplary embodiment, voltage clamping device 602 is a metal oxide varistor (MOV).

5 In alternative embodiments, voltage clamping device 602 may be any device capable of providing over-voltage protection.

Figure 7 is a functional diagram of an exemplary embodiment of a motor controller 700. Components of motor controller 700 that are identical to components of motor controller 100 (shown in Figure 1) are described using the same reference

10 characters as in Figure 1.

In the exemplary embodiment, motor controller 700 includes rectifier 104, controller 106, and inverter 108. Motor controller 700 is coupled to power supply 110 for receiving input power to drive electric motor 102. Electric motor 102 is coupled to and drives a load 112. Controller 106 implements the algorithm described in Figure 2.

15 In the exemplary embodiment, power supply 110 supplies a single-phase AC voltage to motor controller 700. However, power supply 110 may supply three-phase AC, DC voltage, or any other type of input voltage that enables motor controller 700 to function as described herein. Rectifier 104 receives an AC input voltage from power supply 110 and rectifies it to produce a pulsed DC voltage. Inverter 108 conditions the

20 pulsed DC voltage, and supplies it to electric motor 102, which uses the power to drive load 112. In the exemplary embodiment, inverter 108 converts the pulsed DC voltage to a three-phase AC voltage. Alternatively, inverter 108 converts the pulsed DC voltage to any type of voltage that enables motor controller to function as described herein.

In the exemplary embodiment, motor controller 700 includes capacitor 114 for

25 storing small amounts of energy when input voltage is available. Capacitor 114 has a capacitance between about $0.1 \mu\text{F}/\text{kW}$ and about $10 \mu\text{F}/\text{kW}$. The use of bulky, unreliable electrolytic filter capacitors in motor controller 700 is avoided. In some embodiments, capacitor 114 is configured to mitigate switching frequency harmonics of electric motor 102. In other embodiments, the low-capacitance of capacitor 114 reduces

30 inrush input current to electric motor 102. Further, capacitor 114 facilitates motor

controller 700 increasing line input power factor. Voltage sensor 116 (shown in FIG. 1) may also be provided across capacitor 114 for measuring DC link voltage being output by rectifier 104. Voltage sensor 116 provides the DC link voltage measurement to controller 106 for use in controlling electric motor 102 to produce torque when DC link voltage has a 100% voltage ripple.

In the exemplary embodiment, motor controller 700 also includes a diode 702 coupled in series with a capacitor 704. Diode 702 and capacitor 704 are coupled to the DC side of rectifier 104. Diode 702 isolates input line voltage as it drops to zero. Together, diode 702 and capacitor 704 provide a constant voltage to be delivered to a low-voltage power supply 706. In the exemplary embodiment, low-voltage power supply 706 provides power for electronics of motor controller 700, such as, for example, controller 106. Additionally, capacitor 704 makes power supply 706 independent of main DC voltage variations in motor controller 700.

Figure 8 is a functional diagram of an exemplary embodiment of a motor controller 800. Components of motor controller 800 that are identical to components of motor controller 100 (shown in Figure 1) are described using the same reference characters as in Figure 1.

In the exemplary embodiment, motor controller 800 includes rectifier 104, controller 106, and inverter 108. Motor controller 800 is coupled to power supply 110 for receiving input power to drive electric motor 102. Electric motor 102 is coupled to and drives a load 112. Controller 106 implements the algorithm described in Figure 2.

In the exemplary embodiment, power supply 110 supplies a single-phase AC voltage to motor controller 800. However, power supply 110 may supply three-phase AC, DC voltage, or any other type of input voltage that enables motor controller 800 to function as described herein. Rectifier 104 receives an AC input voltage from power supply 110 and rectifies it to produce a pulsed DC voltage. Inverter 108 conditions the pulsed DC voltage, and supplies it to electric motor 102, which uses the power to drive load 112. In the exemplary embodiment, inverter 108 converts the pulsed DC voltage to a three-phase AC voltage. Alternatively, inverter 108 converts the pulsed DC voltage to any type of voltage that enables motor controller to function as described herein.

In the exemplary embodiment, motor controller 800 includes capacitor 114 for storing small amounts of energy when input voltage is available. Capacitor 114 has a capacitance between about 0.1 $\mu\text{F}/\text{kW}$ and about 10 $\mu\text{F}/\text{kW}$. The use of bulky, unreliable electrolytic filter capacitors in motor controller 800 is avoided. In some
5 embodiments, capacitor 114 is configured to filter out switching frequency harmonics of electric motor 102. In other embodiments, the low-capacitance of capacitor 114 reduces inrush input current to electric motor 102. Further, capacitor 114 facilitates motor controller 800 increasing line input power factor. Voltage sensor 116 (shown in FIG. 1) may also be provided across capacitor 114 for measuring DC link voltage being output
10 by rectifier 104. Voltage sensor 116 provides the DC link voltage measurement to controller 106 for use in controlling electric motor 102 to produce torque when DC link voltage has a 100% voltage ripple.

In the exemplary embodiment, motor controller 800 also includes a second rectifier 802 coupled in parallel to a capacitor 804. Second rectifier 802 and capacitor
15 804 are coupled between power supply 110 and rectifier 104. Together, second rectifier 802 and capacitor 804 provide a constant voltage to be delivered to a low-voltage power supply 806. In the exemplary embodiment, low-voltage power supply 806 provides power for electronics of motor controller 800, such as, for example, controller 106.

Figure 9 is a flow chart 900 of a method of operating an electric motor, such as
20 electric motor 102 (shown in Figure 1) using motor controller 100 (shown in Figure 1). In the exemplary embodiment, electric motor 102 is coupled to a load 112 (shown in Figure 1) and to a power supply, such as power supply 110 (shown in Figure 1).

In the exemplary embodiment, motor controller 100 receives 902 a measured amount of current in electric motor 102. The amount of current is measured by at least
25 one current sensor 200 (shown in Figure 2) coupled to electric motor 102 and to motor controller 100.

In the exemplary embodiment, motor controller 100 then controls 904 current flowing to electric motor 102 such that electric motor 102 produces positive torque when input voltage is one of approaching zero and equal to zero.

In one embodiment, to control current flowing to electric motor 102, controller 106 induces a flux linkage component I_d of the current to maintain a torque component I_q of the current above zero while reducing loss of energy stored in the stator windings of electric motor 102.

5 In another embodiment, to control current flowing to electric motor 102, controller 106 is configured to induce the flux linkage component I_d of the current to maintain the torque component I_q of the current above zero while reducing torque ripple in electric motor 102.

10 In yet another embodiment, to control current flowing to electric motor 102, controller 106 is configured to induce the flux linkage component I_d of the current to maintain the torque component I_q of the current above zero while manipulating torque harmonics to reduce audible noise in electric motor 102.

Figure 10 is a block diagram of an exemplary embodiment of motor controller 100 shown in Figure 1 in an air moving control system 1000. System 1000 is an air moving system, such as a residential heating, ventilation and air conditioning (HVAC) system, a light industrial HVAC system, or a clean room filtering system. While described herein as being used in an HVAC system, motor controller 100 may be used in other applications, including, but not limited to, swimming pool pumps, laundry machine motors, and gas pre-mix motors. System 1000 includes an interface circuit 1002 electrically coupled to a system controller 1004, for example a HVAC system controller, and a main unit 1006, for example a HVAC unit. Main unit 1006 includes components 1008 and electric motor 1010. In one embodiment, electric motor 1010 is a motor configured to rotate a blower. Electric motor 1010 includes motor controller 100 including a processing unit (shown in Figure 2) and a memory (not shown) containing an electric motor drive program. In one embodiment, system controller 1004 is connected to a thermostat 1012. Thermostat 1012 includes a plurality of settings, or modes, such as low heat, high heat, cooling, dehumidify, and continuous fan. Additionally, thermostat 1012 measures a temperature in a predetermined space or location and transmits an electrical signal representing the measured temperature to system controller 1004.

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System controller 1004 controls main unit 1006 via interface circuit 1002. Interface circuit 1002 receives control signals in the form of input voltage signals from system controller 1004 and translates the signals to signals suitable for controlling by electric motor 1010. Typically, circuits within system 1000 operate at a different
5 voltage level than does electric motor 1010. Therefore interface circuit 1002 is utilized for communications between system controller 1004 and electric motor 1010. Such interfaces typically control electric motors using pulse width modulation (PWM) by continuously adjusting motor speed.

The translated signals are transmitted to motor controller 100 of electric motor
10 1010, and a torque of electric motor 1010 is varied in accordance with the adjusted voltage outputs. Electric motor 1010 is mechanically connected to a blower 1014. In one embodiment, blower 1014 includes a detection module 1016 which provides signals, for example signals indicative of a speed of rotation of blower 1014, to system controller 1004.

15 In operation, as motor controller 100 varies the torque of electric motor 1010, controller 106 monitors and manages energy storage on a load 112 (shown in Figure 1). In the exemplary embodiment, load 112 is blower 1014. The torque applied to electric motor 1010 translates into rotational speed of blower 1014. When input voltage is available, mechanical energy in the form of inertia of blower 1014 is stored. When
20 input voltage becomes low or approaches zero, controller 106 manages energy transfer from blower 1014 back to electric motor 1010.

The described embodiments provide a cost savings to the manufacturer and ultimately to the consumer as electrolytic filter capacitors are eliminated from a motor controller of an electric motor. Additionally, reliability of such systems increases as
25 there are fewer components within the system. Moreover, the described embodiments reduce total harmonic distortion and increase the power factor of the electric motor in which they are installed.

A technical effect of the methods and systems described herein may include one or more of: (a) controlling an electric motor to produce torque when DC link

voltage is one of approaching zero and equal to zero; and (b) controlling the electric motor to produce torque when DC link voltage has a 100% voltage ripple.

This written description uses examples to disclose the invention, including the best mode, and also to enable any person skilled in the art to practice the invention, including making and using any devices or systems and performing any incorporated methods. The patentable scope of the invention is defined by the claims, and may include other examples that occur to those skilled in the art. Such other examples are intended to be within the scope of the claims if they have structural elements that do not differ from the literal language of the claims, or if they include equivalent structural elements with insubstantial differences from the literal languages of the claims.

In the claims which follow and in the preceding description of the invention, except where the context requires otherwise due to express language or necessary implication, the word “comprise” or variations such as “comprises” or “comprising” is used in an inclusive sense, i.e. to specify the presence of the stated features but not to preclude the presence or addition of further features in various embodiments of the invention.

It is to be understood that, if any prior art publication is referred to herein, such reference does not constitute an admission that the publication forms a part of the common general knowledge in the art, in Australia or any other country.

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THE CLAIMS DEFINING THE INVENTION ARE AS FOLLOWS:

1. An electric motor controller configured to be coupled to an electric motor, said controller configured to increase energy transfer of the electric motor to a load when alternating current (AC) input voltage is available and to mitigate a reduction in energy transfer from the load to the electric motor to produce torque when direct current (DC) link voltage has a 100% voltage ripple.
2. A controller in accordance with Claim 1, further configured to store energy in a load coupled to the electric motor as inertia when input voltage is available, wherein the inertia limits speed variation of the electric motor.
3. A controller in accordance with Claim 1 or claim 2, wherein said controller is further configured to maintain torque of the electric motor above a predetermined level when input voltage is zero.
4. A controller in accordance with any one of Claims 1 to 3, wherein to control the electric motor, said controller is configured to control current flowing to the electric motor to produce torque when input voltage is one of approaching zero and equal to zero.
5. A controller in accordance with Claim 4, wherein to control current to the electric motor, said controller is configured to induce a direct-axis component of current to maintain a torque component of the current above zero while:
 - reducing stator winding losses in the electric motor; or
 - reducing torque ripple in the electric motor; or
 - manipulating torque harmonics to reduce audible noise in the electric motor.
6. A controller in accordance with any one of the preceding Claims, further comprising a rectifier for rectifying an input voltage.
7. A controller in accordance with Claim 6, further comprising an inverter coupled between said rectifier and the electric motor, said inverter configured to condition the rectified voltage to drive the electric motor.

8. A controller in accordance with Claim 6 or claim 7, further comprising a diode in series with a capacitor, said diode and said capacitor coupled to a DC side of said rectifier, said diode and said capacitor configured to provide a low voltage power supply.
- 5 9. A controller in accordance with any one of Claims 6 to 8, further comprising a second rectifier coupled to a capacitor, said second rectifier coupled in parallel to said rectifier, said second rectifier and said capacitor configured to provide a low voltage power supply.
- 10 10. A controller in accordance with any one of the preceding Claims, further comprising a voltage clamping device coupled across a direct current (DC) link of said controller, said voltage clamping device configured to protect said controller against an over-voltage condition.
- 15 11. A controller in accordance with any one of the preceding Claims, further comprising a capacitor coupled across a DC link, said capacitor configured to mitigate switching frequency harmonics.
12. A controller in accordance with Claim 13, wherein said capacitor has a capacitance between about 0.1 $\mu\text{F}/\text{kW}$ and about 10 $\mu\text{F}/\text{kW}$.
- 20 13. A method of controlling an electric motor using a motor controller, the electric motor configured to be coupled to a power supply and to a load, said method comprising:
increasing energy transfer of the electric motor to the load when AC input voltage is available;
mitigating a reduction in energy transfer from the load to the electric motor to produce torque when direct current (DC) link voltage is one of approaching zero and
25 equal to zero.
14. A method in accordance with Claim 13, further comprising maintaining torque of the electric motor above a predetermined level when input voltage is zero.

15. A method in accordance with Claim 13 or claim 14, wherein controlling the electric motor comprises controlling current flowing to the electric motor to produce torque when input voltage is one of approaching zero and equal to zero.
16. A method in accordance with Claim 15, wherein controlling current flowing to the electric motor comprises inducing a direct-axis component of current to maintain a torque component of the current above zero while:
- reducing stator winding losses in the electric motor; or
 - reducing torque ripple; or
 - manipulating torque harmonics to reduce audible noise.
17. An air moving system comprising:
- an electric motor;
 - a load coupled to said electric motor; and
 - a controller coupled to said electric motor, said controller configured to increase energy transfer of the electric motor to a load when alternating current (AC) input voltage is available and to mitigate a reduction in energy transfer from the load to the electric motor to produce torque when direct current (DC) link voltage is one of approaching zero and equal to zero.
18. A system in accordance with Claim 17, wherein said controller is further configured to maintain torque of said electric motor above a predetermined level when input voltage is zero.
19. A system in accordance with Claim 17 or claim 18, wherein to control said electric motor, said controller is configured to control current flowing to said electric motor to produce torque when input voltage is one of approaching zero and equal to zero.
20. A system in accordance with Claim 19, wherein to control current to said electric motor, said controller is configured to induce a direct-axis component of current to maintain a torque component of the current above zero while:
- reducing stator winding losses in said electric motor; or
 - reducing torque ripple in said electric motor; or

manipulating torque harmonics to reduce audible noise in said electric motor.

21. An electric motor controller, method of controlling an electric motor or an air moving system substantially as hereinbefore described with reference to the accompanying drawings.

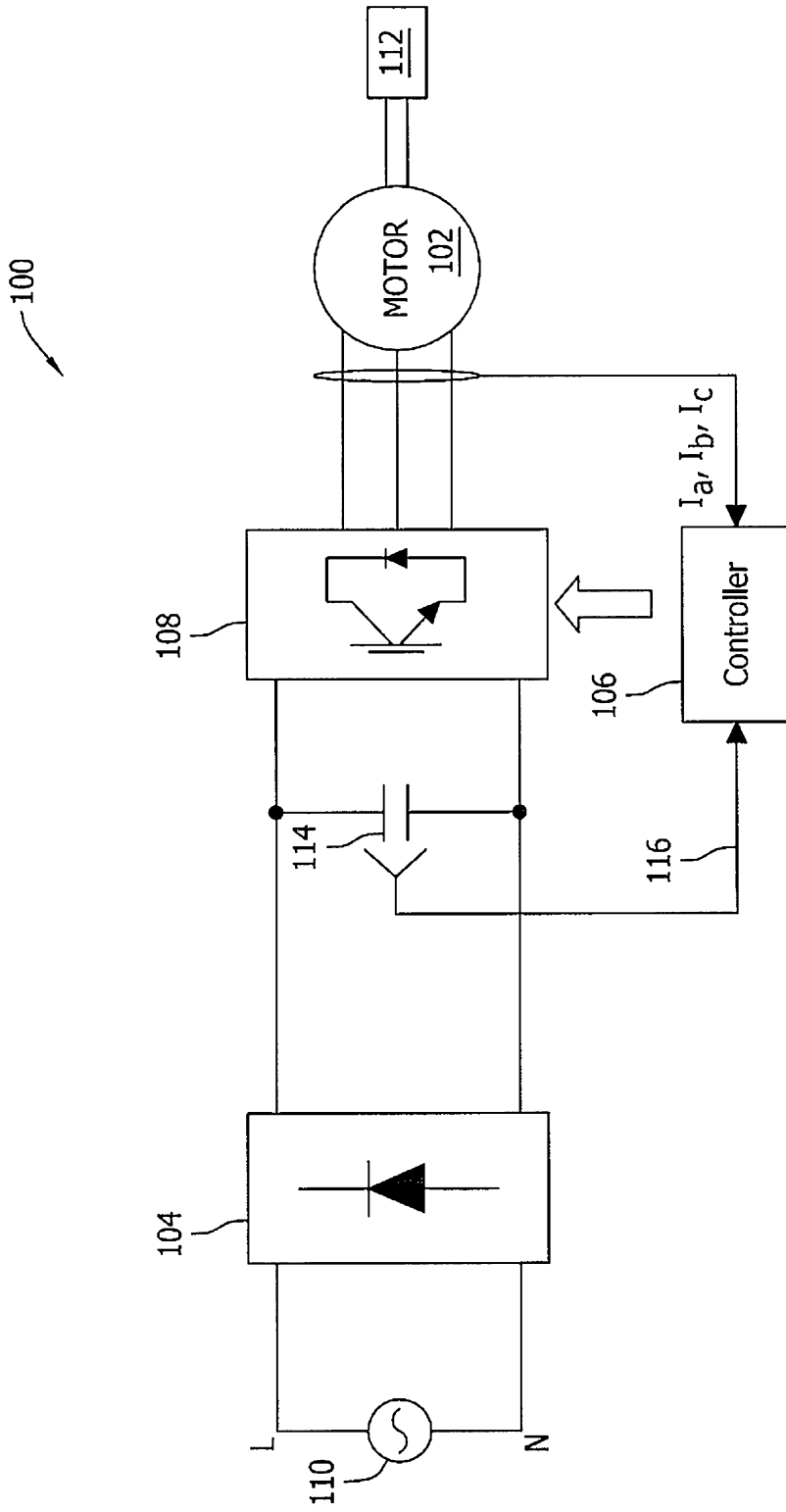


FIG. 1

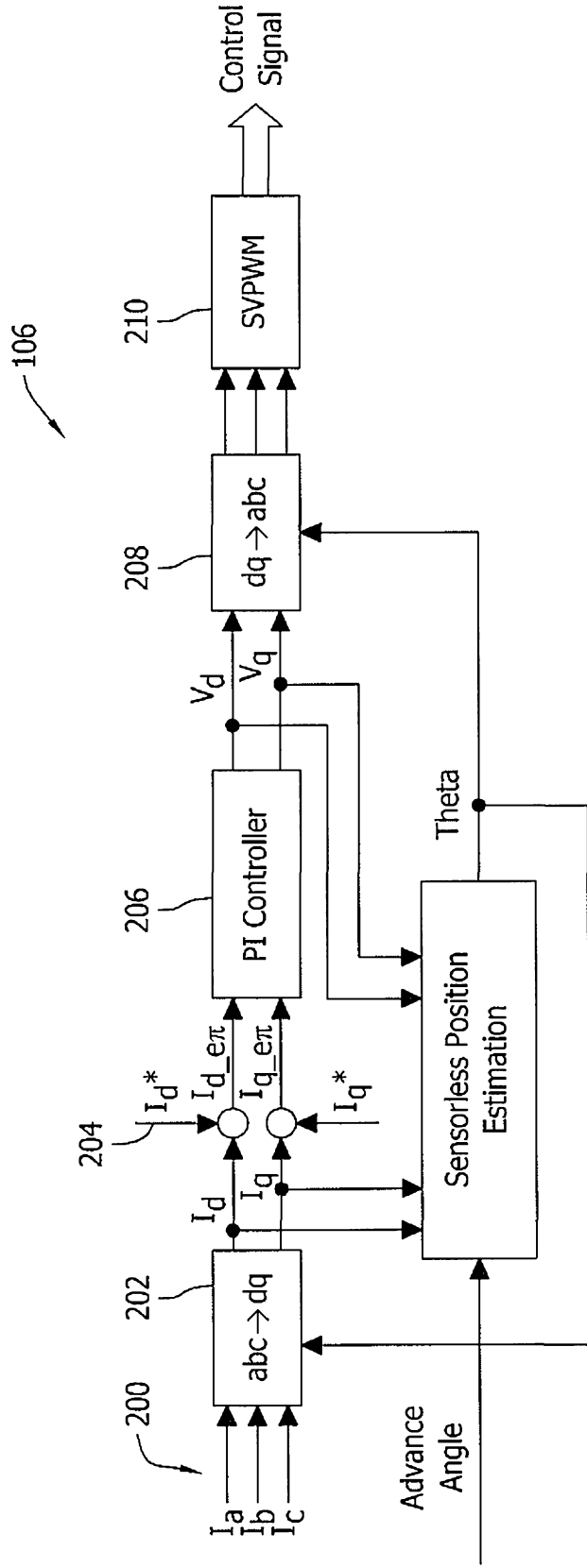


FIG. 2

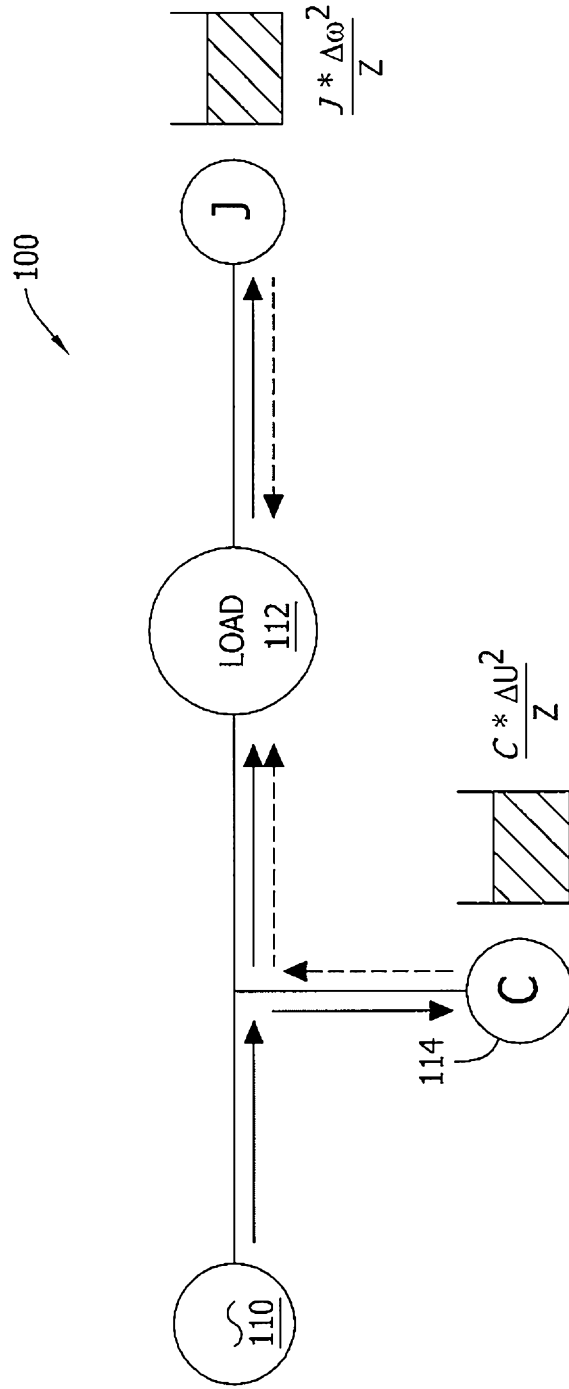


FIG. 3

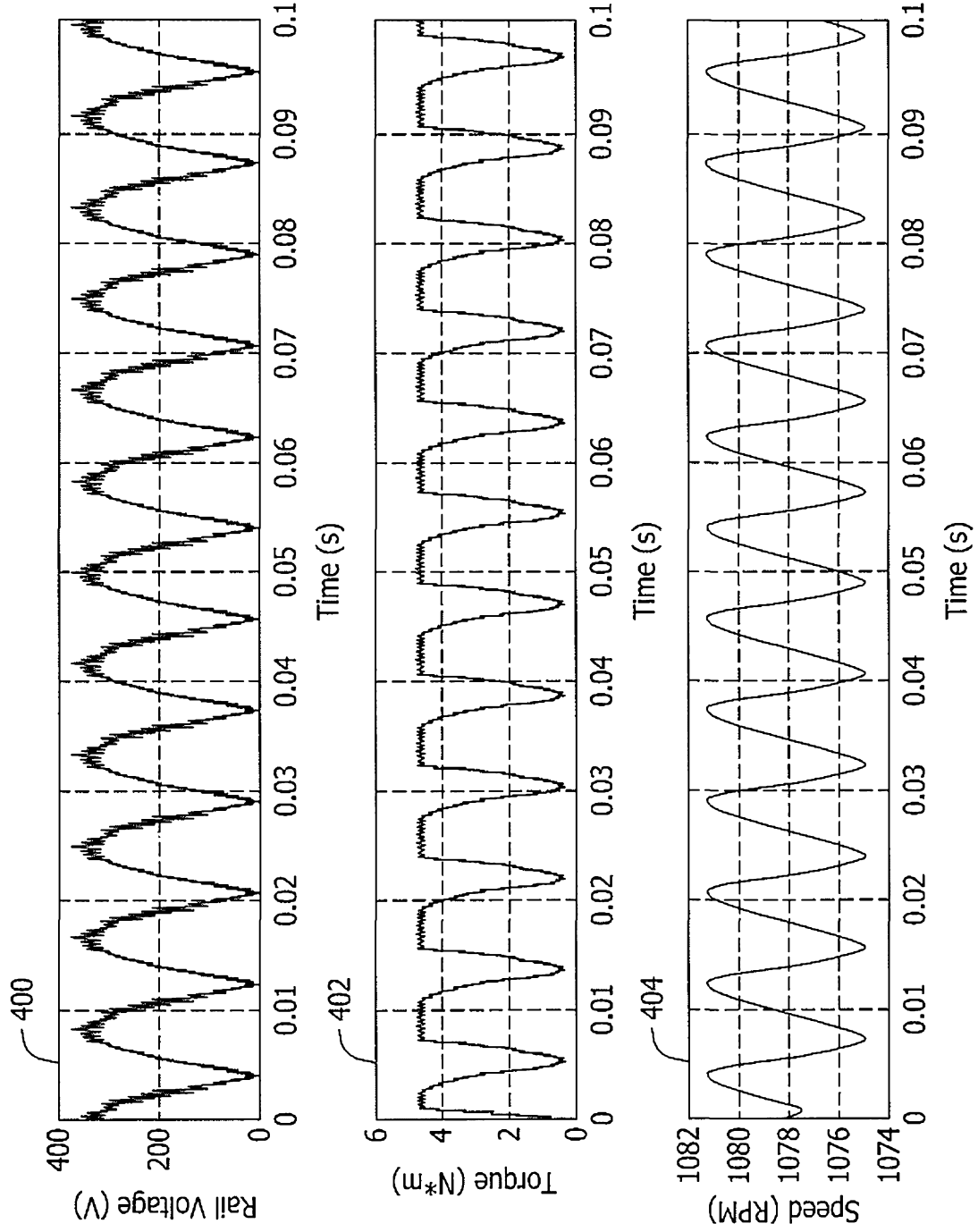


FIG. 4

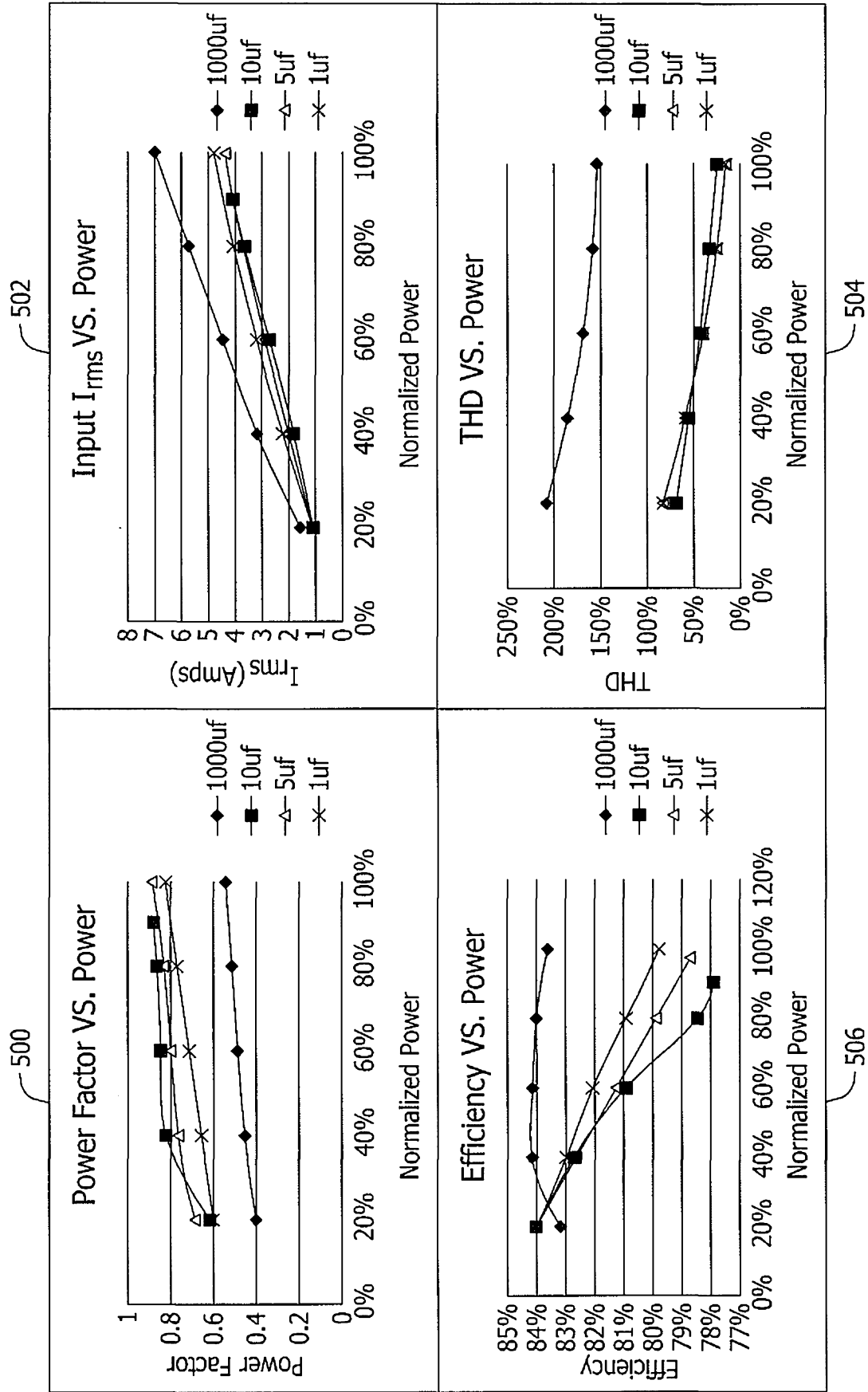


FIG. 5

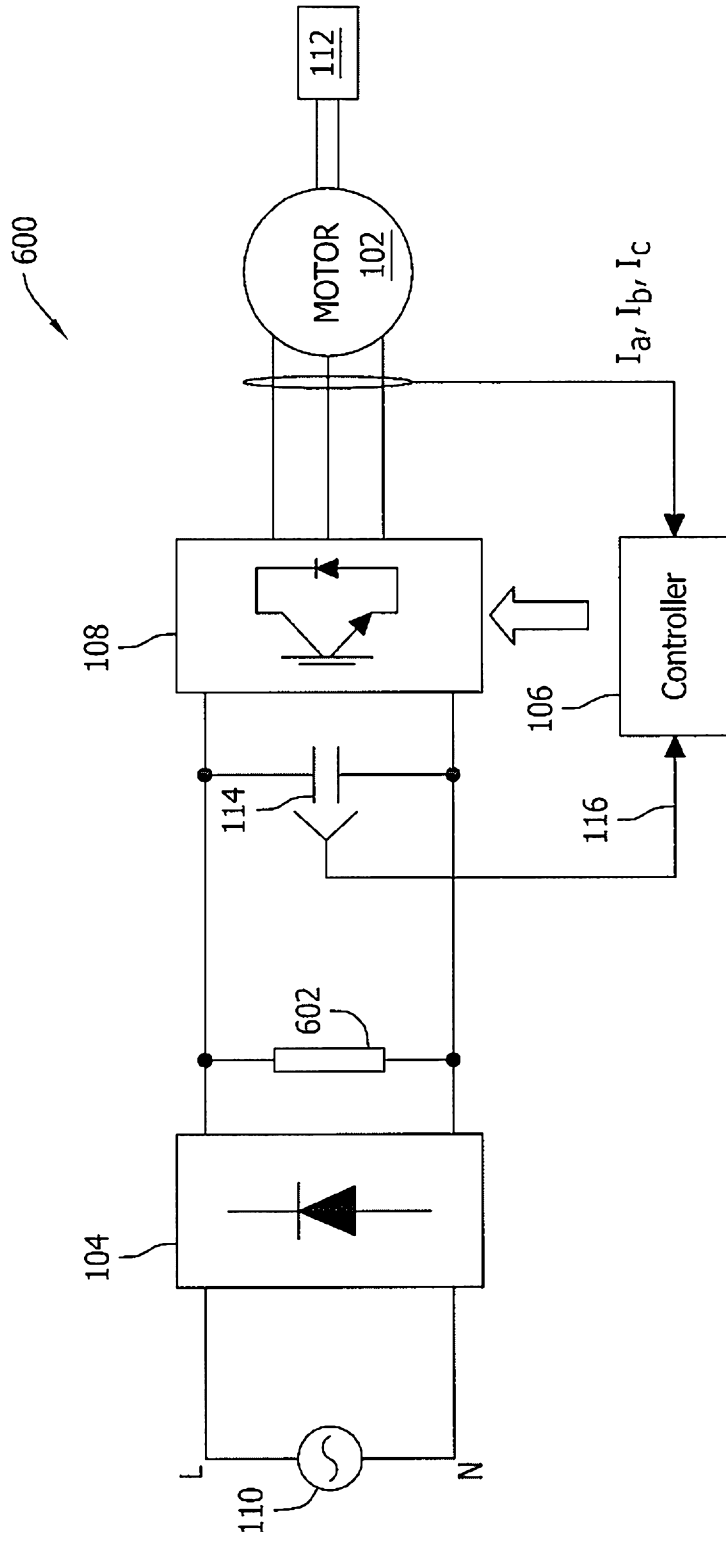


FIG. 6

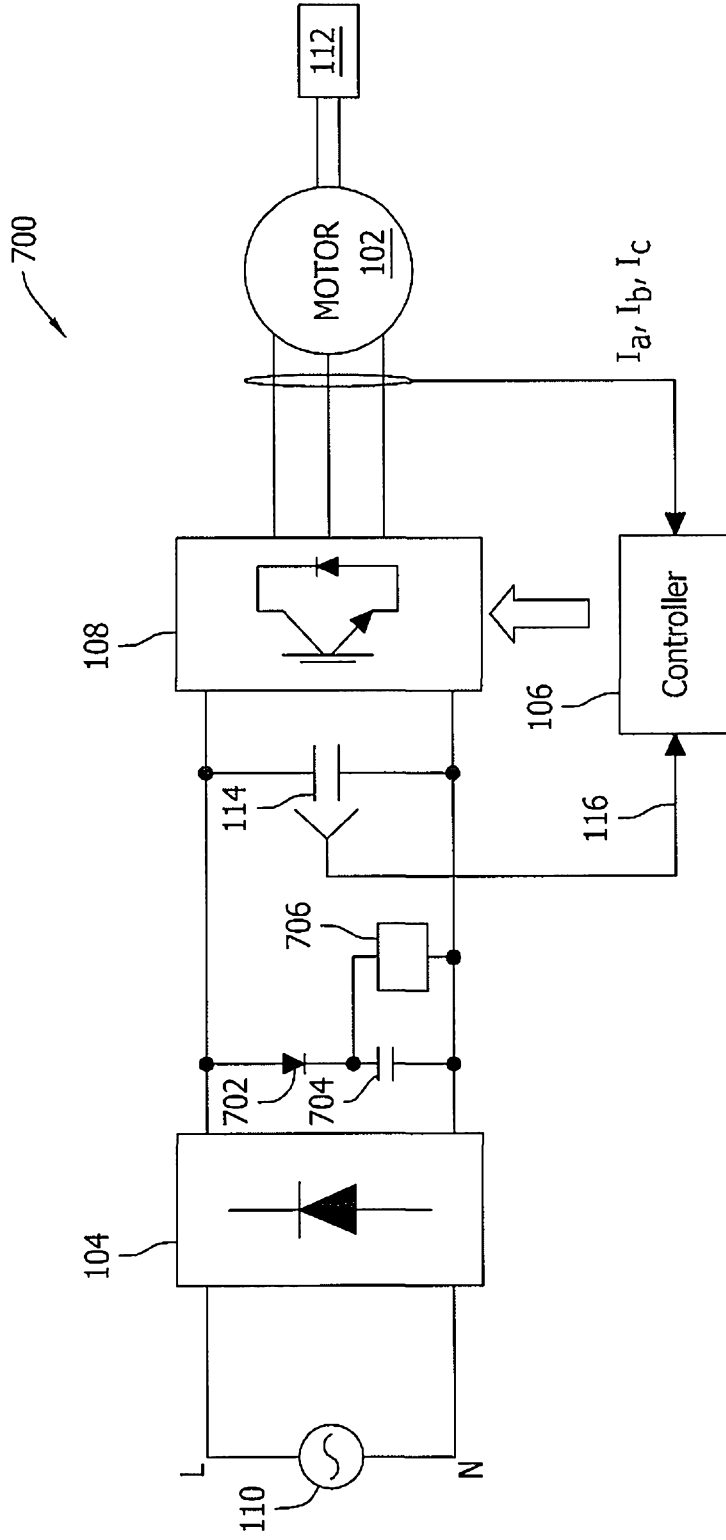


FIG. 7

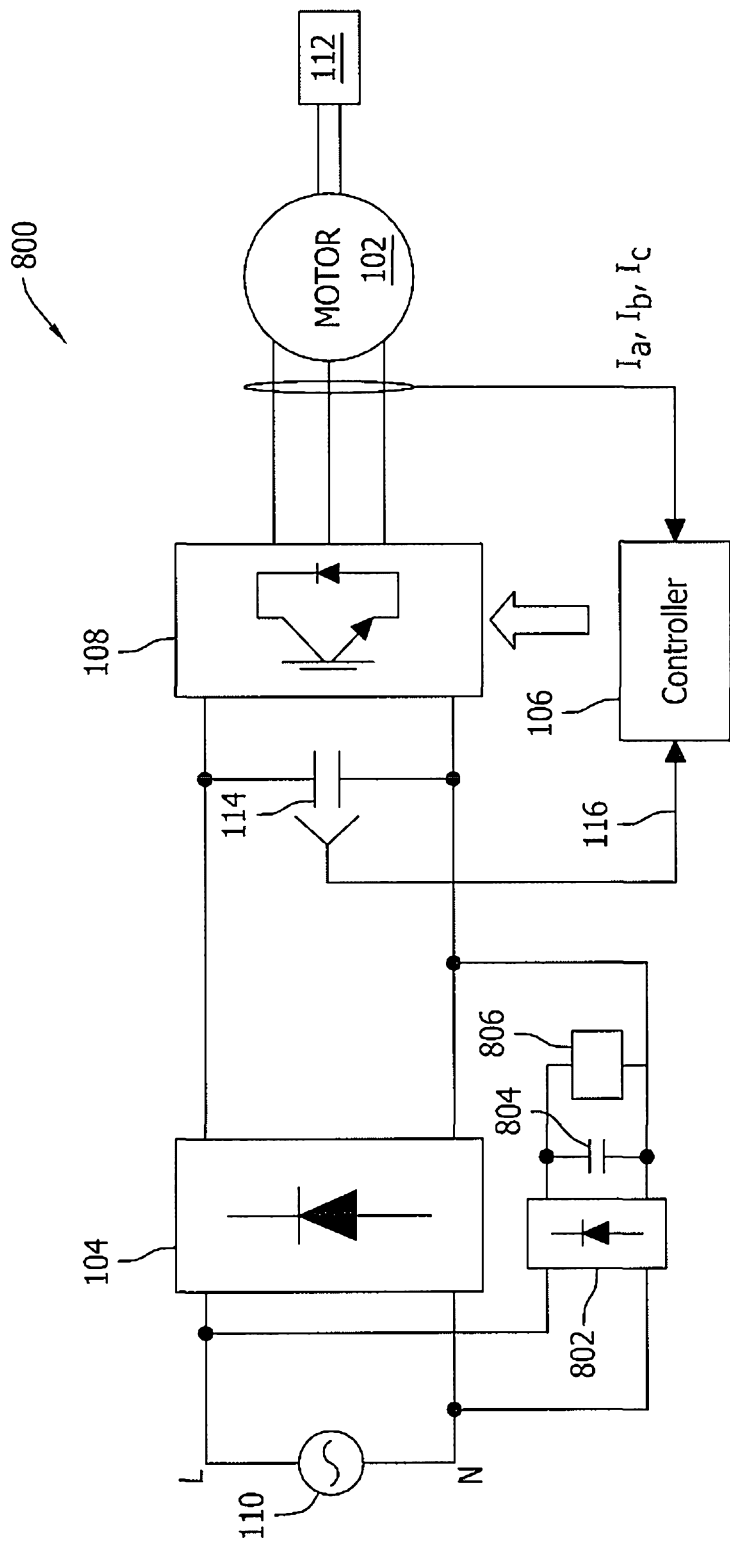


FIG. 8

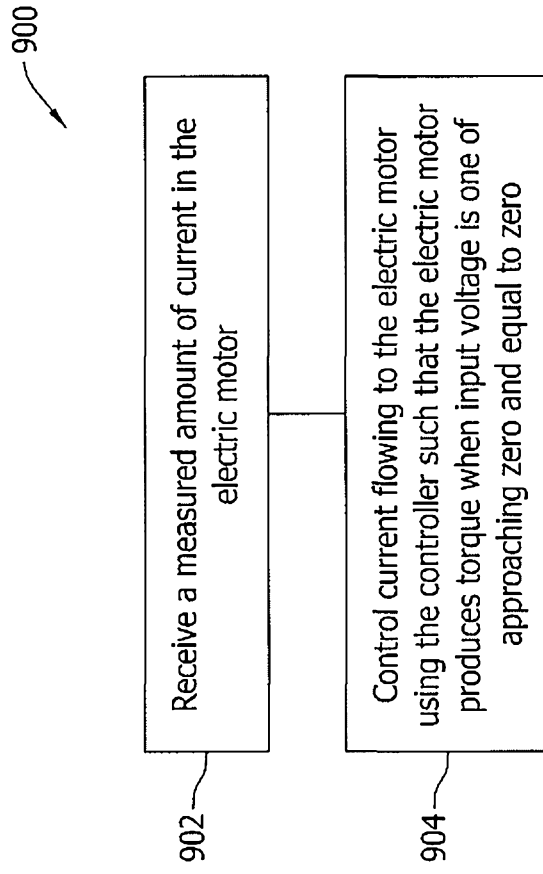


FIG. 9

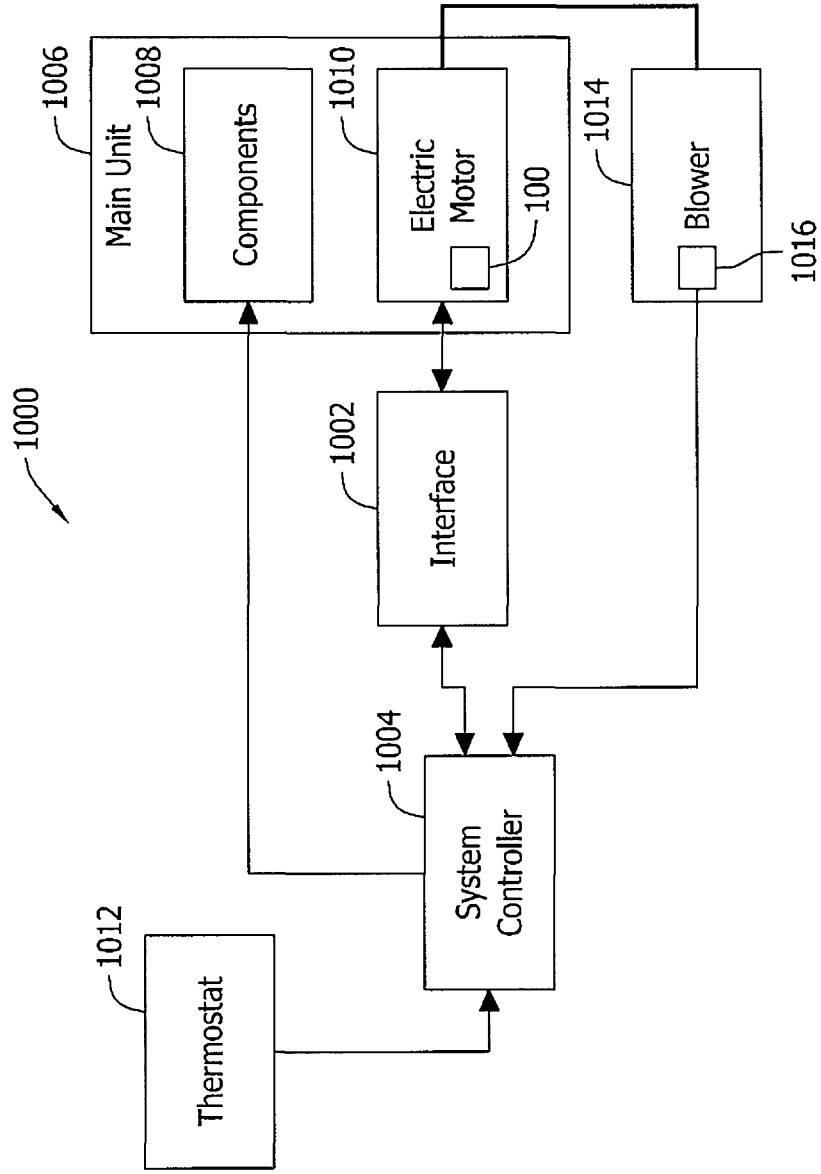


FIG. 10