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(54) **CONTROL SYSTEM AND CONTROL METHOD**

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Description

TECHNICAL FIELD

[0001] The invention relates to a control system for controlling a single phase induction motor. Further, the invention relates to a respective electric drive system and a respective control method.

BACKGROUND

[0002] There exist various types of electric motors. A commonly used type of electric motor is for example the single phase induction motor. Such electric motors require only a single phase of AC supply voltage to provide a rotational movement on the shaft of the motor. Further, such motors comprise mechanically simple arrangements. Single phase induction motors are therefore used in a plurality of applications, like white goods, compressors of e.g. air conditioning devices or the like.

[0003] Since only a single-phase AC supply voltage is provided to single phase induction motors, these motors usually comprise a main winding and a smaller auxiliary winding. While the main winding is supplied with the unmodified single-phase AC supply voltage, the auxiliary winding is supplied with a delayed supply voltage. For example a capacitor may be provided in the supply line of the auxiliary winding to delay the AC supply voltage for the auxiliary winding.

[0004] To start certain motors (e.g. compressor motors) a sufficient starting torque may be required. To increase the starting torque an additional start capacitor may be provided. Such motors may be called CSCR (Capacitor Start Capacitor Run) single phase motors with start capacitor. However, a high starting torque usually also requires or causes a high inrush current.

[0005] Document "Soft starting control of single-phase induction motor using PWM AC Chopper control technique" by Thanyaphirak Veera et al. discloses a soft starting control scheme of a capacitor start and run type single-phase induction motor using a PWM AC Chopper control technique. Document "PWM AC chopper control of single-phase induction motor for variable-speed fan application" by Yildirim D. et al discloses a variable speed control method for fan applications, where a PWM AC chopper changes the effective value of the supply voltage applied to a single-phase induction motor.

[0006] Accordingly, there is a need for reducing the inrush current in electric motors during start of the electric motor.

SUMMARY OF THE INVENTION

[0007] The present invention provides a control system with the features of claim 1, and a control method with the features of claim 7.

[0008] The present invention is based on the finding, that the starting torque produced by a single phase induction motor is mainly influenced by the current through the main winding of the single phase induction motor. The present invention therefore aims at providing a high current in the main winding while at the same time reducing the inrush current to the single phase induction motor during start of the single phase induction motor.

[0009] To this end the present invention provides controllable switches in the supply line of the main winding of the single phase induction motor and in parallel to the main winding. The switches may be controlled in an alternating manner during the single half-waves of the single phase AC supply voltage that is provided to the single phase induction motor.

[0010] By cutting the supply line with the first bidirectional switching element and providing a freewheeling path for the current through the main winding with the second bidirectional switching element, the control system provides a buck converter like arrangement.

[0011] A buck converter, also called step-down converter, is a power converter which steps down voltage while at the same time stepping up current from its input to its output, i.e. a load. It is understood, that although the described arrangement does not comprise an explicit load, the main winding may be seen as the inductor of the buck converter and the load at the same time.

[0012] While the supply line is closed through the first bidirectional switching element, the current through the main winding will begin to increase, and the main inductor will produce an opposing voltage across its terminals in response to the changing current. This voltage drop counteracts the voltage of the source and therefore reduces the voltage across the load, in this case the main winding itself. During this time, the main winding stores energy in the form of a magnetic field.

[0013] When the supply line is then cut by the first switching element the supply voltage will be removed from the circuit, and the current through the main winding will decrease. The main winding acting as inductor of the buck converter arrangement will produce a voltage across the inductor, and now the main winding will become a current source. By closing the second bidirectional switching element, the energy stored in the magnetic field of the main winding may discharge as a current in the freewheeling current path while no current is consumed from the source that provides the single phase AC supply voltage.

[0014] The details of the switching cycle that is used by the control unit may vary according to the application in which the control system is used. For example the switching frequency may e.g. be between 20 kHz and 100 kHz, e.g. 30 kHz, 40 kHz, 50 kHz or more. However, any other adequate switching frequency may be used. The durations of the switching on of the first and the second bidirectional switching element may be fixed, e.g. 30%, 40%, 50%, 60%, or may be controlled by a PWM scheme as will be detailed below.

[0015] The arrangement of the present invention, by alternatingly actuating the first and second bidirectional switching elements, reduces the inrush current at the input of the control circuit, while at the same time increasing the current through the main winding of the single phase induction motor.

[0016] The present invention therefore provides a large motor starting torque and at the same time a high starting current reduction at the supply input. Further, with the arrangement of the present invention, the starting capacitor may be omitted while the high starting torque is provided.

[0017] Common CSCR designs inherently require a start capacitor to generate the initial torque. The present invention in contrast allows starting Capacitor start Capacitor Run (CSCR) without the need of the start capacitor.

[0018] Further embodiments of the present invention are subject of the further subclaims and of the following description, referring to the drawings.

[0019] In an embodiment, the control system may comprise an input filter circuit arranged between the phase supply input of the single phase induction motor and a neutral input of the single phase induction motor.

[0020] The input filter circuit may e.g. be an LC filter that comprises an inductor in the supply line and a capacitor between the supply line and the neutral input. It is understood, that this arrangement is just exemplarily mentioned and that any other adequate filter arrangement may be used.

[0021] With the input filter circuit the high switching harmonics caused by switching the first and second bidirectional switching elements are filtered out and the peak amplitude, which is the peak amplitude of the main winding current, is not propagated to the source of the AC supply voltage.

[0022] In an embodiment, the control system may comprise a bypass switching element arranged between the phase supply input and the main winding.

[0023] The bypass switching element serves for bypassing the first bidirectional switching element. This means that the phase supply input may be connected directly to a terminal of the main winding via the bypass switching element.

[0024] After starting the single phase induction motor, i.e. when the single phase induction motor reaches a settled or running state, it is not necessary any more to further increase the current through the main winding while reducing the inrush current. Therefore, for maximizing efficiency during normal operation, the buck converter arrangement is bypassed and the main winding is used like a standard main winding of a single phase induction motor.

[0025] In an embodiment, the control system may comprise a running capacitor arranged between the phase supply input and the auxiliary winding.

[0026] The running capacitor delays the phase of the single phase AC supply voltage through the auxiliary winding and therefore the build-up of the magnetic field in the auxiliary winding. Usually the auxiliary winding and the main winding will be arranged mechanically in a predefined angle, e.g. 90 °, to each other. Therefore, by providing the auxiliary winding with a voltage that is delayed with respect to the voltage that is provided to the main winding, a rotating magnetic field may be generated in the single phase induction motor.

[0027] In an embodiment, the first bidirectional switching element may comprise two switching elements arranged in common emitter connection or common collector connection, and/or the second bidirectional switching element may comprise two switching elements arranged in common emitter connection or common collector connection. As an alternative the first bidirectional switching element may comprise two parallel reverse blocking transistors, and/or the second bidirectional switching element may comprise two parallel reverse blocking transistors.

[0028] The switching elements may e.g. comprise IGBTs, MOSFETs or the like. Common emitter connection in this regard refers to the emitters of the switching elements being connected to each other. The bases of the switching elements are the control inputs that may be driven by the control unit and the collectors of the switching elements are connected to the respective lines of the control system. The reverse blocking transistors may e.g. be reverse blocking IGBTs or MOSFETs or any other type of reverse blocking switch. It is understood, that any switching element that allows controllably switching the electric current in either one of two directions may be used with the present invention.

[0029] The bidirectional switching elements therefore comprise four terminals, the two collector terminals that provide the power connectors, and the two base terminals that provide the control inputs.

[0030] It is understood, that when transistors like IGBTs are used with opposite polarity, for every half-wave of the single phase AC supply voltage one of the switching elements may be actively controlled, while the antiparallel diode of the respective other switching element bridges the respective other switching element.

[0031] Therefore, the bidirectional switching elements may be used to controllably provide positive and negative current to the main winding of the single phase induction motor and to provide a respective freewheeling path.

[0032] According to the invention, the control system may comprise a current sensor coupled to the control unit and configured to sense the input current to the single phase induction motor at the phase supply input. The control unit may be configured to drive the first bidirectional switching element and the second bidirectional switching element based on the sensed current.

[0033] The switching of the bidirectional switching elements may be adjusted to optimize the inrush current and the starting torque of the single phase induction motor. Since the inrush current should be limited, measuring the input current (i.e. the inrush current during start of the single phase induction motor) allows reacting to an increasing input current and limiting this current.

[0034] As already explained above, the bidirectional switching elements in conjunction with the main winding may be operated as buck converters for the positive half-wave and the negative half-wave of the single phase AC input voltage.

[0035] Therefore, the control unit may start operating the bidirectional switching elements as buck converters when the input current reaches a predetermined threshold value. It is understood, that the predetermined threshold value may define an absolute value that may be valid for the positive and the negative half-wave of the single phase AC input voltage.

[0036] This leads to three current regions. A center current region is the region for which the input current is below the predetermined threshold value. An upper current region is the region for which the input current is positive and the absolute value is above the threshold value. A lower region is the region for which the input current is negative and the absolute value is above the threshold value.

[0037] According to the invention, the control unit may be configured to control the first bidirectional switching element and the second bidirectional switching element in an alternating manner based on a PWM scheme, wherein the control unit may be configured to determine the duty cycle for the PWM scheme based on the measured input current.

[0038] The factor between current increase on the output of a buck converter and the current reduction on the input of the buck converter is determined by the on-time or duty cycle of the switching of the first bidirectional switching element.

[0039] Therefore, in order to limit the inrush current to a predetermined level, the control unit needs to adapt the duty cycle for the switching of the first bidirectional switching element. Since the first and the second bidirectional switching element are switched alternatingly, the duty cycle D_1 of the first bidirectional switching element automatically determines the duty cycle D_2 of the second bidirectional switching element. The duty cycle D_2 of the second bidirectional switching element may be determined as $D_2 = 100\% - D_1$.

[0040] According to the invention, the control unit may comprise an integral controller for determining the duty cycle based on a reference current value and based on the measured supply current.

[0041] A purely integral controller may be used to achieve a stable operation of the control system. The integral controller ensures that the PWM duty cycle does not change rapidly, therefore providing a smooth operation of the control system. This is especially beneficial to avoid the excitation of the LC input filter resonance frequency. The measured supply current of the control system may be used as control variable, since the aim of the control system is to limit the current drawn from the supply.

[0042] The absolute value of the instantaneous supply current may e.g. be compared to a reference current value. The difference between the measured input current absolute value and the reference current value, e.g. called error signal, may be fed into the integral controller. The integral controller may then adjust the duty cycle of the PWM switching of the first and second bidirectional switching elements.

[0043] According to the invention, the control unit may comprise a reference value determination unit configured to determine the reference current value based on a fixed current value and a variable feedback current value, wherein the control unit may be configured to determine the variable feedback current value based on the current duty cycle.

[0044] The reference current value may be provided as a constant value. However, providing the reference current value as a variable value helps in "shaping" the current and provides a more sinusoidal supply current.

[0045] Therefore, the reference current value may be provided as the sum of a constant of fixed current value and a variable feedback value.

[0046] In a purely exemplary embodiment, the fixed current value may be 17 A, a factor for the integral controller may be 120 1/As.

[0047] The duty cycle will therefore be zero when the absolute value of the measured supply current is below the fixed current value. This is the operation in the central current region as explained above. When the duty cycle is zero, the reference current value equals the fixed current value, e.g. 17A. Once the measured supply current exceeds the constant or fixed current value, the error signal increases and the integral controller will gradually increase the PWM duty cycle. Once the duty cycle increases, the variable reference current or variable feedback current increases proportionally.

[0048] Thus, the final reference current value increases when there is an increase in the duty cycle. The controlled supply current will therefore follow the limit set by the fixed current value. The amplitude of the supply current will be gradually limited, thus providing a rather round shape of the supply current. This will produce less harmonics of the supply current and the main winding current. Further, torque pulsations will be reduced.

BRIEF DESCRIPTION OF THE DRAWINGS

[0049] For a more complete understanding of the present invention and advantages thereof, reference is now made to the following description taken in conjunction with the accompanying drawings. The invention is explained in more detail below using exemplary embodiments which are specified in the schematic figures of the drawings, in which:

Fig. 1 shows a block diagram of an embodiment of a control system according to the present invention;
Fig. 2 shows a flow diagram of an embodiment of a control method according to the present invention;
Fig. 3 shows a block diagram of another embodiment of a control system according to the present invention;
Fig. 4 shows a block diagram of a control algorithm for use with an embodiment of a control system according to the present invention;
Fig. 5 shows a diagram of variables in an embodiment of a control system according to the present invention; and
Fig. 6 shows another diagram of variables in an embodiment of a control system according to the present invention.

[0050] In the figures like reference signs denote like elements unless stated otherwise.

DETAILED DESCRIPTION OF THE DRAWINGS

[0051] Fig. 1 shows a block diagram of an embodiment of a control system 100 for a single phase induction motor 150. The single phase induction motor 150 comprises a main winding 151 and an auxiliary winding 152. The single phase induction motor 150 is supplied with electrical energy via a single phase AC source, i.e. via an AC voltage. Such a voltage may for example comprise 230 V with a frequency of 50 Hz or 110 V with a frequency of 60 Hz. However, any other voltage level and frequency is also possible.

[0052] The control system 100 comprises a first bidirectional switching element 101 and a second bidirectional switching element 102. The first bidirectional switching element 101 is arranged between a phase supply input 103 of the single phase induction motor 150 and the main winding 151. The second bidirectional switching element 102 is arranged electrically in parallel to the main winding 151. The ends of the second bidirectional switching element 102 and the main winding 151 that are not coupled to the first bidirectional switching element 101 are coupled to a neutral input 104. A control unit 105 is provided that is coupled to the first bidirectional switching element 101 and the second bidirectional switching element 102 for controlling the first bidirectional switching element 101 and the second bidirectional switching element 102 during a start-up phase of the single phase induction motor 150.

[0053] The first bidirectional switching element 101 and the second bidirectional switching element 102 are switching elements that allow electrical current to flow in both directions, when they are actuated or controlled to be closed. This allows using the first bidirectional switching element 101 and the second bidirectional switching element 102 in AC applications, where the supply voltage comprises positive and negative voltage levels.

[0054] The control unit 105 that is coupled to the first bidirectional switching element 101 and the second bidirectional switching element 102 may e.g. be a microcontroller 105. It is understood, that any other type of control unit is also possible, such a control unit may comprise an ASIC, a FPGA, a CPLD or the like. The control unit 105 may comprise output ports that couple the control unit 105 to the first bidirectional switching element 101 and the second bidirectional switching element 102 to control the switching state of the first bidirectional switching element 101 and the second bidirectional switching element 102. Such outputs may e.g. be logic level outputs with voltage levels of 5 V, or e.g. 3,3 V. It is understood, that either the control unit 105 or the first bidirectional switching element 101 and the second bidirectional switching element 102 may comprise further circuitry, like e.g. resistors and transistors, that couples the control unit 105 to the first bidirectional switching element 101 and the second bidirectional switching element 102.

[0055] For operating the single phase induction motor 150 the single phase induction motor 150 is started in a startup phase until it reaches its operating conditions, i.e. its operating speed or revolutions. In this startup phase the single phase induction motor 150 usually causes a high inrush current that puts a high load on the mains supply network.

[0056] To lower the high inrush current, the control unit 105 may control the first bidirectional switching element 101 and the second bidirectional switching element 102 such that with the main winding 151 they form a type of buck-converter. This buck-converter will reduce the voltage over the main winding 151 and at the same time increase the current through the main winding 151 compared to the voltage and current at the phase supply input 103. With a respective control it is therefore possible to reduce or avoid the inrush current peaks and at the same time increase the current through the main winding 151 that is responsible for producing the starting torque in the single phase induction motor 150.

[0057] To this end, the control unit 105 may alternatingly control during a positive half-wave of the input voltage at the phase supply input 103 the first bidirectional switching element 101 to provide a positive current to the main winding 151 and the second bidirectional switching element 102 to provide a freewheeling current path for the positive current through the main winding 151. This means that while the first bidirectional switching element 101 is closed, the second bidirectional switching element 102 is opened, and vice versa.

[0058] During a negative half-wave of the input voltage at the phase supply input 103 the control unit 105 will control the first bidirectional switching element 101 to provide a negative current to the main winding 151, 251 and the second bidirectional switching element 102 to provide a freewheeling current path for the negative current through the main winding 151, 251. Again, this means that while the first bidirectional switching element 101 is closed, the second bidirectional switching element 102 is opened, and vice versa.

[0059] The amount of current increase and voltage decrease in the main winding 151 compared to the phase supply input 103 may be controlled by the control unit 105 through the switching times of the first bidirectional switching element 101 and the second bidirectional switching element 102. The control unit 105 may e.g. perform a PWM based switching of the first bidirectional switching element 101 and the second bidirectional switching element 102. A specific control scheme will be described with regard to Fig. 5.

[0060] After the single phase induction motor 150 reaches its operating conditions, i.e. after the startup phase, the control unit 105 may permanently open the first bidirectional switching element 101 and permanently close the second bidirectional switching element 102 for normal operation of the single phase induction motor 150. As may be seen in Fig. 3 a bypass for the first bidirectional switching element 101 is also possible.

[0061] For sake of clarity in the following description of the method based Fig. 2 the reference signs used in the description of the apparatus based figures will be maintained.

[0062] Fig. 2 shows a flow diagram of a control method for controlling a single phase induction motor 150, 250 with a main winding 151, 251, with an auxiliary winding 152, 252 and with a running capacitor arranged between a phase supply input 103, 203 and the auxiliary winding 152, 252.

[0063] The control method comprises providing S1 in an alternating manner a positive current to the main winding 151, 251 and a freewheeling current path for the positive current through the main winding 151, 251 during a positive half-wave of a supply voltage of the single phase induction motor 150, 250, and providing S2 in an alternating manner a negative current to the main winding 151, 251 and a freewheeling current path for the negative current through the main winding 151, 251 during a negative half-wave of a supply voltage of the single phase induction motor 150, 250.

[0064] Providing in an alternating manner a positive current to the main winding 151, 251 and a freewheeling current path for the positive current may e.g. be performed with two switching elements 210, 211 arranged in common emitter connection or common collector connection or with two parallel reverse blocking transistors. The same applies to providing in an alternating manner a negative current to the main winding 151, 251 and a freewheeling current path for the negative current. This may be performed with two switching elements 212, 213 arranged in common emitter connection or common collector connection or with two parallel reverse blocking transistors.

[0065] The control method may comprise sensing the input current to the single phase induction motor 150, 250 at the phase supply input 103, 203. Providing in an alternating manner a positive current to the main winding 151, 251 and a freewheeling current path for the positive current and providing in an alternating manner a negative current to the main winding 151, 251 and a freewheeling current path for the negative current may then be performed based on the sensed current.

[0066] Providing in an alternating manner a positive current to the main winding 151, 251 and a freewheeling current path for the positive current and providing in an alternating manner a negative current to the main winding 151, 251 and a freewheeling current path for the negative current may further be performed based on a PWM scheme. The PWM scheme may be based on the measured input current, wherein the duty cycle may be determined with an integral controller 320 based on a reference current value and based on the measured supply current. The reference current value may be determined based on a fixed current value and a variable feedback current value, wherein the variable feedback current value may be determined based on the current duty cycle.

[0067] The control method may further comprise filtering an input voltage between the phase supply input 103, 203 of the single phase induction motor 150, 250 and a neutral input 104, 204 of the single phase induction motor 150, 250.

[0068] Fig. 3 shows a block diagram of another control system 200 for controlling a single phase induction motor 250. The single phase induction motor 250 also comprises a main winding 251 and an auxiliary winding 252. The control system 200 is based on the control system 100 and also comprises a control unit 205 that controls switching elements. However, in the control system 200 the first bidirectional switching element and the second bidirectional switching element are not specifically referenced. Instead, the first bidirectional switching element and the second bidirectional switching element are each represented by two MOSFET-Transistors 210, 211 and 212, 213 in common emitter configuration. A single MOSFET-Transistor is a directional switching element that allows switching a current from the source to the drain with a voltage at the gate that is positive regarding the voltage at the source of the transistor. Current in the other direction may flow via the inherent diode of the MOSFET. Therefore, by arranging two MOSFETs in series with reverse polarity it is possible to controllably switch currents in both directions.

[0069] It is understood, that instead of two MOSFETs in common emitter arrangement other arrangements may be provided. For example IGBTs may be used. Further, a common collector arrangement may be chosen. Further, reverse blocking transistors may be used in a parallel configuration. In addition, although only single MOSFETs 210, 211, 212, 213 are shown, it is understood that every one of the shown MOSFETs may be implemented as a parallel arrangement of two or more MOSFETs or IGBTs or other switching elements.

[0070] In the control system 200 the control unit 205 individually controls the single MOSFETs 210, 211, 212, 213. During a positive half-wave of the input voltage, the control unit 205 will alternatingly control the MOSFETs 210, 212.

During a negative-half wave of the input voltage, the control unit 205 will alternatingly control the MOSFETs 211, 213.

[0071] The control system 200 also comprises a bypass switching element 216 that is arranged in parallel to the MOSFETs 210, 211. This bypass switching element 216 may be used to bypass the MOSFETs 210, 211 during a normal operation of the single phase induction motor 250.

[0072] In addition, the single phase induction motor 250 also comprises an input filter 215 that filters the input voltage and current between the phase supply input 203 and the MOSFETs 210, 211. It can be seen that the bypass switching element 216 also bypasses the input filter 215.

[0073] Fig. 4 shows a block diagram of a control algorithm for use with a control system 300. The output of the control algorithm is a duty cycle d from integral controller 320, that may be used by the control unit 105, 205 to control the first bidirectional switching element 101 and the second bidirectional switching element 102, e.g. the MOSFETs 210, 211, 212, 213.

[0074] Integral controller 320 comprises a proportional element 323 that multiplies an input value with a proportionality factor K_I. An integral element 324 or integrator than integrates over time the output of proportional element 323 to generate the duty cycle d.

[0075] The input to integral controller 320 is generated from the difference of a reference current i_{Ref} and an absolute value of a measured current ABS(i_L), wherein i_L is the current that flows into the single phase induction motor 150, 250 at the phase supply input 103, 203.

[0076] The reference current i_{Ref} is generated in a feedback loop that receives the duty cycle d. A proportional element 322 then multiplies the duty cycle d with factor K1. The output of proportional element 322 is then added to a fixed reference current value $i_{RefFixed}$ to generate the reference current i_{Ref}.

[0077] Possible values for $i_{RefFixed}$, K1, and K_i are:

$i_{RefFixed}$ = 17A
K1 = 34A
K_i = 120 1/As

[0078] It is however understood, that these values are just exemplary values and that the respective values for specific applications may be determined e.g. experimentally or by simulation.

[0079] Fig. 5 shows a diagram of currents over time in a control system 100, 200, 300 according to the present invention.

[0080] In the diagram three regions are marked. The first region 1 comprises currents that are higher than 10 A. The second region 2 comprises currents between 10 A and -10 A. Finally, the third region 3 comprises currents that are lower than -10 A.

[0081] The currents shown are the current i_{Main}, i.e. the current through the main winding, and the current i_2, i.e. the current that flows into the input filter 215 of the control system 200.

[0082] In the diagram it can be seen, that the current i_{Main} comprises a sinusoidal shape. This means that the main winding is supplied with a sinusoidal current. The current reaches levels in region 1 and region 3 that are over the limits of the second region 2.

[0083] In contrast, the current that flows into the input filter is controlled such that it stays within the limits of region 2.

[0084] It can be seen in the diagram of Fig. 5 that with the present invention the inrush current to the single phase induction motor may be limited, while at the same time driving the main winding with a full sinusoidal current.

[0085] Fig. 6 shows a diagram of currents and a diagram of the duty cycle in a control system according to the present invention.

[0086] The current diagram shows the reference current i_{Ref} the supply current i_{supply} and the current in the main winding i_{main}. The supply current i_{supply} is the current that is measured as input value to the controller shown in Fig. 4 and may also be referenced as i_L.

[0087] The lower diagram shows the duty cycle that the controller of Fig. 4 generates for the respective currents as shown in the upper diagram.

[0088] According to the controller schematic as shown in Fig. 4 the duty cycle is zero, when the absolute value of the supply current i_{supply} is lower than the fixed reference current value $i_{RefFixed}$. This is the operation in region 2 as shown in Fig. 5. When the duty cycle d is zero, the reference current i_{Ref} equals the fixed reference current $i_{RefFixed}$, in this case exemplarily 17 A.

[0089] Once the supply current i_{supply} exceeds the reference current i_{Ref}, the error signal in the controller increases and the integral controller will gradually increase the duty cycle. While the duty cycle increases, the variable reference current $i_{RefVariable}$ will increase proportionally and the value of i_{Ref} will also increase. While the duty cycle increases, it can be seen that the supply current i_{supply} follows the limit set by the reference current i_{Ref}. It can also be seen, that the amplitude of the current i_{supply} is gradually limited, giving a rather round shape without sharp corners. This will produce less harmonics in the supply current i_{supply} and will reduce the torque pulsations.

[0090] It should be appreciated that the exemplary embodiment or exemplary embodiments are only examples, and are not intended to limit the scope, applicability, or configuration in any way. Rather, the foregoing summary and detailed description will provide those skilled in the art with a convenient road map for implementing at least one exemplary embodiment, it being understood that various changes may be made in the function and arrangement of elements described in an exemplary embodiment without departing from the scope as set forth in the appended claims.

List of reference signs:

[0091]

100, 200, 300	control system
101	first bidirectional switching element
102	second bidirectional switching element
103, 203	phase supply input
104, 204	neutral input
105, 205	control unit

210, 211, 212, 213	switching element
215	input filter
216	bypass switching element

320	integral controller
321	reference value determination unit
322, 323	proportional element
324	integral element
325	summing point
326	difference point
327	measurement input

150, 250	single phase induction motor
151, 251	main winding
152, 252	auxiliary winding

S1, S2	method steps

Claims

1. Control system (100, 200, 300) for controlling a single phase induction motor (150, 250) with a main winding (151, 251) and with an auxiliary winding (152, 252), the control system (100, 200, 300) comprising:

a first bidirectional switching element (101) and a second bidirectional switching element (102), wherein the first bidirectional switching element (101) is arranged between a phase supply input (103, 203) of the single phase induction motor (150, 250) and the main winding (151, 251) and wherein the second bidirectional switching element (102) is arranged electrically parallel to the main winding (151, 251),
a control unit (105, 205) coupled to the first bidirectional switching element (101) and the second bidirectional switching element (102),
wherein the control unit (105, 205) is configured to control in an alternating manner, during a positive half-wave of a supply voltage of the single phase induction motor (150, 250)

- the first bidirectional switching element (101) to provide a positive current to the main winding (151, 251) and
- the second bidirectional switching element (102) to provide a freewheeling current path for the positive current through the main winding (151, 251), and

wherein the control unit (105, 205) is configured to control in an alternating manner, during a negative half-wave of a supply voltage of the single phase induction motor (150, 250)

- the first bidirectional switching element (101) to provide a negative current to the main winding (151, 251) and

- the second bidirectional switching element (102) to provide a freewheeling current path for the negative current through the main winding (151, 251),

the control system further comprising
a current sensor coupled to the control unit (105, 205) and configured to sense the input current to the single phase induction motor (150, 250) at the phase supply input (103, 203), wherein the control unit (105, 205) is configured to drive the first bidirectional switching element (101) and the second bidirectional switching element (102) based on the sensed current,
wherein the control unit (105, 205) is configured to control the first bidirectional switching element (101) and the second bidirectional switching element (102) in an alternating manner based on a PWM scheme, wherein the control unit (105, 205) is configured to determine the duty cycle for the PWM scheme based on the measured input current,
wherein the control unit (105, 205) comprises an integral controller (320) for determining the duty cycle based on a reference current value and based on the measured supply current, and
characterized in that
the control unit (105, 205) comprises a reference value determination unit (321) configured to determine the reference current value based on a fixed current value and a variable feedback current value, wherein the control unit (105, 205) is configured to determine the variable feedback current value based on the current duty cycle.

2. Control system (100, 200, 300) according to claim 1, comprising an input filter (215) circuit arranged between the phase supply input (103, 203) of the single phase induction motor (150, 250) and a neutral input (104, 204) of the single phase induction motor (150, 250).

3. Control system (100, 200, 300) according to any of the preceding claims, comprising a bypass switching element (216) arranged between the phase supply input (103, 203) and the main winding (151, 251).

4. Control system (100, 200, 300) according to any of the preceding claims, comprising a running capacitor arranged between the phase supply input (103, 203) and the auxiliary winding (152, 252).

5. Control system (100, 200, 300) according to any of the preceding claims,
wherein the first bidirectional switching element (101) comprises two switching elements (210, 211) arranged in common emitter connection or common collector connection, and/or
wherein the second bidirectional switching element (102) comprises two switching elements (212, 213) arranged in common emitter connection or common collector connection; and/or
wherein the first bidirectional switching element (101) comprises two parallel reverse blocking transistors, and/or wherein the second bidirectional switching element (102) comprises two parallel reverse blocking transistors.

6. Electric drive system comprising:

a single phase induction motor (150, 250) with a main winding (151, 251) and with an auxiliary winding (152, 252), and
a control system (100, 200, 300) according to any one of the preceding claims coupled to the single phase induction motor (150, 250) and configured to drive the single phase induction motor (150, 250).

7. Control method for controlling a single phase induction motor (150, 250) with a main winding (151, 251), with an auxiliary winding (152, 252) and with a running capacitor arranged between a phase supply input (103, 203) and the auxiliary winding (152, 252), the control method comprising:

providing (S1) in an alternating manner a positive current to the main winding (151, 251) and a freewheeling current path for the positive current through the main winding (151, 251) during a positive half-wave of a supply voltage of the single phase induction motor (150, 250), and
providing (S2) in an alternating manner a negative current to the main winding (151, 251) and a freewheeling current path for the negative current through the main winding (151, 251) during a negative half-wave of a supply voltage of the single phase induction motor (150, 250),
sensing the input current to the single phase induction motor (150, 250) at the phase supply input (103, 203), wherein providing in an alternating manner a positive current to the main winding (151, 251) and a freewheeling current path for the positive current and providing in an alternating manner a negative current to the main winding

(151, 251) and a freewheeling current path for the negative current is performed based on the sensed current, wherein providing in an alternating manner a positive current to the main winding (151, 251) and a freewheeling current path for the positive current and providing in an alternating manner a negative current to the main winding (151, 251) and a freewheeling current path for the negative current is performed based on a PWM scheme, wherein the PWM scheme is based on the measured input current, especially,
wherein the duty cycle is determined with an integral controller (320) based on a reference current value and based on the measured supply current, and
characterized by
comprising determining the reference current value based on a fixed current value and a variable feedback current value, wherein the variable feedback current value is determined based on the current duty cycle.

8. Control method according to claim 7, comprising filtering an input voltage between the phase supply input (103, 203) of the single phase induction motor (150, 250) and a neutral input (104, 204) of the single phase induction motor (150, 250).

9. Control method according to any of the preceding claims 7 to 8,
wherein providing in an alternating manner a positive current to the main winding (151, 251) and a freewheeling current path for the positive current is performed with two switching elements (210, 211) arranged in common emitter connection or common collector connection or with two parallel reverse blocking transistors, and/or
wherein providing in an alternating manner a negative current to the main winding (151, 251) and a freewheeling current path for the negative current is performed with two switching elements (212, 213) arranged in common emitter connection or common collector connection or with two parallel reverse blocking transistors.

Patentansprüche

1. Steuersystem (100, 200, 300) zum Steuern eines Einphasen-Induktionsmotors (150, 250) mit einer Hauptwicklung (151, 251) und mit einer Hilfswicklung (152, 252), wobei das Steuersystem (100, 200, 300) aufweist:

ein erstes bidirektionales Schaltelement (101) und ein zweites bidirektionales Schaltelement (102), wobei das erste bidirektionale Schaltelement (101) zwischen einem Phasenversorgungseingang (103, 203) des Einphasen-Induktionsmotors (150, 250) und der Hauptwicklung (151, 251) angeordnet ist und wobei das zweite bidirektionale Schaltelement (102) elektrisch parallel zu der Hauptwicklung (151, 251) angeordnet ist,
eine Steuereinheit (105, 205), die mit dem ersten bidirektionalen Schaltelement (101) und dem zweiten bidirektionalen Schaltelement (102) gekoppelt ist,
wobei die Steuereinheit (105, 205) so konfiguriert ist, dass sie während einer positiven Halbwelle einer Versorgungsspannung des Einphasen-Induktionsmotors (150, 250) in abwechselnder Weise steuert

- das erste bidirektionale Schaltelement (101) zur Bereitstellung eines positiven Stroms für die Hauptwicklung (151, 251) und
- das zweite bidirektionale Schaltelement (102), um einen Freilauf-Strompfad für den positiven Strom durch die Hauptwicklung (151, 251) bereitzustellen, und

wobei die Steuereinheit (105, 205) so konfiguriert ist, dass sie während einer negativen Halbwelle einer Versorgungsspannung des Einphasen-Induktionsmotors (150, 250) in abwechselnder Weise steuert

- das erste bidirektionale Schaltelement (101) zur Bereitstellung eines negativen Stroms für die Hauptwicklung (151, 251) und
- das zweite bidirektionale Schaltelement (102), um einen Freilauf-Strompfad für den negativen Strom durch die Hauptwicklung (151, 251) bereitzustellen,

wobei das Steuersystem ferner aufweist
einen Stromsensor, der mit der Steuereinheit (105, 205) gekoppelt und so konfiguriert ist, dass er den Eingangsstrom zum Einphasen-Induktionsmotor (150, 250) am Phasenversorgungseingang (103, 203) erfasst, wobei die Steuereinheit (105, 205) so konfiguriert ist, dass sie das erste bidirektionale Schaltelement (101) und das zweite bidirektionale Schaltelement (102) auf der Grundlage des abgetasteten Stroms ansteuert,
wobei die Steuereinheit (105, 205) konfiguriert ist, das erste bidirektionale Schaltelement (101) und das zweite bidirektionale Schaltelement (102) abwechselnd auf der Grundlage eines PWM-Schemas zu steuern, wobei

die Steuereinheit (105, 205) konfiguriert ist, das Tastverhältnis für das PWM-Schema auf der Grundlage des gemessenen Eingangsstroms zu bestimmen,
wobei die Steuereinheit (105, 205) einen Integralregler (320) zur Bestimmung des Tastverhältnisses auf der Grundlage eines Referenzstromwertes und auf der Grundlage des gemessenen Versorgungsstroms aufweist, und
dadurch gekennzeichnet, dass
die Steuereinheit (105, 205) eine Referenzwertbestimmungseinheit (321) aufweist, die so konfiguriert ist, dass sie den Referenzstromwert basierend auf einem festen Stromwert und einem variablen Rückkopplungsstromwert bestimmt, wobei die Steuereinheit (105, 205) so konfiguriert ist, dass sie den variablen Rückkopplungsstromwert basierend auf dem aktuellen Tastverhältnis bestimmt.

2. Steuersystem (100, 200, 300) nach Anspruch 1, umfassend eine Eingangsfilter-Schaltung (215), die zwischen dem Phasenversorgungseingang (103, 203) des Einphasen-Induktionsmotors (150, 250) und einem Neutraleingang (104, 204) des Einphasen-Induktionsmotors (150, 250) angeordnet ist.

3. Steuersystem (100, 200, 300) nach einem der vorstehenden Ansprüche, mit einem Überbrückungsschaltelement (216), das zwischen dem Phasenversorgungseingang (103, 203) und der Hauptwicklung (151, 251) angeordnet ist.

4. Steuersystem (100, 200, 300) nach einem der vorhergehenden Ansprüche, mit einem zwischen dem Phasenversorgungseingang (103, 203) und der Hilfswicklung (152, 252) angeordneten Betriebskondensator.

5. Steuersystem (100, 200, 300) nach einem der vorhergehenden Ansprüche,
wobei das erste bidirektionale Schaltelement (101) zwei Schaltelemente (210, 211) aufweist, die in gemeinsamer Emitterverbindung oder gemeinsamer Kollektorverbindung angeordnet sind, und/oder wobei das zweite bidirektionale Schaltelement (102) zwei Schaltelemente (212, 213) aufweist, die in einer gemeinsamen Emitterverbindung oder einer gemeinsamen Kollektorverbindung angeordnet sind; und/oder
wobei das erste bidirektionale Schaltelement (101) zwei parallele Sperrtransistoren in Sperrrichtung aufweist und/oder wobei das zweite bidirektionale Schaltelement (102) zwei parallele Sperrtransistoren in Sperrrichtung aufweist.

6. Elektrisches Antriebssystem, umfassend:

einen Einphasen-Induktionsmotor (150, 250) mit einer Hauptwicklung (151, 251) und mit einer Hilfswicklung (152, 252), und
ein Steuersystem (100, 200, 300) gemäß einem der vorstehenden Ansprüche, das mit dem Einphasen-Induktionsmotor (150, 250) gekoppelt und so konfiguriert ist, dass es den Einphasen-Induktionsmotor (150, 250) antreibt.

7. Steuerverfahren zum Steuern eines Einphasen-Induktionsmotors (150, 250) mit einer Hauptwicklung (151, 251), mit einer Hilfswicklung (152, 252) und mit einem Betriebskondensator, der zwischen einem Phasenversorgungseingang (103, 203) und der Hilfswicklung (152, 252) angeordnet ist, wobei das Steuerverfahren aufweist:

abwechselnd einen positiven Strom an die Hauptwicklung (151, 251) und einen Freilaufstrompfad für den positiven Strom durch die Hauptwicklung (151, 251) während einer positiven Halbwelle einer Versorgungsspannung des Einphasen-Induktionsmotors (150, 250) bereitzustellen (S1), und
abwechselnd einen negativen Strom an die Hauptwicklung (151, 251) und einen Freilaufstrompfad für den negativen Strom durch die Hauptwicklung (151, 251) während einer negativen Halbwelle einer Versorgungsspannung des Einphasen-Induktionsmotors (150, 250) bereitzustellen (S2),
Erfassen des Eingangsstroms zu dem Einphasen-Induktionsmotor (150, 250) an dem Phasenversorgungseingang (103, 203), wobei das Bereitstellen eines positiven Stroms für die Hauptwicklung (151, 251) und eines Freilaufstrompfads für den positiven Strom in wechselnder Weise und das Bereitstellen eines negativen Stroms für die Hauptwicklung (151, 251) und eines Freilaufstrompfads für den negativen Strom in wechselnder Weise auf der Grundlage des erfassten Stroms durchgeführt wird,
wobei das Bereitstellen eines positiven Stroms in wechselnder Weise an die Hauptwicklung (151, 251) und eines Freilaufstrompfads für den positiven Strom und das Bereitstellen eines negativen Stroms in wechselnder Weise an die Hauptwicklung (151, 251) und eines Freilaufstrompfads für den negativen Strom auf der Grundlage eines PWM-Schemas durchgeführt wird, wobei das PWM-Schema auf dem gemessenen Eingangsstrom basiert, insbesondere wobei das Tastverhältnis mit einem Integralregler (320) auf der Grundlage eines Referenz-

stromwerts und auf der Grundlage des gemessenen Versorgungsstroms bestimmt wird, und
gekennzeichnet durch
umfassen das Bestimmen des Referenzstromwertes basierend auf einem festen Stromwert und einem variablen Rückkopplungsstromwert, wobei der variable Rückkopplungsstromwert basierend auf dem aktuellen Tastverhältnis bestimmt wird.

8. Steuerverfahren nach Anspruch 7, umfassend das Filtern einer Eingangsspannung zwischen dem Phasenversorgungseingang (103, 203) des Einphasen-Induktionsmotors (150, 250) und einem Neutraleingang (104, 204) des Einphasen-Induktionsmotors (150, 250).

9. Steuerverfahren nach einem der vorstehenden Ansprüche 7 bis 8,
wobei das abwechselnde Bereitstellen eines positiven Stroms für die Hauptwicklung (151, 251) und eines Freilauf-Strompfades für den positiven Strom mit zwei Schaltelementen (210, 211), die in gemeinsamer Emitterverbindung oder gemeinsamer Kollektorverbindung angeordnet sind, oder mit zwei parallelen Sperrtransistoren in Sperrrichtung erfolgt, und/oder
wobei das abwechselnde Bereitstellen eines negativen Stroms für die Hauptwicklung (151, 251) und eines Freilaufstrompfades für den negativen Strom mit zwei Schaltelementen (212, 213), die in gemeinsamer Emitterverbindung oder gemeinsamer Kollektorverbindung angeordnet sind, oder mit zwei parallelen Sperrtransistoren in Sperrrichtung durchgeführt wird.

Revendications

1. Système de commande (100, 200, 300) pour commander un moteur à induction monophasé (150, 250) comportant un enroulement principal (151, 251) et comportant un enroulement auxiliaire (152, 252), le système de commande (100, 200, 300) comprenant :

un premier élément de commutation bidirectionnel (101) et un second élément de commutation bidirectionnel (102), dans lequel le premier élément de commutation bidirectionnel (101) est agencé entre une entrée d'alimentation phasée (103, 203) du moteur à induction monophasé (150, 250) et l'enroulement principal (151, 251) et dans lequel le second élément de commutation bidirectionnel (102) est agencé électriquement parallèle à l'enroulement principal (151, 251),
une unité de commande (105, 205) couplée au premier élément de commutation bidirectionnel (101) et au second élément de commutation bidirectionnel (102),
dans lequel l'unité de commande (105, 205) est configurée pour commander de manière alternée, durant une demi-onde positive d'une tension d'alimentation du moteur à induction monophasé (150, 250)

- le premier élément de commutation bidirectionnel (101) pour délivrer un courant positif à l'enroulement principal (151, 251) et
- le second élément de commutation bidirectionnel (102) pour délivrer un trajet de courant de roue libre pour le courant positif à travers l'enroulement principal (151, 251), et

dans lequel l'unité de commande (105, 205) est configurée pour commander de manière alternée, durant une demi-onde négative d'une tension d'alimentation du moteur à induction monophasé (150, 250)

- le premier élément de commutation bidirectionnel (101) pour délivrer un courant négatif à l'enroulement principal (151, 251) et
- le second élément de commutation bidirectionnel (102) pour délivrer un trajet de courant de roue libre pour le courant négatif à travers l'enroulement principal (151, 251),

le système de commande comprenant en outre un capteur de courant couplé à l'unité de commande (105, 205) et configuré pour détecter le courant d'entrée vers le moteur à induction monophasé (150, 250) au niveau de l'entrée d'alimentation phasée (103, 203), dans lequel l'unité de commande (105, 205) est configurée pour entraîner le premier élément de commutation bidirectionnel (101) et le second élément de commutation bidirectionnel (102) sur la base du courant détecté,
dans lequel l'unité de commande (105, 205) est configurée pour commander le premier élément de commutation bidirectionnel (101) et le second élément de commutation bidirectionnel (102) de manière alternée sur la base d'un schéma PWM, dans lequel l'unité de commande (105, 205) est configurée pour déterminer le cycle de

service pour le schéma PWM sur la base du courant d'entrée mesuré,
dans lequel l'unité de commande (105, 205) comprend un dispositif de commande intégré (320) pour déterminer le cycle de service sur la base d'une valeur de courant de référence et sur la base du courant d'alimentation mesuré, et
caractérisé en ce que
l'unité de commande (105, 205) comprend une unité de détermination de valeur de référence (321) configurée pour déterminer la valeur de courant de référence sur la base d'une valeur de courant fixe et d'une valeur de courant de rétroaction variable, dans lequel l'unité de commande (105, 205) est configurée pour déterminer la valeur de courant de rétroaction variable sur la base du cycle de service du courant.

2. Système de commande (100, 200, 300) selon la revendication 1, comprenant un circuit de filtre d'entrée (215) agencé entre l'entrée d'alimentation phasée (103, 203) du moteur à induction monophasé (150, 250) et une entrée neutre (104, 204) du moteur à induction monophasé (150, 250).

3. Système de commande (100, 200, 300) selon l'une quelconque des revendications précédentes, comprenant un élément de commutation de dérivation (216) agencé entre l'entrée d'alimentation phasée (103, 203) et l'enroulement principal (151, 251).

4. Système de commande (100, 200, 300) selon l'une quelconque des revendications précédentes, comprenant un condensateur de marche agencé entre l'entrée d'alimentation phasée (103, 203) et l'enroulement auxiliaire (152, 252).

5. Système de commande (100, 200, 300) selon l'une quelconque des revendications précédentes,
dans lequel le premier élément de commutation bidirectionnel (101) comprend deux éléments de commutation (210, 211) agencés dans une connexion d'émetteur commun ou une connexion de collecteur commun, et/ou
dans lequel le second élément de commutation bidirectionnel (102) comprend deux éléments de commutation (212, 213) agencés dans une connexion d'émetteur commun ou une connexion de collecteur commun ; et/ou
dans lequel le premier élément de commutation bidirectionnel (101) comprend deux transistors parallèles à blocage inverse, et/ou dans lequel le second élément de commutation bidirectionnel (102) comprend deux transistors parallèles à blocage inverse.

6. Système d'entraînement électrique comprenant :

un moteur à induction monophasé (150, 250) comportant un enroulement principal (151, 251) et comportant un enroulement auxiliaire (152, 252), et
un système de commande (100, 200, 300) selon l'une quelconque des revendications précédentes couplé au moteur à induction monophasé (150, 250) et configuré pour entraîner le moteur à induction monophasé (150, 250) .

7. Procédé de commande pour commander un moteur à induction monophasé (150, 250) comportant un enroulement principal (151, 251), comportant un enroulement auxiliaire (152, 252) et comportant un condensateur de marche agencé entre une entrée d'alimentation phasée (103, 203) et l'enroulement auxiliaire (152, 252), le procédé de commande comprenant :

la délivrance (S1) de manière alternée d'un courant positif à l'enroulement principal (151, 251) et d'un trajet de courant de roue libre pour le courant positif à travers l'enroulement principal (151, 251) durant une demi-onde positive d'une tension d'alimentation du moteur à induction monophasé (150, 250), et
la délivrance (S2) de manière alternée d'un courant négatif à l'enroulement principal (151, 251) et d'un trajet de courant de roue libre pour le courant négatif à travers l'enroulement principal (151, 251) durant une demi-onde négative d'une tension d'alimentation du moteur à induction monophasé (150, 250),
la détection du courant d'entrée vers le moteur à induction monophasé (150, 250) au niveau de l'entrée d'alimentation phasée (103, 203), dans lequel la délivrance de manière alternée d'un courant positif à l'enroulement principal (151, 251) et d'un trajet de courant de roue libre pour le courant positif et la délivrance de manière alternée d'un courant négatif à l'enroulement principal (151, 251) et d'un trajet de courant de roue libre pour le courant négatif est effectuée sur la base du courant détecté,
dans lequel la délivrance de manière alternée d'un courant positif à l'enroulement principal (151, 251) et d'un trajet de courant de roue libre pour le courant positif et la délivrance de manière alternée d'un courant négatif à l'enroulement principal (151, 251) et d'un trajet de courant de roue libre pour le courant négatif est effectuée

sur la base d'un schéma PWM, dans lequel le schéma PWM est fondé sur le courant d'entrée mesuré, en particulier, dans lequel le cycle de service est déterminé avec un dispositif de commande intégré (320) sur la base d'une valeur de courant de référence et sur la base du courant d'alimentation mesuré, et
caractérisé en ce qu'il
comprend la détermination de la valeur de courant de référence sur la base d'une valeur de courant fixe et d'une valeur de courant de rétroaction variable, dans lequel la valeur de courant de rétroaction variable est déterminée sur la base du cycle de service du courant.

8. Procédé de commande selon la revendication 7, comprenant le filtrage d'une tension d'entrée entre l'entrée d'alimentation phasée (103, 203) du moteur à induction monophasé (150, 250) et une entrée neutre (104, 204) du moteur à induction monophasé (150, 250) .

9. Procédé de commande selon l'une quelconque des revendications précédentes 7 et 8,
dans lequel la délivrance de manière alternée d'un courant positif à l'enroulement principal (151, 251) et d'un trajet de courant de roue libre pour le courant positif est effectuée avec deux éléments de commutation (210, 211) agencés dans une connexion d'émetteur commun ou une connexion de collecteur commun ou avec deux transistors parallèles à blocage inverse, et/ou
dans lequel la délivrance de manière alternée d'un courant négatif à l'enroulement principal (151, 251) et d'un trajet de courant de roue libre pour le courant négatif est effectuée avec deux éléments de commutation (212, 213) agencés dans une connexion d'émetteur commun ou une connexion de collecteur commun ou avec deux transistors parallèles à blocage inverse.

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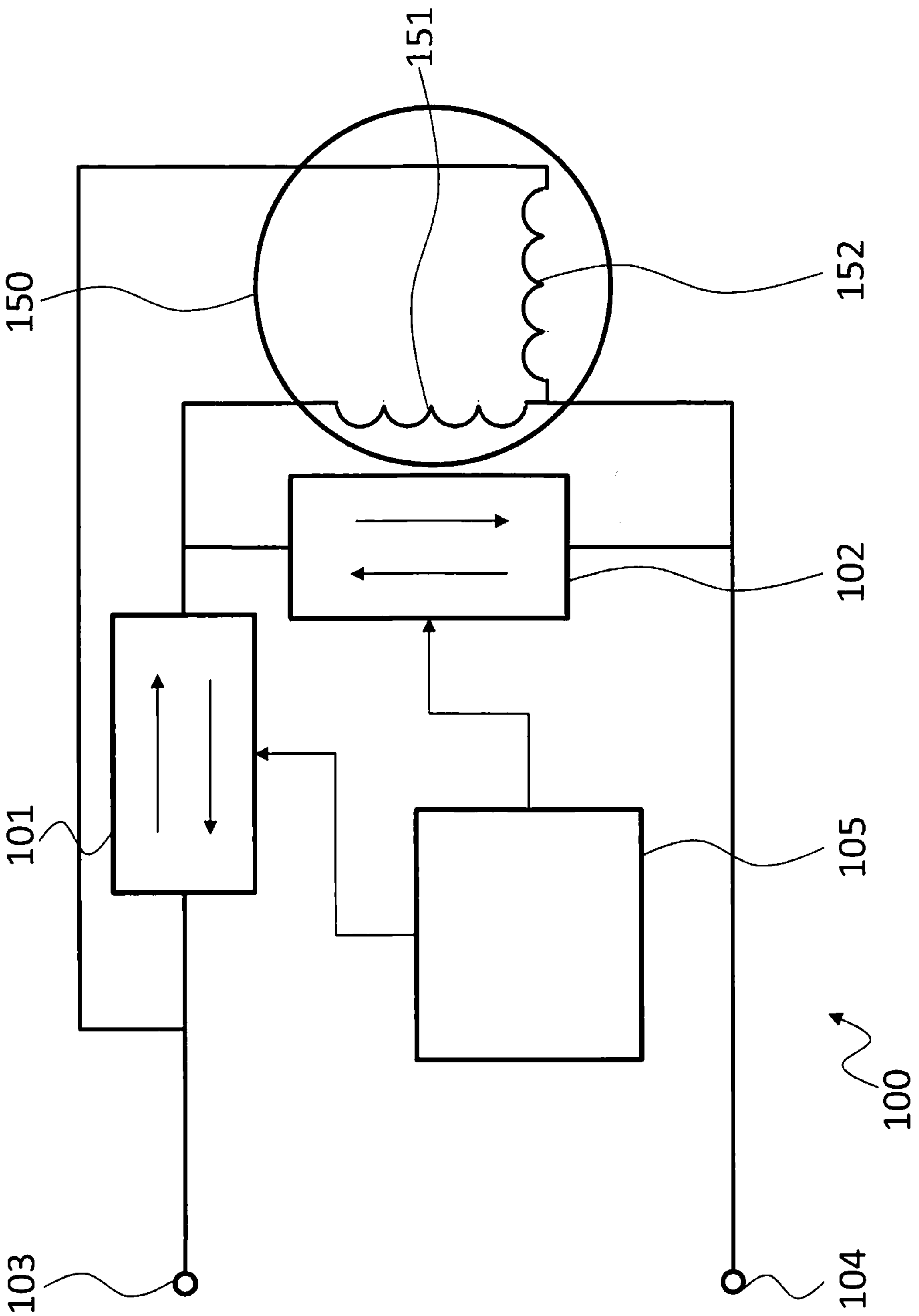

Fig. 1

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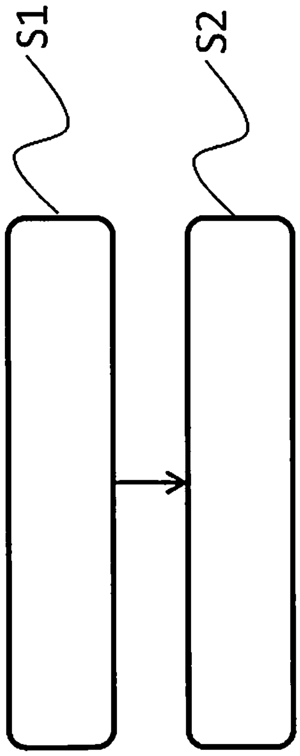

Fig. 2

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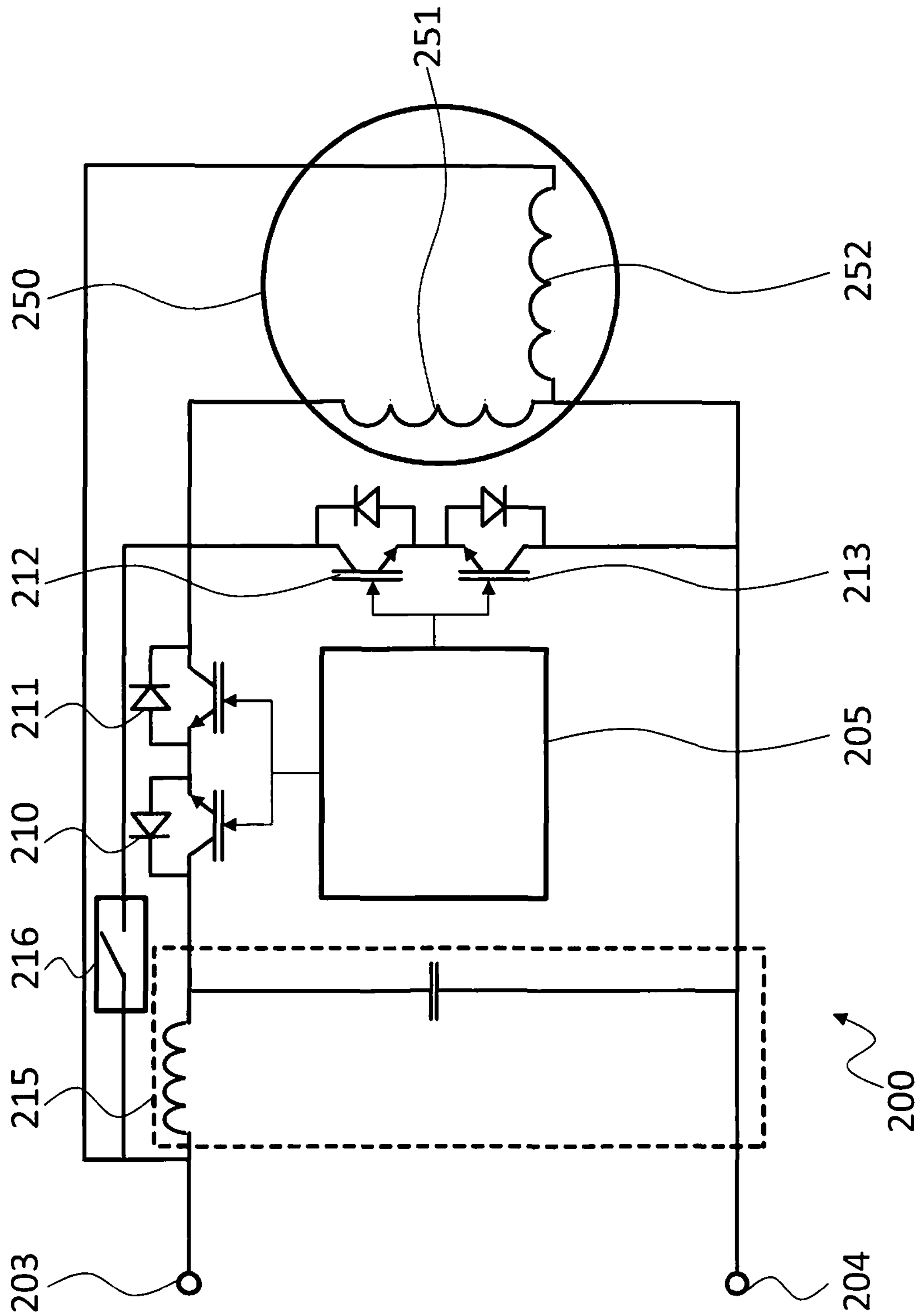

Fig. 3

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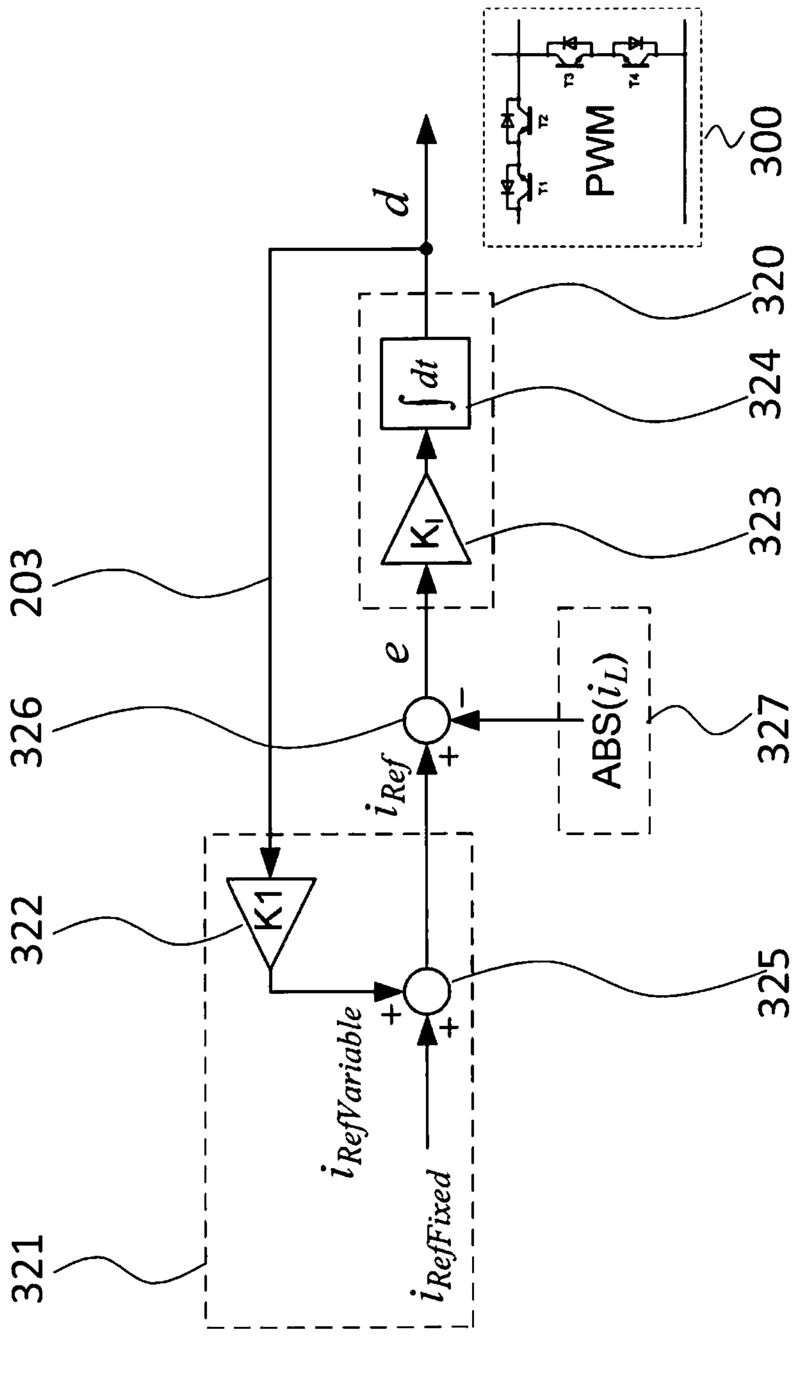

d
e
K1
K_I
$\int dt$
$ABS(i_L)$
i_{Ref}
$i_{RefVariable}$
$i_{RefFixed}$
PWM
T1
T2
T3
T4
300
320
324
323
327
203
326
322
325
321

Fig. 4

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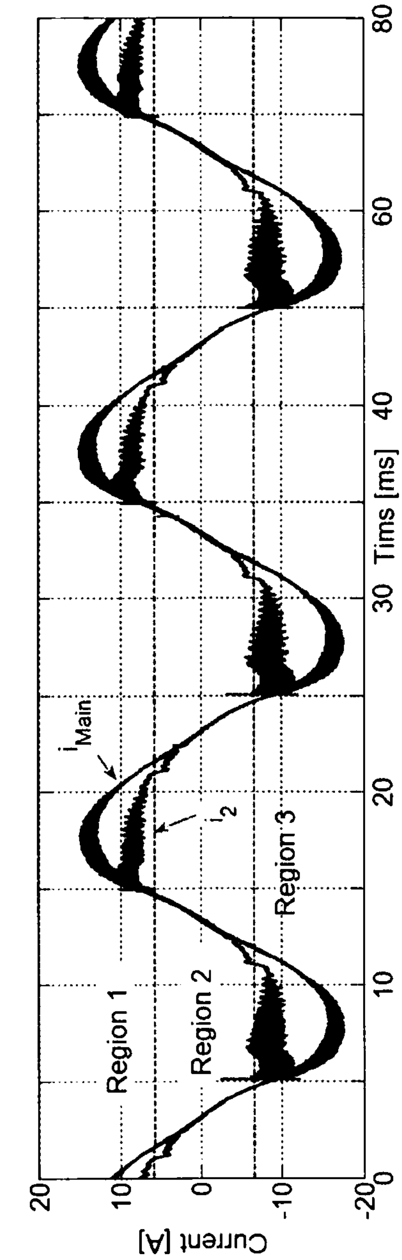
Current [A]
20
10
0
-10
-20
0
10
20
30
40
60
80
Tims [ms]
Region 1
Region 2
Region 3
i_{Main}
i_2

Fig. 5

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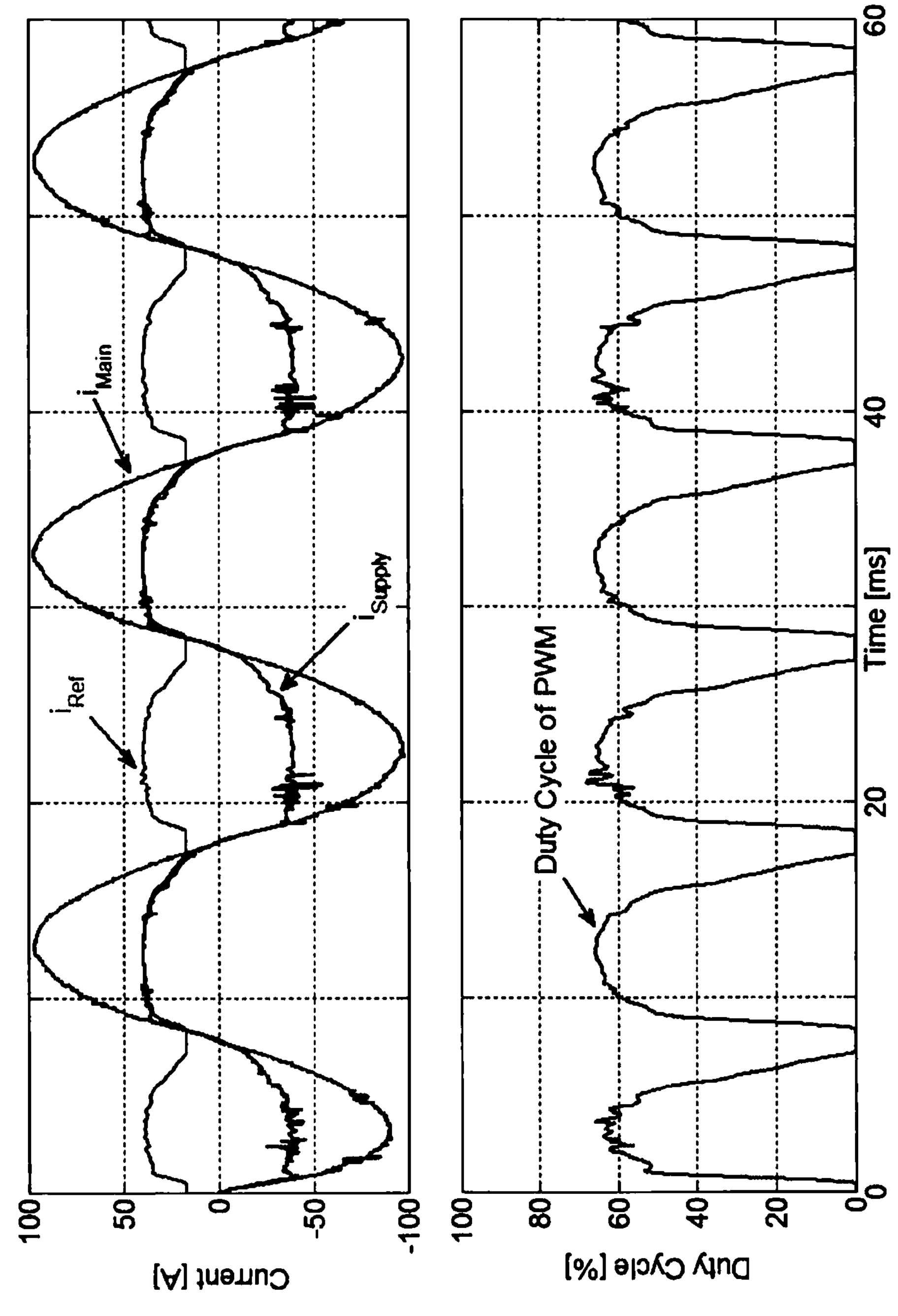

100
50
0
-50
-100
Current [A]
i_Ref
i_Supply
i_Main
100
80
60
40
20
0
Duty Cycle [%]
Duty Cycle of PWM
0
20
40
60
Time [ms]

Fig. 6

REFERENCES CITED IN THE DESCRIPTION

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Non-patent literature cited in the description

- **THANYAPHIRAK VEERA.** *Soft starting control of single-phase induction motor using PWM AC Chopper control technique* **[0005]**
- **YILDIRIM D.** *PWM AC chopper control of single-phase induction motor for variable-speed fan application* **[0005]**