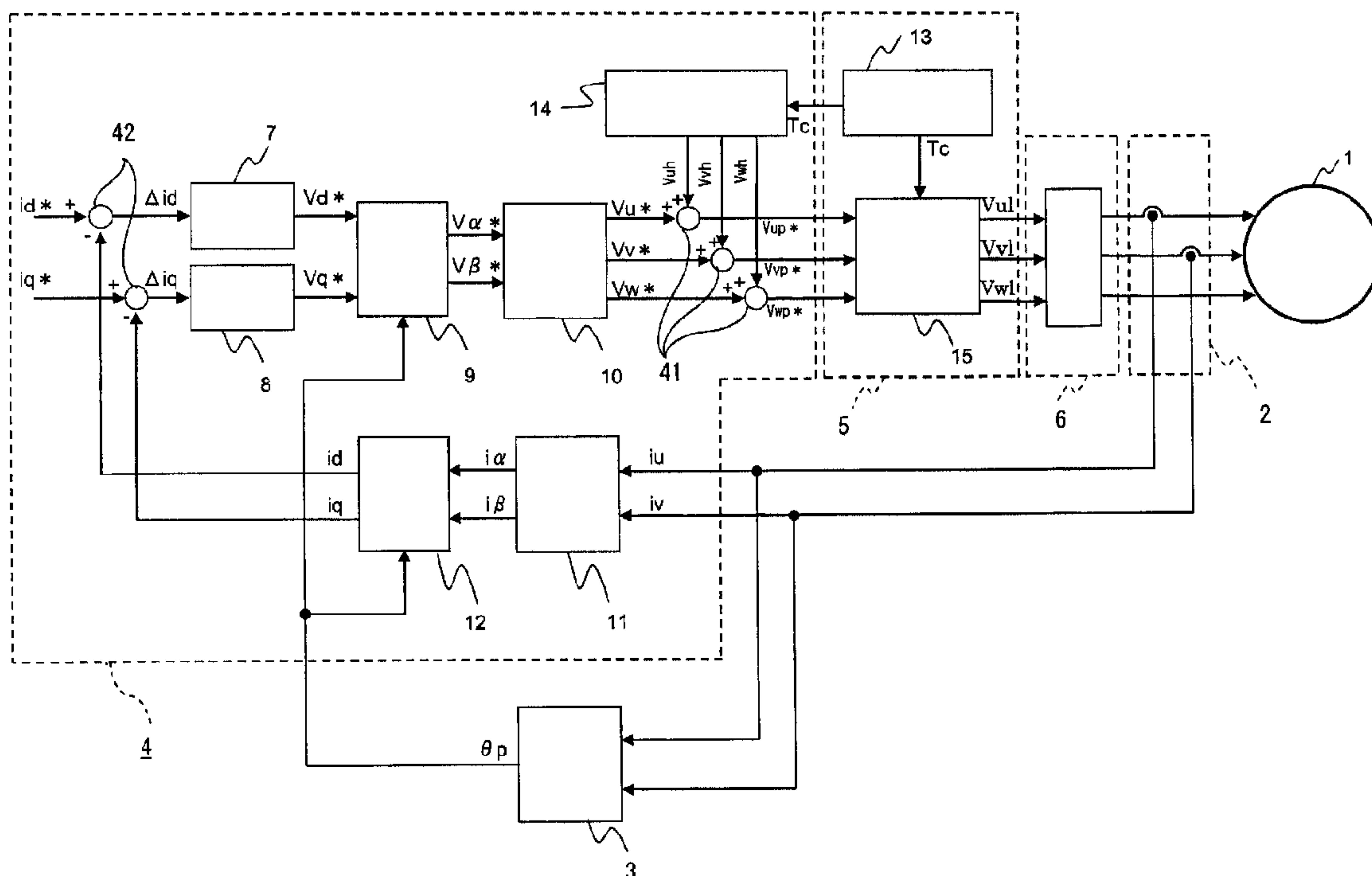




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(57) Abrégé/Abstract:

The invention relates to a controller of a rotary electric machine, being able to perform rotation control without using a rotor position sensor. An object of the invention is to provide a controller of a rotary electric machine, being able to accurately estimate the rotor position and control the rotary electric machine with using a single carrier signal. The voltage commands outputted by the control means are obtained by superimposing, on fundamental voltages for driving the rotary electric machine, position detection voltages having a cycle equal to m times (m is an integer of three or more) of the switching cycle and different in phase among respective phases. The rotary electric machine currents are detected by the current detection means, and the position detection alternating currents included in the currents are extracted by the position estimation means, whereby the rotor position can be estimated.



ABSTRACT

The invention relates to a controller of a rotary electric machine, being able to perform rotation control without using a rotor position sensor. An object of the invention is to provide a controller of a rotary electric machine, being able to accurately estimate the rotor position and control the rotary electric machine with using a single carrier signal. The voltage commands outputted by the control means are obtained by superimposing, on fundamental voltages for driving the rotary electric machine, position detection voltages having a cycle equal to m times (m is an integer of three or more) of the switching cycle and different in phase among respective phases. The rotary electric machine currents are detected by the current detection means, and the position detection alternating currents included in the currents are extracted by the position estimation means, whereby the rotor position can be estimated.

DESCRIPTION

CONTROLLER OF ROTARY ELECTRIC MACHINE

TECHNICAL FIELD

5 [0001] The present invention relates to a controller of a rotary electric machine, the controller being capable of performing rotation control by obtaining rotor position information without using a rotor position sensor in the rotary electric machine such as an induction machine, a
10 synchronous machine, and the like.

BACKGROUND ART

[0002] In order to accurately control a rotation operation of a rotary electric machine, there are required rotor
15 position information of the rotary electric machine and current information about a current flowing in the rotary electric machine. Conventionally, the rotor position information is obtained by separately mounting a rotor position sensor to the rotary electric machine. However, it
20 is considerably disadvantageous to separately mount the rotor position sensor from the viewpoints of cost reduction, space-saving, and improvement in reliability, and thus there is a demand for a sensorless method which does not require the rotor position sensor.

25 [0003] As a sensorless control method not requiring a

rotor position sensor in a rotary electric machine, there are mainly the following methods: a method in which a rotor position of a rotary electric machine is estimated based on an induced voltage of the rotary electric machine; and a
5 method in which a rotor position of a rotary electric machine is estimated utilizing a saliency. Since the magnitude of the induced voltage used in the former method is characteristically proportional to a speed of the rotary electric machine, the induced voltage is decreased at a zero-
10 speed or in a low-speed range, and an S/N ratio deteriorates. Therefore, it is difficult to estimate the rotor position of the rotary electric machine. On the other hand, in the latter method which utilizes the saliency, a rotor position estimation signal for estimating a rotor position of a rotary
15 electric machine needs to be injected to the rotary electric machine, however, it is advantageous that the rotor position of the rotary electric machine can be estimated regardless of the speed of the rotary electric machine. Therefore, the sensorless control method utilizing the saliency is employed
20 for position detection in the zero- or low-speed range.

[0004] Conventionally, in the sensorless control method utilizing the saliency, in order to generate high-frequency signals (for detecting a position of a magnetic pole rotor), which are different from a driving frequency for a rotary
25 electric machine, as signals for estimating a rotor position,

carrier signals of three phases, which each have an arbitrary frequency and are generated by a carrier signal generator, are subjected to phase shift by a phase shifter, and phases of a V-phase and a W-phase are shifted by an angle $\Delta\theta$ and an angle $2\Delta\theta$, respectively, with respect to a U-phase. The phase-shifted signals are compared to voltage command values by using a comparator to generate switching signals which are then inputted to an inverter circuit. In the inverter circuit, high-frequency currents of three phases, which are generated due to driving of the rotary electric machine by the switching signals, are extracted through a band-pass filter (BPF). Next, the high-frequency currents of three phases are converted by a coordinate converter to an α -axis, a β -axis, an α' -axis, and an β' -axis, and peak values of the current components are extracted and then subjected to an averaging process by using an absolute value calculation unit and a low pass filter, and then θ is estimated by a magnetic pole position calculation unit (see Patent Document 1, for example).

[0005] Further, as another conventional method which utilizes the saliency, there is known a method in which a d-q axis rectangular coordinate system, which rotates synchronously with a rotor or a magnetic flux vector, is used as control coordinates, and a high-frequency signal is superimposed on a d-axis excitation current command value, so

as to detect currents flowing to the rotary electric machine. Two-phase currents are obtained by three-phase/two-phase conversion of the above currents. The square of the amplitude of a vector of each detected current, which is the square sum of the currents of two phases, is calculated, and the sum between the square of the d-axis excitation current command value and the square of a q-axis torque current command value, i.e., the square of the amplitude of a command current vector, is calculated, and the square of the amplitude of the command current vector is subtracted from the square of the amplitude of the detecting current vector. Based on a value obtained by the subtraction, an error from the control coordinates is calculated, whereby a rotor position in the rotary electric machine is estimated (see Patent Document 2, for example).

[0006] On the other hand, current information about a current flowing to a rotary electric machine is conventionally detected by arranging a plurality of current sensors between voltage application means such as an inverter or the like and the rotary electric machine, and by detecting, by using the current sensors, the rotary electric machine current flowing between the voltage application means and the rotary electric machine. For example, in the case of a three-phase AC rotary electric machine, rotary electric machine currents of at least two phases, among three phases,

are detected using two current sensors. However, arrangement of a plurality of current sensors requires extra costs. Thus, for the sake of reduction in costs of the current sensors, there is a method in which only one current sensor is used to
5 detect a value of a DC bus current flowing between a DC voltage source, which is an input source to voltage application means such as an inverter or the like, and the inverter, so as to calculate and identify the phase, of the rotary electric machine, in which the current is flowing at
10 the time of the detection in accordance with the difference in switching patterns of switches of respective phases of the voltage application means such as the inverter or the like.

[0007] The above method enhances the reduction in costs of the current sensors. However, when voltage command values
15 are overlapped with or close to each other, for example, when the modulation percentage of fundamental waves for driving a rotary electric machine is small, or when command values of two phases, among voltage command values of three phases, are overlapped with each other, then switching elements of the
20 respective phases of voltage application means, such as an inverter or the like, perform switching substantially simultaneously, which leads to substantially no difference in the switching pattern. Therefore, the method has a problem in that it is difficult to identify the phase, of the rotary
25 electric machine, in which a current is flowing.

[0008] To solve the above problem, conventionally proposed is a method which is combined with the sensorless control, and in the method, three phase carriers are prepared to estimate a rotor position by using high-frequency currents generated by three phase carrier modulation, and the three phase carriers utilized for estimation of the rotor position are utilized to generate difference in switching patterns of switching elements of the respective phases of voltage application means, such as an inverter or the like, thereby detecting a DC bus current even when the modulation percentage of fundamental waves for driving the rotary electric machine is small. Accordingly, it is possible to identify the phase, of the rotary electric machine, in which a current is flowing, and to calculate the current flowing to the rotary electric machine (see Non-patent Document 1, for example).

[0009]

[Patent Document 1] Japanese Laid-Open Patent Publication No. 2003-52193

[Patent Document 2] Japanese Patent No. 3707528

[Non-patent Document 1] Initial Rotor Position Estimation Characteristics of Mechanical-Current Sensorless IPM Motor Using PWM Harmonics Detected in DC-Bus Current (I.E.E. Japan Industry Application Society Conference 1-100 (2005))

DISCLOSURE OF THE INVENTION

PROBLEMS TO BE SOLVED BY THE INVENTION

[0010] In a commercially available general-purpose microcomputer for controlling a rotary electric machine, one carrier signal is used to perform PWM modulation on voltage commands of three phases. On the other hand, in Patent Document 1, in order to generate a position estimation signal, carrier signals of three phases are prepared, and in Non-patent Document 1, in order to calculate a current flowing to a rotary electric machine based on a DC bus current, carrier signals of three phases need to be prepared. In this manner, in the conventional technologies, since carrier signals of three phases need to be prepared, it is difficult to utilize a commercially available general-purpose microcomputer, which results in a problem that an inexpensive configuration cannot be utilized.

[0011] Further, since carrier signals of three phases are used, when a current sampling is performed in the vicinity of a peak and a trough of each of carrier signals, there may be a case where the time when a current sampling is performed in one phase coincides with a switching timing of another phase, and consequently the current sampling is affected by ON/OFF of the inverter, which may cause failure in sampling.

[0012] Further, in the position estimation method disclosed in Patent Document 2, the position estimation is

performed using two pieces of information, i.e., a current command and a detecting current, which leads to a problem of an increase in arithmetic processing for calculating an estimation position by processing the two pieces of
5 information.

[0013] The present invention is made to solve the above problems, and an object of the present invention is to provide a controller of a rotary electric machine, the controller being capable of accurately estimating the rotor
10 position and controlling the rotary electric machine by detecting current information about a current flowing to the rotary electric machine with the use of only a single carrier signal and without using a rotor position sensor, in particular.

15 [0014] Further, the present invention is directed to a case where the phase, of the rotary electric machine, in which a current is flowing is determined based on a DC bus current. That is, another object of the present invention is to allow calculation of a current flowing to the rotary
20 electric machine, based on the DC bus current by utilizing a position estimation signal generated using a single carrier signal and a simple configuration, even when voltage command values are overlapped with or close to each other, which cannot be achieved by the conventional technologies.

SOLUTION TO THE PROBLEMS

[0015] A controller of a rotary electric machine according to the present invention performs rotation control of the rotary electric machine, and includes: current detection means for detecting rotary electric machine currents flowing to the rotary electric machine; position estimation means for estimating a rotor position in accordance with the rotary electric machine currents detected by the current detection means; control means for outputting voltage commands in accordance with the rotor position estimated by the position estimation means; pulse-width modulation means for outputting logic signals which are pulse-width modulated based on the voltage commands from the control means and on a switching cycle used for pulse-width modulation control; and voltage application means for applying voltages to the rotary electric machine in accordance with the logic signals outputted by the pulse-width modulation means. The voltage commands outputted by the control means are obtained by superimposing, on fundamental voltages for driving the rotary electric machine, position detection voltages which each have a cycle equal to m times (m is an integer of three or more) of the switching cycle and which are different in phase among respective phases.

[0016] In this case, a configuration may be applicable in which the current detection means is replaced with bus

current detection means for detecting a bus current flowing between the voltage application means and a DC voltage source supplying DC power to the voltage application means, and with rotary electric machine current calculation means for
5 calculating the rotary electric machine currents flowing to the rotary electric machine in accordance with the bus current detected by the bus current detection means, and with both or either of the logic signals and the voltage commands.

According to an aspect of the present invention there is
10 provided a controller of a rotary electric machine performing rotation control of the rotary electric machine, comprising:

current detection means for detecting rotary electric machine currents flowing to the rotary electric machine;

position estimation means for estimating a rotor
15 position in accordance with the rotary electric machine currents detected by the current detection means;

control means for outputting voltage commands in accordance with the rotor position estimated by the position estimation means;

20 pulse-width modulation means for outputting logic signals which are pulse-width modulated based on the voltage commands from the control means and on a switching cycle used for pulse-width modulation control; and

10a

voltage application means for applying voltages to the rotary electric machine in accordance with the logic signals outputted by the pulse-width modulation means, wherein

the voltages outputted by the voltage application means
5 are obtained by superimposing, position detection voltages which each have a cycle equal to m times (m is an integer of three or more) of the switching cycle and which are different in phase among respective phases.

EFFECT OF THE INVENTION

10 [0017] In the controller of the rotary electric machine of the present invention, the voltage commands outputted by the control means to the pulse-width modulation means are obtained by superimposing, on the fundamental voltages for driving the rotary electric machine, position detection
15 voltages which each have a cycle equal to m times (m is an integer of three or more) of the switching cycle used for the pulse-width modulation control and which are different in phase among respective phases. Thus, when the AC voltages are applied to drive the rotary electric machine, the rotary
20 electric machine currents flowing to the rotary electric machine include position detection alternating currents having a frequency corresponding to the position detection voltages. Therefore, the rotary electric machine currents are detected by the current detection means, and the position
25 detection alternating currents included in the rotary

electric machine currents are extracted by the position estimation means, whereby the rotor position can be estimated.

[0018] Accordingly, by using only a single carrier signal, and without using a rotor position sensor particularly, it is possible to accurately estimate the rotor position and control the rotary electric machine by detecting the rotary electric machine currents flowing to the rotary electric machine.

[0019] Further, a bus current is detected by bus current detection means, and the rotary electric machine currents flowing to the rotary electric machine are calculated by the rotary electric machine current calculation means in accordance with the bus current and with both or either of the logic signals and the voltage commands, whereby it is possible to reduce the number of pieces of the current detection means, and also possible to enhance cost reduction. Moreover, at the same time, three-phase AC voltages which each have a cycle equal to m times of the switching cycle and which are different in phase among the respective phases are used as the position detection voltages used for position estimation, whereby it is possible to calculate currents flowing to the rotary electric machine by using a simple configuration and based on the DC bus current even when values of the fundamental voltages of three phases for driving the rotary electric machine are substantially

identical to one another (when a modulation percentage is small or when two phase of the three phases are overlapped with each other).

[0020] A cycle of calculation by the control means is usually set to be equal to or multiple times of the switching cycle. Thus, when a cycle of the position detection voltages of the three-phase AC currents used for position estimation is not multiple times of the switching cycle, the position detection voltages will be discontinuous, and its time average value is not zero, which causes generation of swell. However, in the present invention, the cycle of the position detection voltages of the three-phase AC currents used for the position estimation is set to be equal to m times (m is an integer of three or more) of the switching cycle, and thus, the position detection voltages change continuously, and it is possible to prevent generation of swell.

BRIEF DESCRIPTION OF THE DRAWINGS

[0021] [FIG. 1] FIG. 1 is a block diagram showing a controller of a rotary electric machine according to a first embodiment of the present invention.

[FIG. 2] FIG. 2 is a block diagram showing, in detail, position estimation means provided to the controller shown in FIG. 1.

[FIGS. 3(a)-3(b)] FIGS. 3(a)-3(b) are explanatory diagrams

illustrating an operation in the first embodiment.

[FIG. 4] FIG. 4 is an explanatory diagram illustrating an operation in the first embodiment.

[FIG. 5] FIG. 5 is an explanatory diagram
5 illustrating an operation in the first embodiment.

[FIG. 6] FIG. 6 is an explanatory diagram illustrating an operation in the first embodiment.

[FIGS. 7(a)-7(d)] FIGS. 7(a)-7(d) are explanatory diagrams illustrating an operation in the first embodiment.

10 [FIG. 8] FIG. 8 is a block diagram showing, in detail, position estimation means provided to a controller according to a second embodiment of the present invention.

[FIG. 9] FIG. 9 is an explanatory diagram illustrating an operation of the position estimation means
15 shown in FIG. 8.

[FIG. 10] FIG. 10 is a block diagram showing a controller of a rotary electric machine according to a third embodiment of the present invention.

[FIG. 11] FIG. 11 is a block diagram showing a
20 controller of a rotary electric machine according to a fourth embodiment of the present invention.

[FIG. 12] FIG. 12 is an explanatory diagram illustrating an operation of a controller according to a fifth embodiment of the present invention.

25 [FIG. 13] FIG. 13 is a block diagram showing a

controller of a rotary electric machine according to a sixth embodiment of the present invention.

[FIG. 14] FIG. 14 is a block diagram showing a controller of a conventional rotary electric machine, the controller calculating rotary electric machine currents from a DC bus current.

[FIGS. 15(a)-15(b)] FIGS. 15(a)-15(b) are explanatory diagrams illustrating an operation of the controller of the rotary electric machine having a configuration shown in FIG. 14.

[FIG. 16] FIG. 16 is a block diagram showing voltage application means of the controller of the rotary electric machine shown in FIG. 14.

[FIG. 17] FIG. 17 is a block diagram showing a controller of another conventional rotary electric machine, the controller calculating rotary electric machine currents from a DC bus current.

[FIGS. 18(a)-18(b)] FIGS. 18(a)-18(b) are explanatory diagrams illustrating an operation of the controller of the rotary electric machine having a configuration shown in FIG. 17.

[FIGS. 19(a)-19(b)] FIGS. 19(a)-19(b) are explanatory diagrams illustrating an operation in the controller of the rotary electric machine having the configuration shown in FIG. 14 or FIG. 17, in the case where a problem occurs in calculation of the rotary electric machine currents based on the DC bus current.

[FIG. 20] FIG. 20 is a block diagram showing a controller of a rotary electric machine according to a seventh embodiment of the present invention.

[FIGS. 21(a)-21(b)] FIGS. 21(a)-21(b) are
5 explanatory diagrams illustrating an operation of the controller of the rotary electric machine shown in FIG. 20.

[FIG. 22] FIG. 22 is an explanatory diagram illustrating an operation of a controller according to an eighth embodiment of the present invention.

10 [FIGS. 23(a)-23(b)] FIGS. 23(a)-FIG. 23(b) are explanatory diagrams illustrating an operation in the eighth embodiment of the present invention.

[FIG. 24] FIG. 24 is a block diagram showing a controller of a rotary electric machine according to a ninth
15 embodiment of the present invention.

[FIGS. 25(a)-25(d)] FIGS. 25(a)-25(d) are explanatory diagrams illustrating an operation of the controller of the rotary electric machine having a configuration shown in FIG. 24.

20 BEST MODE FOR CARRYING OUT THE INVENTION

[0022] First Embodiment

FIG. 1 to FIG. 7 show a first embodiment of the present invention. FIG. 1 is a block diagram showing an overall configuration of a controller of a rotary electric
25 machine, FIG. 2 is a block diagram showing, in detail,

position estimation means shown in FIG. 1, and FIG. 3 to FIG. 7 are each a explanatory diagram for operational explanation.

[0023] In the first embodiment, a rotary electric machine 1 is, for example, an interior permanent magnet type synchronous machine, and to the rotary electric machine 1, an inverter 6 is connected as voltage application means which applies thereto a predetermined control voltage. In addition, arranged are current detection means 2 which detects rotary electric machine currents i_u and i_v of two phases flowing between the inverter 6 and the rotary electric machine 1, position estimation means 3 which calculates a rotor position of the rotary electric machine 1, control means 4 (to be described later in detail) which outputs voltage commands V_{up}^* , V_{vp}^* , and V_{wp}^* which are driving voltage commands to be applied to the rotary electric machine 1, pulse-width modulation control means 5 (to be described later in detail) which outputs logic signals V_{ul} , V_{vl} , and V_{wl} which are pulse-width modulated in accordance with the voltage commands V_{up}^* , V_{vp}^* , and V_{wp}^* outputted from the control means 4.

[0024] The control means 4 includes a subtractor 42, a d-axis current controller 7, a q-axis current controller 8, a coordinate converter 9, a two-phase/three-phase converter 10 as voltage command means, a three-phase/two-phase converter 11, and a coordinate converter 12. The control means 4 also includes a position detection voltage generator 14 and an

adder 41. Further, the pulse-width modulation means 5 includes a switching cycle generator 13 as a switching cycle generation section, and a pulse-width modulation controller 15.

5 [0025] The current detection means 2 according to the first embodiment is a current transformer or the like, for example, and detects currents of two phases, i.e., a U-phase current i_u and a V-phase current i_v , from a power line connecting between the rotary electric machine 1 and the
10 inverter 6. However, alternatively, any currents of two phases among the U-phase current, the V-phase current, and a W-phase current may be detected. Still alternatively, the current detection means 2 may detect currents of three phases, i.e., the U-phase current, the V-phase current, and the W-
15 phase current. Still alternatively, as the current detection means 2, a method utilizing a DC bus current inputted to the inverter 6, which is to be described later, may be used to calculate and detect currents.

[0026] As described later in detail, position detection
20 voltages V_{uh} , V_{vh} , and V_{wh} of three phases outputted from the position detection voltage generator 14 are superimposed on fundamental voltages V_{up}^* , V_{vp}^* , and V_{wp}^* for driving the rotary electric machine, and consequently the rotary electric machine currents of two phases, i.e., the U-phase current i_u
25 and the V-phase current i_v of the rotary electric machine 1,

detected by the current detection means 2, include position detection alternating current components which have frequencies corresponding to the position detection voltages V_{uh} , V_{vh} , and V_{wh} .

5 [0027] Accordingly, the position estimation means 3 extracts high-frequency position detection alternating currents which is generated in the rotary electric machine 1 and included in the rotary electric machine currents, and obtains and outputs, based on the position detection currents,
10 information θ_p of a rotor position. As shown in FIG. 2, the position estimation means 3 is configured such that a three-phase/two-phase converter 19, Fourier transformers 20, two multipliers 21, a subtractor 22, and a position calculation unit 23 are connected sequentially. It is noted that the
15 three-phase/two-phase converter 19 is arranged since conversion to two-phase currents decreases information amount required for position estimation performed in steps thereafter, which leads to a simple calculation. In addition, the Fourier transformer 20 is designed to extract the
20 position detection alternating currents included in the rotary electric machine currents.

[0028] The d-axis current controller 7 uses proportional-plus-integral control or the like to eliminate a deviation Δi_d between a d-axis current command value i_d^* and i_d
25 outputted from the coordinate converter 12, the deviation Δi_d

being obtained from the subtractor 42, thereby outputting a d-axis fundamental voltage V_d^* . The q-axis current controller 8 uses the proportional-plus-integral control or the like to eliminate a deviation Δi_q between a q-axis current command value i_q^* and i_q outputted from the coordinate converter 12, the deviation Δi_q being obtained from the subtractor 42, thereby outputting a q-axis fundamental voltage V_q^* . The coordinate converter 9 uses the rotor position information outputted by the position estimation means 3 so as to convert the d-axis fundamental voltage V_d^* and the q-axis fundamental voltage V_q^* into fundamental voltages V_α^* and V_β^* on fixed two axes (α - β axes). In addition, the two-phase/three-phase converter 10 converts the fundamental voltages V_α^* and V_β^* into fundamental voltages V_u^* , V_v^* , and V_w^* of three phases, each in the form of a sine waveform or the like.

[0029] On the other hand, the three-phase/two-phase converter 11 converts the U-phase current i_u and the V-phase current i_v , which are detected by the current detection means 2, into currents i_α and i_β on the fixed two axes (α - β axes). In addition, the coordinate converter 12 uses the information θ_p of the rotor position outputted by the position estimation means 3 to convert the i_α and i_β into the currents i_d and i_q on rotating two axes (d-q axes).

[0030] The switching cycle generator 13 outputs a value of

a switching cycle T_c to the pulse-width modulation controller 15 and to the position detection voltage generator 14. It is noted that the switching cycle T_c has a significantly shorter cycle than cycles of the fundamental voltages V_u^* , V_v^* , and V_w^* of three phases, and the switching cycle T_c is set, in advance, to an optimal value in consideration of electrical characteristics of the rotary electric machine 1, a frequency of an electromagnetic noise generated due to inverter drive, and the like.

10 [0031] The position detection voltage generator 14 generates position detection voltages V_{uh} , V_{vh} , and V_{wh} , which each have a cycle $m \cdot T_c$ that is equal to m times (m is an integer of three or more, and the reason of "three or more" will be described later) of the switching cycle T_c provided from the switching cycle generator 13 and which are different in phase from one another, so as to be outputted to the adder 41.

[0032] The adder 41 superimposes the position detection voltages V_{uh} , V_{vh} , and V_{wh} at high frequencies (cycle $m \cdot T_c$), which are outputted from the position detection voltage generator 14, on the fundamental voltages V_u^* , V_v^* , and V_w^* which are outputted from the two-phase/three-phase converter 10, and outputs voltage commands V_{up}^* , V_{vp}^* , and V_{wp}^* , as the resultants, to the pulse-width modulation controller 15.

25 Here, the reason why m is an integer of three or more is that

when m is 1 or 2, the position detection voltages V_{uh} , V_{vh} , and V_{wh} of three phases, each having a cycle equal to the cycle $m \cdot T_c$, i.e., m times of the switching cycle T_c , are not different in phase from one another, and consequently it is impossible to accurately obtain the information θ_p of the rotor position by using the position estimation means 3.

[0033] In the above configuration, the adder 41 of the control means 4 superimposes the position detection voltages V_{uh} , V_{vh} , and V_{wh} on the fundamental voltages V_u^* , V_v^* , and V_w^* of three phases, respectively and individually, and applies the resultants to the rotary electric machine 1. In this case, a voltage vector, which is a vector sum of the position detection voltages V_{uh} , V_{vh} , and V_{wh} , represents a rotating voltage, instead of an alternating voltage. The alternating voltage is a voltage indicating voltage vectors in two or less directions during a cycle of the three-phase AC voltages, the voltage vectors being the sum of vectors in respective phases of the three-phase AC voltages being applied. On the other hand, the rotating voltage is a voltage indicating voltage vectors in three or more directions during a cycle of the three-phase AC voltages, the voltage vectors being the sum of vectors in respective phases of the three-phase AC voltages being applied.

[0034] As examples of the position detection voltages V_{uh} , V_{vh} , and V_{wh} outputted by the position detection voltage

generator 14, voltage waveforms thereof in the case of $m = 4$ are shown in FIG. 3(a), where a switching cycle T_c and a position detection voltage cycle T_{hv} ($= 4 \cdot T_c$) are used. Further, a vector diagram of a voltage vector V_{sum} , which is the vector sum of the position detection voltages V_{uh} , V_{vh} , and V_{wh} , is shown in FIG. 3(b). In FIG. 3(a), $+V_h$ and $-V_h$, each having an arbitrary value, are alternately outputted at every two intervals, and the phase difference among the respective phases is one interval. In this case, the voltage vector V_{sum} , which is the vector sum of the position detection voltages V_{uh} , V_{vh} , and V_{wh} , represents a rotating voltage which indicates V_{sum1} to V_{sum4} in this order in intervals $K1$ to $K4$ (FIG. 3(a)), respectively, during one cycle of the three-phase AC voltage as shown in FIG. 3(b).

[0035] It is noted that the number of intervals in which each of the position detection voltages V_{uh} , V_{vh} , and V_{wh} is either $+V_h$ or $-V_h$ need not be two intervals, but may be one interval. Alternatively, as shown in FIG. 4, the number of the intervals may be three intervals. However, when three-phase AC voltages, which each have a cycle that is m times of the switching cycle and which are different in phase from one another, are outputted, the number of intervals of either $+V_h$ or $-V_h$ needs to be in the range of 1 to $(m-1)$, and in addition, the sum of the number of intervals of $+V_h$ and $-V_h$ needs to be m intervals. Further, the phase difference among

the respective phases need not necessarily be one interval as shown in FIG. 3(a), but may be two intervals, three intervals, or the like. However, when three-phase AC voltages, which each have a cycle that is m times of the switching cycle and which are different in phase from one another, are outputted, the phase difference among the respective phases needs to be in the range of 1 to $(m-1)$. Further, the position detection voltages V_{uh} , V_{vh} , and V_{wh} , need not necessarily be represented by square waves which are shown in FIG. 3 and FIG. 4, but may be represented by sine waves.

[0036] By using the voltage commands V_{up}^* , V_{vp}^* , and V_{wp}^* outputted by the control means 4 and the value of the switching cycle T_c outputted by the switching cycle generator 13, the pulse-width modulation controller 15 generates logic signals V_{ul} , V_{vl} , and V_{wl} which are pulse-width modulated and which are supplied to the inverter 6. As a pulse-width modulation control method, any of the following methods may be used, i.e., (a) a pulse-width modulation control method using a triangle wave C_s as a carrier signal, (b) a pulse-width modulation control method using a saw-tooth wave W_{st} as a carrier signal, and (c) a pulse-width modulation control method using instantaneous space voltage vector V_s .

[0037] First, the pulse-width modulation control method using the triangle wave C_s will be described. FIG. 5 shows a waveform of the pulse-width modulation operation in the case

where the pulse-width modulation control method using the triangle wave C_s is used. In the pulse-width modulation control method using the triangle wave C_s , a cycle T_{cs} of the triangle wave C_s is set to two times (i.e., $T_{cs} = 2T_c$) of the switching cycle T_c outputted by the switching cycle generator 13.

[0038] With reference to FIG. 5, the pulse-width modulation operation performed by the pulse-width modulation controller 15 will be described, specifically. It is noted that, in FIG. 5, although the voltage commands V_{up}^* , V_{vp}^* , and V_{wp}^* are sine wave signals, the voltage commands are represented linearly since the frequencies of the voltage commands are lower as compared to the carrier signal of the triangle wave C_s or the position detection voltages V_{uh} , V_{vh} , and V_{wh} . Further, although the position detection voltages V_{uh} , V_{vh} , and V_{wh} are superimposed on the voltage commands V_{up}^* , V_{vp}^* , and V_{wp}^* , actually, the superimposed voltages are omitted from the drawing since the pulse-width modulation operation will be explained herein.

[0039] As shown in FIG. 5, the magnitude relation between the triangle wave C_s and each of the voltage commands V_{up}^* , V_{vp}^* , and V_{wp}^* is obtained. When the magnitude of each of the voltage commands V_{up}^* , V_{vp}^* , and V_{wp}^* is greater than the magnitude of the triangle wave C_s , then a Hi logic signal is outputted. On the other hand, when the magnitude of each of

the voltage commands is lower, a Low logic signal is outputted. It may be set such that upon comparison of the magnitude between the triangle wave C_s and each of the voltage commands V_{up}^* , V_{vp}^* , and V_{wp}^* , when the magnitude of each of the voltage commands V_{up}^* , V_{vp}^* , and V_{wp}^* is greater than the magnitude of the triangle wave C_s , then a Low logic signal is outputted, whereas when the magnitude of each of the voltage commands is lower, then a Hi logic signal is outputted.

10 [0040] Next, a pulse-width modulation control method using the saw-tooth wave W_{st} will be described. FIG. 6 is a waveform of the pulse-width modulation operation in the case where the pulse-width modulation control method using the saw-tooth wave W_{st} is used. In the pulse-width modulation control method using the saw-tooth wave W_{st} , the cycle T_{wst} of the saw-tooth wave W_{st} is the same as the switching cycle T_c outputted by the switching cycle generator 13.

[0041] With reference to FIG. 6, the pulse-width modulation operation will be described specifically. As shown in FIG. 6, the magnitude relation between the saw-tooth wave W_{st} and each of the voltage commands V_{up}^* , V_{vp}^* , and V_{wp}^* is obtained. When the magnitude of each of the voltage commands V_{up}^* , V_{vp}^* , and V_{wp}^* is greater than the magnitude of the saw-tooth wave W_{st} , a Hi logic signal is outputted, whereas when the magnitude of each of the voltage commands is

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lower, a Low logic signal is outputted. It may be set such that upon comparison of the magnitude between the saw-tooth wave W_{st} and each of the voltage commands V_{up}^* , V_{vp}^* , and V_{wp}^* , when the magnitude of the voltage commands V_{up}^* , V_{vp}^* , and V_{wp}^* is greater than the magnitude of the saw-tooth wave W_{st} , a Low logic signal is outputted, whereas when the voltage commands are lower, a Hi logic signal is outputted.

[0042] Next, a pulse-width modulation control method using the instantaneous space voltage vector V_s will be described.

10 In the pulse-width modulation control method, the vector sum of the voltage commands V_{up}^* , V_{vp}^* , and V_{wp}^* outputted by the control means 4 is set as the instantaneous space voltage vector V_s , and logic signals V_{ul} , V_{vl} , and V_{wl} are time-shared and combined within an arbitrary time frame T_f so that
15 the magnitude and the direction thereof coincide with the magnitude and the direction of the instantaneous space voltage vector V_s , whereby an average of the vector sum of the logic signals within the arbitrary time frame T_f is controlled so as to coincide with the instantaneous space
20 voltage vector V_s . In the present embodiment, the arbitrary time frame T_f is the same as the switching cycle T_c outputted by the switching cycle generator 13.

[0043] With reference to FIG. 7, the pulse-width modulation operation will be described specifically. FIG. 7
25 is an explanatory diagram illustrating an operation of the

instantaneous space voltage vector control method. FIG. 7(a) is a diagram showing combinations of logic signals outputted by the pulse-width modulation controller 15, and FIG. 7(b) is a diagram showing eight voltage vectors obtained by combining the logic signals shown in FIG. 7(a). A vector V0 and a vector V7 shown in FIG. 7(a) and FIG. 7(b) are each indicated as a zero-voltage vector since the vector V0 and the vector V7 represent Low and Hi in their all switches, respectively, and thus the vectors do not have magnitude or direction. For example, as shown in FIG. 7(c), suppose a case where the instantaneous space voltage vector Vs, which is a vector sum of the voltage commands Vup*, Vvp*, and Vwp* outputted by the control means 4, is provided, and the instantaneous space voltage vector Vs is outputted during the arbitrary time frame Tf. The instantaneous space voltage vector Vs can be divided into a vector V1 direction and a vector V2 direction, and the magnitude of the instantaneous space voltage vector Vs divided into the vector V1 direction is regarded as V1s, and the magnitude of that divided into the vector V2 direction is regarded as V2s.

[0044] Based on the V1s and V2s, output time T1 of the vector V1 and output time T2 of the vector V2 during the arbitrary time frame Tf are calculated using Formulas (1) and (2) described below.

[Formula 1]

$$T1 = V1s \div V1 \times Tf \quad (1)$$

[Formula 2]

$$T2 = V2s \div V2 \times Tf \quad (2)$$

[0045] Further output time T3 of the zero-voltage vector during the arbitrary time frame Tf is calculated using Formula (3) described below.

[Formula 3]

$$T3 = Tf - T1 - T2 \quad (3)$$

[0046] As described above, the output times T1, T2, and T3 are calculated, and based on the respective output times T1 to T3, combinations of the logic signals of the vector V1, the vector V2, and the vector V0 or V7 are outputted from the pulse-width modulation controller 15, as shown in FIG. 7(d). Accordingly, the average in the output times during the arbitrary time frame Tf is set to coincide with the instantaneous space voltage vector Vs.

[0047] When the zero-voltage vector is outputted, the combinations of logic signals of both the vector V0 and the vector V7 may be used. However, when the respective phase voltages are viewed from a neutral point of the rotary electric machine 1, whichever of the vector V0 and the vector V7 may be used, the potentials of the respective phase

voltages of the rotary electric machine 1 are equal to each other and do not show any difference. Thus, it is not necessary to use both of the vector V_0 and the vector V_7 , but a combination of logic signals of only either one thereof may
5 be used.

[0048] Next, an operation of the position estimation means 3 will be described.

As shown in FIG. 2, the three-phase/two-phase converter 19 converts rotary electric machine currents i_u and
10 i_v which are detected by the current detection means 2 to two-phase currents $i_{\alpha s}$ and $i_{\beta s}$ on an α - β axis system. As described above, the position detection voltages V_{uh} , V_{vh} , and V_{wh} , which are higher frequency voltages than the fundamental voltages are superimposed on the three-phase
15 fundamental voltages V_u^* , V_v^* , and V_w^* , and accordingly, high-frequency position detection alternating currents corresponding to the position detection voltages V_{uh} , V_{vh} , V_{wh} are generated in the rotary electric machine currents detected by the current detection means 2. Therefore,
20 Fourier transformers 20 arranged subsequently extract the amplitudes (magnitude) $I_{\alpha s}$ and $I_{\beta s}$ of the position detection alternating currents from the two-phase currents $i_{\alpha s}$ and $i_{\beta s}$, which are outputs from the three-phase/two-phase converter 19. Subsequently, for the sake of simple calculation processing,
25 the multipliers 21 square $I_{\alpha s}$ and $I_{\beta s}$, which are outputs from

the Fourier transformers 20, respectively, and then output
($I_{as} \cdot I_{as}$) and ($I_{\beta s} \cdot I_{\beta s}$). Next, the subtractor 22 outputs
difference $\Delta I_{\alpha\beta}$ therebetween by subtracting ($I_{as} \cdot I_{as}$) from
($I_{\beta s} \cdot I_{\beta s}$). The position calculation unit 23 then calculates
5 a rotor position θ_p , based on the difference $\Delta I_{\alpha\beta}$, which is
an output of the subtractor 22.

[0049] The rotor position θ_p obtained as above is not
based on direct detection of the position using a sensor or
the like, but is based on an estimate value obtained by
10 calculation. That is, obtaining the rotor position θ_p in the
present invention indicates that it is possible to estimate
an accurate rotor position sensorlessly. Hereinafter,
details of processing of obtaining the rotor position θ_p by
position estimation means 3 will be described, further
15 specifically.

[0050] In the case where the rotary electric machine 1 is
an interior permanent magnet synchronous machine, a voltage
equation on fixed rectangular coordinates (α - β axes) can be
expressed as Formula (4) described below.

20 [Formula 4]

$$\begin{bmatrix} V_{\alpha s} \\ V_{\beta s} \end{bmatrix} = \begin{bmatrix} R + PL\alpha & PL\alpha\beta \\ PL\alpha\beta & R + PL\beta \end{bmatrix} \begin{bmatrix} i_{\alpha s} \\ i_{\beta s} \end{bmatrix} + \omega\phi \begin{bmatrix} -\sin\theta \\ \cos\theta \end{bmatrix} \quad (4)$$

where,

$[V_{\alpha s} \ V_{\beta s}]^T$: voltage value on fixed rectangular coordinates

10 $[i_{\alpha s} \ i_{\beta s}]^T$: current value on fixed rectangular coordinates (two-phase currents)

R : stator resistance, P : differential operator

Ld : d-axis inductance, Lq : q-axis inductance

ω : rotational angular velocity (electrical angle)

20 θ : phase difference between a-axis and magnetic pole

$$\begin{cases} L = (L_d + L_q)/2 \\ l = (L_d - L_q)/2 \end{cases} \quad \begin{cases} L\alpha = L + l \cos 2\theta \\ L\beta = L - l \cos 2\theta \\ L\alpha\beta = l \sin 2\theta \end{cases}$$

[0051] Suppose that the rotary electric machine 1 is in a stopped state or in a low-speed operation state. When ω is set to satisfy $\omega = 0$, and the differential operator P is replaced with a Laplace operator s, the currents $i_{\alpha s}$ and $i_{\beta s}$ in the fixed rectangular coordinates is expressed as Formula (5) below.

[Formula 5]

$$35 \quad \begin{bmatrix} i_{\alpha s} \\ i_{\beta s} \end{bmatrix} = \begin{bmatrix} R + sL\alpha & sL\alpha\beta \\ sL\alpha\beta & R + sL\beta \end{bmatrix}^{-1} \begin{bmatrix} v_{\alpha s} \\ v_{\beta s} \end{bmatrix} \quad (5)$$

[0052] Here, when the position detection voltages V_{uh} , V_{vh} , and V_{wh} each having an angular frequency ω_h , which is sufficiently higher than the angular frequency of the AC

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voltages for driving the rotary electric machine 1 are applied from the position detection voltage generator 14, $R \ll L\alpha \cdot \omega h$ and $R \ll L\beta \cdot \omega h$ are satisfied (in the case of $s = j\omega h$ (j is an imaginary unit)). When the effect of a stator resistance R is ignored, Formula (5) is expressed as Formula (6) below.

[0053]

[Formula 6]

$$\begin{aligned}
 10 \quad \begin{bmatrix} i\alpha s \\ i\beta s \end{bmatrix} &= \begin{bmatrix} sL\alpha & sL\alpha\beta \\ sL\alpha\beta & sL\beta \end{bmatrix}^{-1} \begin{bmatrix} v\alpha s \\ v\beta s \end{bmatrix} \\
 &= \frac{1}{s^2(L\alpha L\beta - L\alpha\beta^2)} \begin{bmatrix} sL\beta & -sL\alpha\beta \\ -sL\alpha\beta & sL\alpha \end{bmatrix} \begin{bmatrix} v\alpha s \\ v\beta s \end{bmatrix} \\
 &= \frac{1}{(L^2 - l^2)s} \begin{bmatrix} L - l \cos 2\theta & -l \sin 2\theta \\ -l \sin 2\theta & L + l \cos 2\theta \end{bmatrix} \begin{bmatrix} v\alpha s \\ v\beta s \end{bmatrix}
 \end{aligned} \quad (6)$$

[0054] Further, the position detection voltages V_{uh} , V_{vh} , and V_{wh} applied by the position detection voltage generator 14 can be expressed as Formula (7) below, on the fixed rectangular coordinates.

[0055]

[Formula 7]

$$\begin{cases} V_{\alpha sh} = V_{\alpha\beta h} \cdot \sin \omega h \cdot t \\ V_{\beta sh} = V_{\alpha\beta h} \cdot \cos \omega h \cdot t \end{cases} \quad (7)$$

where,

$[V_{\alpha sh} \ V_{\beta sh}]^T$: position detection voltage values on fixed rectangular coordinates

$V_{\alpha\beta h}$: amplitude of position detection voltages on fixed rectangular coordinates

ωh : angular frequency of position detection voltages

[0056] The position detection voltage values in Formula (7) on the fixed rectangular coordinates are expressed as Formula (8) below.

[Formula 8]

$$[V_{\alpha sh} \ V_{\beta sh}]^T \quad (8)$$

[0057] Therefore, when values of the position detection voltages in Formula (8) are substituted for $[V_{\alpha s} \ V_{\beta s}]$, in Formula (6), on the fixed rectangular coordinate system, and when $s = j\omega h$ (j is an imaginary unit) is applied, Formula (9) as follows can be obtained.

[0058]

15 [Formula 9]

$$\left. \begin{aligned} i_{\alpha s} &= \frac{V_{\alpha \beta h}}{(L^2 - l^2)j\omega h} \{ (L - l \cos 2\theta) \sin \omega h \cdot t - l \sin 2\theta \cos \omega h \cdot t \} \\ &= -j \frac{V_{\alpha \beta h}}{(L^2 - l^2)\omega h} \sqrt{L^2 + l^2 - 2Ll \cos 2\theta} \cdot \sin(\omega h \cdot t - \varphi_{\alpha}) \\ i_{\beta s} &= \frac{V_{\alpha \beta h}}{(L^2 - l^2)j\omega h} \{ -l \sin 2\theta \sin \omega h \cdot t + (L + l \cos 2\theta) \cos \omega h \cdot t \} \\ &= -j \frac{V_{\alpha \beta h}}{(L^2 - l^2)\omega h} \sqrt{L^2 + l^2 + 2Ll \cos 2\theta} \cdot \cos(\omega h \cdot t + \varphi_{\beta}) \end{aligned} \right\} \quad (9)$$

$$\text{where, } \varphi_{\alpha} = \tan^{-1} \left(\frac{l \sin 2\theta}{L - l \cos 2\theta} \right) \quad \varphi_{\beta} = \tan^{-1} \left(\frac{l \sin 2\theta}{L + l \cos 2\theta} \right)$$

[0059] As shown in Formula (9), it is found that the amplitudes of the currents $i_{\alpha s}$ and $i_{\beta s}$ on the fixed rectangular coordinates include rotor position information θ (= rotor position θ_p). Therefore, by using the Fourier

transformers 20, the amplitudes I_{as} and $I_{\beta s}$ of the currents i_{as} and $i_{\beta s}$ on the fixed rectangular coordinates are extracted. That is, by using the Fourier transformers 20, the currents i_{as} and $i_{\beta s}$ of high frequency, which are caused by the position detection voltages V_{uh} , V_{vh} , and V_{wh} , are extracted from the rotary electric machine currents, and the amplitudes I_{as} and $I_{\beta s}$ thereof are obtained. Based on the extracted amplitudes I_{as} and $I_{\beta s}$, calculation using the following Formula (10) is performed. Accordingly, it is possible to extract a term which includes the rotor position information θ only. To realize the calculation, the multipliers 21 are used to square the amplitudes I_{as} and $I_{\beta s}$, respectively, and the subtractor 22 is used to subtract $(I_{as} \cdot I_{as})$ from $(I_{\beta s} \cdot I_{\beta s})$, which are outputs from the multipliers 21, and to output $\Delta i_{\alpha\beta}$ which includes information of the rotor position θ .

[0060]

[Formula 10]

$$\begin{aligned}
 \Delta I_{\alpha\beta} = I_{\beta s}^2 - I_{as}^2 &= \left\{ -j \frac{V_{\alpha\beta h}}{(L^2 - l^2)\omega h} \sqrt{L^2 + l^2 + 2Ll \cos 2\theta} \right\}^2 \\
 &\quad - \left\{ -j \frac{V_{\alpha\beta h}}{(L^2 - l^2)\omega h} \sqrt{L^2 + l^2 - 2Ll \cos 2\theta} \right\}^2 \\
 &= \frac{4V_{\alpha\beta h}^2 Ll}{(L^2 - l^2)^2 \omega h^2} \cos 2\theta
 \end{aligned} \tag{10}$$

[0061] In the position calculation unit 23, $\Delta i_{\alpha\beta}$ in

Formula (10) is divided by Formula (11) below, whereby only cos2θ is extracted. By calculating an inverse cosine of cos2θ, θ (rotor position θ_p) is obtained. As to the calculation of the rotor position θ_p, the rotor position θ_p may be obtained not by using the inverse cosine operation, but by preparing a table having stored therein values of cos2θ and by using the values of cos2θ stored in a storage device.

[Formula 11]

$$\frac{4V\alpha\beta h^2 Ll}{(L^2 - l^2)^2 \omega h^2} \quad (11)$$

[0062] As described above, in the first embodiment, based on the switching cycle T_c, the position detection voltages V_{uh}, V_{vh}, and V_{wh}, which each have a cycle m·T_c that is m times (m is an integer of three or more) of the switching cycle T_c and which are different in phases from one another, are superimposed on the fundamental voltages V_u*, V_v*, and V_w*, and the resultants are outputted. Thus, unlike the conventional art, it is not necessary to generate carrier signals of three phases, and it is possible to easily output the position detection voltages (position detection voltage commands). In addition, since the rotor position can be obtained by using the rotary electric machine currents only, it is possible to estimate the rotor position of the rotary electric machine 1 with a simple configuration, and also

possible to simplify calculations, which leads to a reduction in the computational complexity. Further, even when a current sampling is performed in the vicinity of a peak or a trough of a carrier signal of a triangle wave, a saw-tooth wave, or the like, it is not necessary to generate carrier signals of three phases. Therefore, it is possible to perform the current sampling while reducing the effect of a switching noise or the like caused by inverter switching.

[0063] Second Embodiment

FIG. 8 is a block diagram showing position estimation means in a controller of a rotary electric machine according to a second embodiment of the present invention.

[0064] In the position estimation means 3 of the first embodiment, the rotor position θ_p is calculated by using the inverse cosine operation, or by preparing a table having a value of $\cos 2\theta$ stored therein and using the value. However, in such methods, there may be a possibility of an increase in the computational complexity. Thus, in the second embodiment, the computational complexity is reduced as compared to the first embodiment, and the rotor position θ_p is obtained simply.

[0065] In FIG. 8, the position estimation means 3 includes three circuits: i.e., a first circuit including a three-phase/two-phase converter 24, Fourier transformers 20, multipliers 21, and a subtractor 22; a second circuit

including a three-phase/two-phase converter 25, Fourier transformers 20, multipliers 21, and a subtractor 22; and a third circuit including a three-phase/two-phase converter 26, Fourier transformers 20, multipliers 21, and a subtractor 22.

5 An output from each of the subtractors 22 is provided to a position calculation unit 27.

[0066] The three-phase/two-phase converter 24 in the first circuit performs three-phase/two-phase conversion so that a stator U-phase direction coincides with a directions of two-
10 phase currents after conversion, and outputs two-phase currents i_{asu} and $i_{\beta su}$. The three-phase/two-phase converter 25 in the second circuit performs the three-phase/two-phase conversion so that a stator V-phase direction coincides with a directions of two-phase currents after conversion, and
15 outputs two-phase currents i_{asv} and $i_{\beta sv}$. The three-phase/two-phase converter 26 in the third circuit performs the three-phase/two-phase conversion so that a stator W-phase direction coincides with a directions of two-phase currents after conversion, and outputs two-phase currents i_{asw} and
20 $i_{\beta sw}$.

[0067] In a similar manner to the first embodiment, an amplitude is extracted from each of the two-phase currents outputted from the three-phase/two-phase converters 24, 25, and 26 by using the Fourier transformer 20, and is squared by
25 the multiplier 21. Then, by using the subtractor 22, the

square of the amplitude of each a current is subtracted from the square of the amplitude of each β current, whereby differences $\Delta I_{\alpha\beta u}$, $\Delta I_{\alpha\beta v}$, and $\Delta I_{\alpha\beta w}$ are obtained. In this case, the respective differences $\Delta I_{\alpha\beta u}$, $\Delta I_{\alpha\beta v}$, and $\Delta I_{\alpha\beta w}$ are
 5 expressed as Formula (12) below.

[0068]

[Formula 12]

$$\left. \begin{aligned} \Delta I_{\alpha\beta u} &= \frac{4V\alpha\beta h^2 Ll}{(L^2 - l^2)^2 \omega h^2} \cos 2\theta \\ \Delta I_{\alpha\beta v} &= \frac{4V\alpha\beta h^2 Ll}{(L^2 - l^2)^2 \omega h^2} \cos(2\theta + 2/3\pi) \\ 15 \quad \Delta I_{\alpha\beta w} &= \frac{4V\alpha\beta h^2 Ll}{(L^2 - l^2)^2 \omega h^2} \cos(2\theta - 2/3\pi) \end{aligned} \right\} (12)$$

where, stator U-phase direction satisfies $\theta=0$

20 [0069] According to the magnitude relation among $\Delta I_{\alpha\beta u}$, $\Delta I_{\alpha\beta v}$, and $\Delta I_{\alpha\beta w}$, the position calculation unit 27 generates intervals I to VI as shown in FIG. 9. In each interval, one of $\Delta I_{\alpha\beta u}$, $\Delta I_{\alpha\beta v}$, and $\Delta I_{\alpha\beta w}$, which crosses the zero point, is approximated by using linear approximation, and the rotor
 25 position θ_p is obtained by using Formula (13) below.
 $\Delta I_{\alpha\beta_uvw}$ in Formula (13) is a value, in $\Delta I_{\alpha\beta u}$, $\Delta I_{\alpha\beta v}$, and $\Delta I_{\alpha\beta w}$, which crosses the zero point, and $|\Delta I_{\alpha\beta_uvw}|$ represents the amplitude of one of the $\Delta I_{\alpha\beta u}$, $\Delta I_{\alpha\beta v}$, and $\Delta I_{\alpha\beta w}$ which crosses the zero point. It is noted that
 30 $|\Delta I_{\alpha\beta_uvw}|$ may be obtained from the square route of the sum of the respective squares of $\Delta I_{\alpha\beta u}$, $\Delta I_{\alpha\beta v}$, and $\Delta I_{\alpha\beta w}$.

[Formula 13]

5
$$\theta_p = \Delta I a \beta_{uvw} / |\Delta I a \beta_{uvw}| \quad (13)$$

[0070] With the above configuration, it is possible to simply obtain the rotor position θ_p without performing the inverse cosine operation or using the table having stored
10 therein a cosine value, which is performed in the first embodiment, and also possible to reduce the computational complexity.

Other configurations, and operations and effects are similar to those of the first embodiment, and thus
15 details thereof will be omitted herein.

[0071] Third Embodiment

FIG. 10 is a block diagram showing a configuration of a controller of a rotary electric machine according to a third embodiment. Those component parts which correspond to
20 component parts of the first embodiment are provided with identical reference characters.

[0072] In the third embodiment, the controller of the rotary electric machine includes rotary electric machine constant input means 16 which inputs a constant of the rotary
25 electric machine 1 (e.g., an inductance value or the like of the rotary electric machine 1). Based on the constant of the rotary electric machine obtained from the rotary electric machine constant input means 16, a position detection voltage

generator 14 of a control means 4 determines position detection voltages V_{uh} , V_{vh} , and V_{wh} of three phases which each have a cycle ($= m \cdot T_{cl}$) that is equal to m times (m is an integer of three or more) of a switching cycle T_{cl} and which
5 are different in phase from one another.

[0073] That is, in the third embodiment, the constant of the rotary electric machine is inputted from the rotary electric machine constant input means 16 to a switching cycle generator 13 and to the position detection voltage generator
10 14. Based on the inputted constant of the rotary electric machine, the switching cycle generator 13 determines an optimal switching cycle T_{cl} so as to be outputted to a pulse-width modulation controller 15 and to the position detection voltage generator 14.

15 [0074] On the other hand, based on the inputted constant of the rotary electric machine, the position detection voltage generator 14 determines an optimal multiple m , calculates a product between the switching cycle T_{cl} outputted by the switching cycle generator 13 and the
20 multiple m , and outputs the position detection voltages V_{uh} , V_{vh} , and V_{wh} which each have a cycle $m \cdot T_{cl}$ and which are different in phase from one another. The position detection voltages V_{uh} , V_{vh} , and V_{wh} are superimposed, by an adder 41, on the fundamental voltages V_u^* , V_v^* , and V_w^* , and as a
25 result, voltage commands V_{up}^* , V_{vp}^* , and V_{wp}^* are supplied to

the pulse-width modulation controller 15. In the same manner as the first embodiment, the pulse-width modulation controller 15 uses a pulse-width control method based on the switching cycle T_{c1} , and outputs logic signals V_{u1} , V_{v1} , and V_{w1} to an inverter 6.

[0075] The amplitude (magnitude) of the high-frequency currents included in the rotary electric machine currents detected from the rotary electric machine 1 vary depending on the position detection voltages V_{uh} , V_{vh} , and V_{wh} which each have a cycle equal to m times ($= m \cdot T_c$) of the switching cycle T_c and which are different in phase from one another. Thus, with the characteristics of the rotary electric machine 1 being ignored, when m and T_c are constantly fixed value, there may be a case where the amplitudes (magnitude) of the high-frequency currents generated in the rotary electric machine 1 are decreased due to application of the position detection voltages V_{uh} , V_{vh} , and V_{wh} , and as a result, accuracy of the high-frequency currents detected by the current detection means 2 deteriorates, which leads to deterioration in accuracy in estimation of the rotor position.

[0076] On the other hand, in the third embodiment, based on the constant of the rotary electric machine, the constant depending on the type of the rotary electric machine 1, an appropriate value of at least either of the multiple m or the switching cycle T_c is calculated, and the cycle of the

position detection voltages V_{uh} , V_{vh} , and V_{wh} which are different in phase from one another is determined such that the cycle is equal to m times of the switching cycle T_c . Therefore, even when the rotary electric machine 1 having a
5 different rotary electric machine constant is driven, the controller is capable of accurately estimating the rotor position of the rotary electric machine 1.

Since other configurations, and operations and effects of the present embodiment are similar to those of the
10 first embodiment, detailed description thereof will be omitted herein.

[0077] Fourth Embodiment

FIG. 11 is a block diagram showing a configuration of a controller of a rotary electric machine according to a
15 fourth embodiment. Those component parts which correspond to the component parts of the first embodiment are provided with identical reference characters.

[0078] In the fourth embodiment, the controller of the rotary electric machine includes position detection voltage
20 cycle input means 17. In the position detection voltage cycle input means 17, a cycle or a frequency of position detection voltages V_{uh} , V_{vh} , and V_{wh} outputted by the position detection voltage generator 14 is set and inputted so as to change either of the cycle or the frequency.
25 Accordingly, in the position detection voltage generator 14,

a multiple m (m is an integer of three or more) of a switching cycle T_c set by the switching cycle generator 13 is determined.

[0079] Namely, in the fourth embodiment, the position
5 detection voltage cycle input means 17 determines either of the cycle or the frequency of the position detection voltages V_{uh} , V_{vh} , and V_{wh} outputted by the position detection voltage generator 14. For example, when a user inputs an arbitrary cycle to the position detection voltage cycle input means 17,
10 the position detection voltage generator 14 determines, based on the cycle obtained from the position detection voltage cycle input means 17, the multiple m (m is an integer of three or more) by which the switching cycle T_c is multiplied to set the cycle of the position detection voltages V_{uh} , V_{vh} ,
15 and V_{wh} . Further, when a user inputs an arbitrary frequency to the position detection voltage cycle input means 17, the position detection voltage generator 14 calculates a reciprocal of the frequency obtained from the position detection voltage cycle input means 17 so as to obtain the
20 cycle of the position detection voltages, and determines, based on the obtained cycle, the multiple m (m is an integer of three or more) by which the switching cycle T_c is multiplied to set the cycle of the position detection voltages V_{uh} , V_{vh} , and V_{wh} .

25 [0080] In this manner, in the fourth embodiment, with

arrangement of the position detection voltage cycle input means 17, the cycle or the frequency of the respective position detection voltages V_{uh} , V_{vh} , and V_{wh} applied to the rotary electric machine 1 can be changed arbitrarily, and thus, it is possible to change a frequency of a noise being generated, thereby reducing a discomfortable feeling caused by the noise.

Since other configurations, and operations and effects of the present embodiment are similar to those of the first embodiment, detailed description thereof will be omitted herein.

[0081] Fifth Embodiment

In the first embodiment, the position detection voltage generator 14 outputs the position detection voltages V_{uh} , V_{vh} , and V_{wh} , which each have a cycle equal to m times of the switching cycle T_c outputted by the switching cycle generator 13 and which are different in phase from one another, where m is set as an integer of three or more. However, the value of m is not specified.

[0082] In the fifth embodiment, the value of m is limited to $6n$ (n is a natural number). Namely, a cycle T_{hv} of the position detection voltages V_{uh} , V_{vh} , and V_{wh} is limited to $6n$ times (n is a natural number) of the switching cycle T_c . Accordingly, the phase difference among the position detection voltages V_{uh} , V_{vh} , and V_{wh} is 120° , and the

position detection voltages V_{uh} , V_{vh} , and V_{wh} can be set as balanced three-phase voltage commands.

[0083] As an example, voltage waveforms in the case of $n = 1$ are shown in FIG. 12, where the switching cycle T_c and the position detection voltage cycle T_{hv} are used. In FIG. 12, $+V_h$ and $-V_h$, each having an arbitrary value, are outputted alternately at every three intervals, and the phase difference among the position detection voltages V_{uh} , V_{vh} , and V_{wh} is two intervals. In this case, since the cycle T_{hv} of the position detection voltages has six intervals, the phase difference between two intervals is $360^\circ / 6 \text{ intervals} \times 2 \text{ intervals} = 120^\circ$, and consequently, the position detection voltages V_{uh} , V_{vh} , and V_{wh} become balanced three-phase AC voltages. Therefore, it is possible to minimize the effect of application of unbalanced three-phase AC voltages to the rotary electric machine 1. In addition, compared to a case where the unbalanced three-phase AC voltages are applied, it is possible to simplify calculation, such as Fourier transformation or the like, required for position estimation.

Since other configurations, and operations and effects of the present embodiment are similar to those of the first embodiment, detailed description thereof will be omitted herein.

[0084] Sixth Embodiment

FIG. 13 is a block diagram showing a configuration

of a controller of a rotary electric machine according to a sixth embodiment. Those component parts which correspond to the component parts of the first embodiment are provided with identical reference characters.

5 [0085] In the sixth embodiment, a control means 4 has a speed calculation unit 18 for calculating, based on a rotor position θ_p outputted by position calculation means 3, a rotation speed of a rotary electric machine 1. Information of the rotation speed calculated by the speed calculation
10 unit 18 is provided to the position detection voltage generator 14.

[0086] When the rotation speed of the rotary electric machine 1 is relatively high, it is possible to easily estimate the rotor position of the rotary electric machine 1
15 by using an induced voltage of the rotary electric machine 1, not by superimposing position detection voltages V_{uh} , V_{vh} , and V_{wh} on fundamental voltages V_u^* , V_v^* , and V_w^* . In the sixth embodiment, when the rotation speed of the rotary electric machine 1 outputted by the speed calculation unit 18
20 reaches a predetermined speed or more, the position detection voltage generator 14 sets the position detection voltages V_{uh} , V_{vh} , and V_{wh} to zero, so that the position detection voltages do not affect the fundamental voltages V_u^* , V_v^* , and V_w^* . In addition, the estimation method is switched to a method in
25 which the rotor position of the rotary electric machine is

estimated based on the induced voltage of the rotary electric machine 1.

[0087] By using the above configuration, it is possible to eliminate extra energy loss which is caused by applying, to
5 the rotary electric machine 1, high-frequency voltages including the position detection voltages V_{uh} , V_{vh} , and V_{wh} which each have a cycle equal to m times of the switching cycle and which are different in phase from one another.

Since other configurations, and operations and
10 effects of the present embodiment are similar to those of the first embodiment, detailed description thereof will be omitted herein.

[0088] Seventh Embodiment

First, prior to description of a controller of a
15 rotary electric machine according to a seventh embodiment of the present invention, a conventional technique will be described, in which, as described in BACKGROUND ART, for the sake of reduction in costs of a current sensor, a DC bus current which flows between the DC voltage source supplying a
20 DC voltage to an inverter and the inverter is detected using a current sensor, and then the phase, of the rotary electric machine 1, in which the current is currently flowing is obtained by calculation based on the difference in switching timing among switches of the respective phases of the
25 inverter at the time of detecting the DC bus current.

[0089] FIG. 14 is a block diagram showing a controller of a conventional rotary electric machine including a rotary electric machine current calculation means 30 which calculates a rotary electric machine current from a DC bus current I_{dc} which is detected by a single piece of bus current detection means (current sensor) 29. It is noted that, in FIG. 14, the rotary electric machine 1 is not provided with position estimation means but is provided with a rotor position sensor 31 for detecting a rotating position of the machine. However, since such a configuration is not directly related to calculation of the rotary electric machine currents performed by the rotary electric machine current calculation means 30, description thereof will be omitted.

[0090] The controller of the rotary electric machine shown in FIG. 14 includes the bus current detection means 29, which is a single current sensor, for detecting a DC bus current I_{dc} flowing between a DC voltage source 28 and an inverter 6, and also includes the rotary electric machine current calculation means 30 for calculating rotary electric machine currents i_u and i_v which flow to the rotary electric machine 1 in accordance with the DC bus current I_{dc} detected by the bus current detection means 29 and with logic signals V_{ul} , V_{vl} , and V_{wl} outputted from a pulse-width modulation means 5.

[0091] FIG. 15 shows temporal changes (FIG. 15(a)) of

fundamental voltages V_u^* , V_v^* , and V_w^* outputted from a two-phase/three-phase converter 10 and a triangle wave C_s in the case where a pulse-width modulation control method using the triangle wave C_s is used, and also shows temporal changes
5 (FIG. 15(b)) of logic signals V_{u1} , V_{v1} , and V_{w1} outputted from the pulse-width modulation controller 15. The pulse-width modulation controller 15 outputs "Hi" logic signals V_{u1} , V_{v1} , and V_{w1} when the respective fundamental voltages V_u^* , V_v^* , and V_w^* are greater than the triangle wave C_s , and on
10 the other hand, outputs "Low" logic signals V_{u1} , V_{v1} , and V_{w1} when the fundamental voltages are lower than the triangle wave C_s .

[0092] FIG. 16 is a block diagram showing the state of connection between the DC voltage source 28 and the bus
15 current detection means 29, and connection between the DC voltage source 28 and the inverter 6.

Switches U_P , V_P , W_P , U_N , V_N , W_N of the inverter 6 is turned ON/OFF by a gate drive circuit 31 in accordance with logic signals V_{u1} , V_{v1} , and V_{w1} which are outputted from
20 the pulse-width modulation means 5. For example, the switch U_P is turned ON and OFF when the logic signal V_{u1} is "Hi" and "Low", respectively. The switch U_N is turned ON and OFF when the logic signal V_{u1} is "Low" and "Hi", respectively. The switch V_P is turned ON and OFF when the logic signal V_{v1} is
25 "Hi" and "Low", respectively. The switch V_N is turned ON and

OFF when the logic signal V_{w1} is "Low" and "Hi", respectively.
The switch WP is turned ON and OFF when the logic signal V_{w1}
is "Hi" and "Low", respectively. The switch WN is turned ON
and OFF when the logic signal V_{w1} is "Low" and "Hi",
5 respectively.

[0093] Next, an operating principle of calculation of the
rotary electric machine currents by using the DC bus current
 I_{dc} will be described.

When the logic signals are outputted as shown in
10 FIG. 15(b), in an interval T_1 , the switches UP, VP, and WN
are turned ON, and the remaining switches are turned OFF.
Thus, at the switching timing in the interval T_1 , a current
 i_w flowing in a W-phase of the rotary electric machine 1 is
identical to the current I_{dc} detected by the bus current
15 detection means 29. Next, in an interval T_2 , the switches UP,
VN, and WN are turned ON, and the remaining switches are
turned OFF. Thus, during the switching timing of interval T_2 ,
a current i_u flowing in a U-phase of the rotary electric
machine 1 is identical to the current I_{dc} detected by the bus
20 current detection means 29. That is, in the interval T_1 , the
rotary electric machine current i_w of the W-phase can be
obtained, and in the interval T_2 , the rotary electric machine
current i_u of the U-phase can be obtained. A rotary electric
machine current i_v of the remaining V-phase can be obtained
25 using Formula (14) below since the sum of the three-phase

currents is zero. In this manner, the bus current detection means 29 is capable of detecting the rotary electric machine currents i_u , i_v , and i_w of three phases during a half cycle (switching cycle T_c) of the triangle wave C_s .

5 [Formula 14]

$$i_v = -(i_u + i_w) \quad (14)$$

10 [0094] In this manner, based on the difference in the switching timing among the logic signals V_{u1} , V_{v1} , and V_{w1} , which are outputted from the pulse-width modulation means 5, and on the DC bus current I_{dc} detected by the bus current detection means 29, the rotary electric machine current
15 detection means 30 identifies the phase, of the rotary electric machine 1, in which a current corresponding to the detected DC bus current I_{dc} is flowing, and calculates the rotary electric machine current of each phase.

[0095] For detecting three-phase currents, it is
20 essentially preferable to detect rotary electric machine currents of three phases at the same timing. However, since the difference in the switching timing among the logic signals V_{u1} , V_{v1} , and V_{w1} is utilized, it is impossible to detect the rotary electric machine currents of three phases
25 at the same timing. Specifically, the rotary electric machine currents of the W-phase and the U-phase are detected

in the switch interval T1 and T2, respectively, and the rotary electric machine current of the V-phase is obtained by using Formula (14). Thus, a time difference occurs after the rotary electric machine current of the W-phase is detected in the switch interval T1 until the rotary electric machine current of the U-phase is detected in the switch interval T2. Therefore, there may be a case where values of the rotary electric machine currents of three phases change during the time difference, resulting in an occurrence of a detection error. However, the switch interval T1 and the switch interval T2 are adjacent to each other, and in most cases the time difference is minute. Therefore, it is possible to actually ignore the detection error caused by the change in the currents during the time difference.

[0096] In the configuration shown in FIG. 14, the rotary electric machine current calculation means 30 calculates the rotary electric machine currents i_u and i_v flowing to the rotary electric machine 1, in accordance with the DC bus current I_{dc} detected by the bus current detection means 29 and with the logic signals V_{u1} , V_{v1} , and V_{w1} outputted from the pulse-width modulation means 5. However, as shown in FIG. 17, the rotary electric machine current calculation means 30 may calculate the rotary electric machine currents flowing to the rotary electric machine 1, in accordance with the DC bus current I_{dc} detected by the bus current detection means 29

and the fundamental voltages V_u^* , V_v^* , and V_w^* outputted from the two-phase/three-phase converter 10. That is, in the configuration shown in FIG. 14, signals inputted to the rotary electric machine current calculation means 30 are the DC bus current I_{dc} , and the logic signals V_{ul} , V_{vl} , and V_{wl} which are outputted from the pulse-width modulation means 5, whereas in the configuration shown in FIG. 17, signals inputted to the rotary electric machine current calculation means 30 are the DC bus current I_{dc} and the fundamental voltages V_u^* , V_v^* , and V_w^* .

[0097] Based on the configuration shown in FIG. 17, an operating principle of the rotary electric machine current calculation means 30, which calculates the rotary electric machine currents in accordance with the DC bus current I_{dc} , will be described with reference to FIG. 18.

FIG. 18 shows, similarly to FIG. 15, temporal changes of the fundamental voltages V_u^* , V_v^* , and V_w^* outputted from a two-phase/three-phase converter 10 and the triangle wave C_s in the case where a pulse-width modulation control method using the triangle wave C_s is used (FIG. 18(a)), and also shows which phase of rotary electric machine current is obtained from the DC bus current I_{dc} detected by the bus current detection means 29, in accordance with temporal changes of the logic signals and the difference among the logic signals (FIG. 18(b)).

[0098] Among the fundamental voltages V_u^* , V_v^* , and V_w^* , as shown in FIG. 18(a), one which is the greatest in value is referred to as a maximum phase (V_u^* in FIG. 18(a)), one which is the lowest in value is referred to as a minimum phase (V_w^* in FIG. 18(a)), and one which is between the greatest one and the lowest one is referred to as an intermediate phase (V_v^* in FIG. 18(a)). In the case where the pulse-width modulation control method using the triangle wave C_s is used, when the rotary electric machine currents are calculated based on the DC bus current I_{dc} , the phase rotary electric machine currents of the maximum phase and the minimum phase can be obtained during a half cycle of the triangle wave C_s (switching cycle T_c). In addition, the currents are detected before and after the intermediate phase overlaps with the triangle wave C_s (see FIG. 18(b)).

[0099] When the triangle wave C_s is a positive slope, the rotary electric machine current of the minimum phase can be obtained before the intermediate phase overlaps with the triangle wave C_s (in FIG. 18, the W-phase can be detected in the interval T_1), whereas the rotary electric machine current of the maximum phase can be obtained after the intermediate phase overlaps with the triangle wave C_s (in FIG. 18, the U-phase can be detected in the interval T_2). When the triangle wave C_s is a negative slope, the rotary electric machine current of the maximum phase can be obtained before the

intermediate phase overlaps with the triangle wave C_s (in FIG. 18, the U-phase can be detected in the interval T_4), whereas the rotary electric machine current of the minimum phase can be obtained after the intermediate phase overlaps with the triangle wave C_s , (in FIG. 18, the W-phase can be detected in the interval T_5). The fundamental voltages V_u^* , V_v^* , and V_w^* and the rotary electric machine currents which is obtained based on the DC bus current I_{dc} have the above described relation, and thus, by using the DC bus current I_{dc} detected by the DC bus current 29 and the fundamental voltages V_u^* , V_v^* , and V_w^* , it is possible to obtain the rotary electric machine currents from the DC bus current I_{dc} .

[0100] In this manner, as shown in FIG. 14 to FIG. 18, in the case where the phase, of the rotary electric machine 1, in which a current is flowing currently is calculated by utilizing the DC bus current I_{dc} and the difference in the switching timing among the switches of the respective phases of the inverter at the time of detecting the DC bus current I_{dc} , only a single current sensor is required to detect the DC bus current I_{dc} , unlike the cases described in the first to sixth embodiments, where a plurality of current sensors is required to directly detect the rotary electric machine currents of at least two phases. Therefore, advantageously, it is possible to reduce costs of the current sensor.

[0101] However, as described above, the method of

calculating the rotary electric machine currents, based on the DC bus current I_{dc} , utilizes the difference in the switching timing among the switches of the respective phases of the inverter at the time of detecting the DC bus current I_{dc} . Thus, as shown in FIG. 19(a), for example, when values of the fundamental voltages V_u^* , V_v^* , and V_w^* are close or identical to one another, the switching timings of the respective phases become close or identical to one another. As a result, in the case of the configuration shown in FIG. 14 or FIG. 17, a period of each switch interval such as T_1 , T_2 , and the like becomes extremely short or disappears, as shown in FIG. 19(b). Thus, it becomes extremely difficult to determine the phase, of the rotary electric machine 1, in which a current identical to the current detected by the bus current detection means 29 is flowing. Therefore, in order to determine the phase in which the current identical to the DC bus current I_{dc} is flowing, a predetermined value or more of time needs to be secured as the switch interval.

[0102] It is noted that the controller described in each of the first to the sixth embodiments detects rotary electric machine currents of at least two phases directly by using a current sensor or the like, and does not utilize the difference in the switching timing among the respective phases. Therefore, even if values of the fundamental voltages V_u^* , V_v^* , and V_w^* are close or identical to one

another, it is possible to detect the rotary electric machine currents of the respective phases of the rotary electric machine 1 in a secured manner, and the above problem does not occur.

5 [0103] When the rotary electric machine currents are calculated based on the DC bus current I_{dc} , in order to achieve determination of the phase in which a current identical to the DC bus current I_{dc} is flowing, even when the fundamental voltages V_u^* , V_v^* , and V_w^* are close or identical
10 to one another as shown in FIG. 19(a), the position detection voltages V_{uh} , V_{vh} , and V_{wh} are superimposed on the fundamental voltages V_u^* , V_v^* , and V_w^* outputted from the two-phase/three-phase converter 10, whereby the above problem can be solved. Hereinafter, the seventh embodiment of the
15 present invention will be described in which the rotary electric machine currents are calculated based on the DC bus current I_{dc} by utilizing the position detection voltages V_{uh} , V_{vh} , and V_{wh} .

[0104] FIG. 20 is a block diagram showing a controller of
20 a rotary electric machine according to the seventh embodiment. Those component parts which correspond to the component parts of the first embodiment are provided with identical reference characters.

[0105] The controller of the rotary electric machine
25 according to the seventh embodiment is based on the

configuration of the first embodiment shown in FIG. 1, and the current detection means 2 shown in FIG. 1 is omitted. Instead of that, the controller includes bus current detection means 29 for detecting the bus current I_{dc} which
5 flows between an inverter 6 and a DC voltage source 28 supplying DC power to the inverter 6, and rotary electric machine current calculation means 30 for calculating rotary electric machine currents in accordance with the bus current I_{dc} detected by the bus current detection means 29 and with
10 logic signals V_{ul} , V_{vl} , and V_{wl} outputted from pulse-width modulation means 5. It is noted that even when a configuration in which the logic signals V_{ul} , V_{vl} , and V_{wl} outputted from the pulse-width modulation means 5 are inputted to the rotary electric machine current calculation
15 means 30 is replaced with a configuration in which the fundamental voltages V_u^* , V_v^* , and V_w^* outputted from a two-phase/three-phase converter 10 are inputted to the rotary electric machine current calculation means 30, in the same manner as the case shown in FIG. 17, a similar effect can be
20 exerted.

[0106] Here, in the case where the fundamental voltages V_u^* , V_v^* , and V_w^* outputted from the two-phase/three-phase converter 10 are close to one another as shown in FIG. 19(a), then when the position detection voltages V_{uh} , V_{vh} , and V_{wh}
25 having waveforms (cycle $T_{hv} = 6n \cdot T_c$, $n = 1$) shown in FIG. 12

described in the fifth embodiment, for example, are superimposed by using an adder 41 of control means 4 shown in FIG. 20, the voltage commands V_{up}^* , V_{vp}^* , and V_{wp}^* , which are resultant outputs, have waveforms shown in FIG. 21(a). It is
5 noted that average values of the voltage commands V_{up}^* , V_{vp}^* , and V_{wp}^* are identical to the fundamental voltages V_u^* , V_v^* , and V_w^* shown in FIG. 19(a), respectively. Thus, when the frequencies of the position detection voltages V_{uh} , V_{vh} , and V_{wh} are set at a certain level or higher that does not affect
10 control of the rotary electric machine 1, it is possible to control the rotary electric machine 1 in the same manner as the case where the position detection voltages V_{uh} , V_{vh} , and V_{wh} are not superimposed.

[0107] In the case where the voltage commands V_{up}^* , V_{vp}^* ,
15 and V_{wp}^* outputted from the control means 4 have waveforms shown in FIG. 21(a), logic signals V_{ul} , V_{vl} , and V_{wl} outputted accordingly from the pulse-width modulation controller 15 are as shown in FIG. 21(b). That is, the periods of the switch intervals T_1 and T_4 , which are short in
20 FIG. 19(b), are extended in FIG. 21(b). Since the switch intervals T_1 and T_4 are extended, in the switch interval T_1 , it is possible to detect the rotary electric machine current i_v of the V-phase, and in the switch interval T_4 , it is possible to detect the rotary electric machine current i_u of
25 the U-phase. The rotary electric machine current i_w of the

remaining W-phase can be calculated using the above-described Formula (14). In other words, by superimposing the position detection voltages V_{uh} , V_{vh} , and V_{wh} , it becomes possible to detect rotary electric machine currents of three phases during one cycle (two times of the switching cycle T_c) of the triangle wave C_s . It is noted, however, that since switch intervals T_2 and T_5 are the same as those in FIG. 19(b), it is impossible to obtain the rotary electric machine currents during the intervals.

10 [0108] A maximum value of the amplitude V_h of the position detection voltages V_{uh} , V_{vh} , and V_{wh} outputted from the position detection voltage generator 14 is a value obtained by subtracting a voltage necessary for driving the rotary electric machine 1 from a maximum voltage outputted by the inverter 6, whereas a minimum value of the amplitude V_h is equal to or greater than an error voltage caused by dead time for preventing a short circuit of a switching element included in the inverter 6. Accordingly, it is possible to exert an effect of calculation of the rotary electric machine currents based on the DC bus current.

[0109] As described above, in the seventh embodiment, the position detection voltages V_{uh} , V_{vh} , and V_{wh} which are different in phase from one another are superimposed on the fundamental voltages V_u^* , V_v^* , and V_w^* in advance, and the rotary electric machine currents are calculated based on the

25

DC bus current I_{dc} . Accordingly, only a single piece of bus current detection means such as a current sensor or the like is required, which enhances cost reduction. In addition, even when the values of the fundamental voltages V_u^* , V_v^* , and V_w^* are close or identical to one another, it is possible to calculate and obtain the rotary electric machine currents of three phases.

[0110] Eighth Embodiment

As described in the seventh embodiment, when the position detection voltages V_{uh} , V_{vh} , and V_{wh} which are different in phase from one another are superimposed on the fundamental voltages V_u^* , V_v^* , and V_w^* in advance, and then the rotary electric machine currents are calculated, based on the DC bus current I_{dc} , even if the values of the fundamental voltages V_u^* , V_v^* , and V_w^* are close or identical to one another, it is advantageously possible to obtain the respective rotary electric machine currents of three phases.

[0111] However, when the rotary electric machine currents are calculated based on the DC bus current by using the position detection voltages V_{uh} , V_{vh} , and V_{wh} having the waveforms (cycle $T_{hv} = 6n \cdot T_c$, $n = 1$) shown in FIG. 12, a detection interval of the rotary electric machine currents of three phases is a cycle T_{cs} of the triangle wave C_s ($= 2T_c$, i.e., two times of the switching cycle T_c) as shown in FIG. 21. On the other hand, in the configuration in FIG. 14 or

FIG. 17, when the rotary electric machine currents of three phases are detectable (when the values of the fundamental voltages V_u^* , V_v^* , and V_w^* are not close or identical to one another), the detection interval of the rotary electric machine currents of three phases is a half cycle of the triangle wave C_s (= switching cycle T_c) as shown in FIG. 15(b) or 18(b). That is, when the rotary electric machine currents are calculated based on the DC bus current I_{dc} by using the position detection voltages V_{uh} , V_{vh} , and V_{wh} having the waveforms shown in FIG. 12 as they are, the detection interval of the rotary electric machine currents of three phases becomes two times of the switching cycle T_c .

[0112] Further, in the method in which the rotary electric machine currents are calculated based on the DC bus current, by using the position detection voltages V_{uh} , V_{vh} , and V_{wh} having the waveforms shown in FIG. 12, the rotary electric machine currents of the V-phase and the U-phase are detected in the switch interval T_1 and in the switch interval T_4 , respectively, as shown in FIG. 21(b). In addition, the rotary electric machine current of the W-phase is obtained based on Formula (14). Thus, a time difference occurs after the rotary electric machine current of the V-phase is detected in the switch interval T_1 until the rotary electric machine current of the U-phase is detected in the switch interval T_4 . That is, in the configuration shown in each of

FIG. 14 and FIG. 17, the time difference occurring in the case where the rotary electric machine currents are calculated based on the DC bus current is equal to a time difference between the switch interval T1 and the switch interval T2 which are adjacent to each other, as shown in FIG. 15(b) or FIG. 18(b). On the other hand, in the method in which the rotary electric machine currents are calculated based on the DC bus current, by using the position detection voltages V_{uh} , V_{vh} , and V_{wh} having the waveforms shown in FIG. 12, the time difference is equal to a time difference between the switch interval T1 and the switch interval T4 which are separated from each other by a distance of two switch intervals, as shown in FIG. 21(b). Thus, the values of the three-phase rotary electric machine currents may change significantly during the time difference, and there is a possibility that an unignorable detection error occurs.

[0113] Thus, the eighth embodiment is directed to overcome the problem occurring in the seventh embodiment. That is, as to the position detection voltages V_{uh} , V_{vh} , and V_{wh} to be superimposed on the fundamental voltages V_{u*} , V_{v*} , and V_{w*} , although the position detection voltages V_{uh} , V_{vh} , and V_{wh} , having waveforms shown in FIG. 12, each have only two values, i.e., $+V_h$ and $-V_h$, the position detection voltages V_{uh} , V_{vh} , and V_{wh} are each set, as shown in FIG. 22, for example, to have three values, i.e., $+V_h$, $-V_h$, and 0, whereby it is

possible to calculate rotary electric machine currents based on the DC bus current. An overall configuration except for that above described is the same as the configuration according to the seventh embodiment shown in FIG. 20.

5 [0114] Here, when the position detection voltages V_{uh} , V_{vh} , and V_{wh} each having three values as shown in FIG. 22 are superimposed, respectively, by an adder 41 of control means 4 shown in FIG. 20, then voltage commands V_{up}^* , V_{vp}^* , and V_{wp}^* , which are resultant outputs, have waveforms as shown in FIG.
10 23(a). Logic signals V_{ul} , V_{vl} , and V_{wl} outputted from the pulse-width modulation controller 15 in accordance with the voltage commands V_{up}^* , V_{vp}^* , and V_{wp}^* are as shown in FIG. 23(b).

[0115] In this manner, by utilizing the position detection
15 voltages V_{uh} , V_{vh} , and V_{wh} each having three values, i.e., $+V_h$, $-V_h$, and 0 shown in FIG. 22, it is possible to overcome the problem of the seventh embodiment, and also possible to reduce the detection interval of rotary electric machine currents of three phases to the switching cycle T_c .

20 [0116] It is noted that even if the position detection voltages V_{uh} , V_{vh} , and V_{wh} each having three values, i.e., $+V_h$, $-V_h$, and 0 shown in FIG. 22 are utilized, there may be a case where the voltage commands V_{up}^* , V_{vp}^* , and V_{wp}^* become close to one another depending on the values of the
25 fundamental voltages V_u^* , V_v^* , and V_w^* , and consequently

there occurs a switch interval in which rotary electric machine currents cannot be detected. In such a case, it is possible to detect the rotary electric machine currents, for example, by arranging position detection voltages V_{uh} , V_{vh} , and V_{wh} each having four values, i.e., $+2V_h$, $+V_h$, $-2V_h$, and $-V_h$, or by arranging position detection voltages V_{uh} , V_{vh} , and V_{wh} each having a continuously changing magnitude, such as a sine wave, that is, by arranging the position detection voltages V_{uh} , V_{vh} , and V_{wh} having a plurality of values.

[0117] It is noted that, in the eighth embodiment, in order to calculate the rotary electric machine currents from the DC bus current I_{dc} , each of the position detection voltages V_{uh} , V_{vh} , and V_{wh} has three values, whereas a cycle of each voltage is always set to a cycle $m \cdot T_c$ which is equal to m times (m is an integer of three or more) of the switching cycle T_c . Accordingly, estimation calculation of the rotor position by the position estimation means 3 is not affected at all. Therefore, when the rotary electric machine currents are calculated based on the DC bus current I_{dc} by utilizing the position detection voltages V_{uh} , V_{vh} , and V_{wh} , it is not necessary to mount a position sensor, and in addition, it is possible to reduce the number of the current sensors. Thus it is possible to achieve a controller of the rotary electric machine 1 having a simple and inexpensive configuration.

[0118] Ninth Embodiment

FIG. 24 is a block diagram showing a controller of a rotary electric machine according to a ninth embodiment of the present invention. Those component parts which correspond to the component parts of the seventh embodiment (FIG. 20) are provided with identical reference characters.

[0119] The controller of the rotary electric machine according to the ninth embodiment is based on the configuration according to the seventh embodiment (FIG. 20), and additionally includes, in a control means 4, a position detection voltage changer 34 in such a manner as to be interposed between a position detection voltage generator 14 and an adder 41.

[0120] The position detection voltage changer 34 receives fundamental voltages V_u^* , V_v^* , and V_w^* for driving the rotary electric machine 1 outputted from a two-phase/three-phase converter 10, and changes, based on the fundamental voltages V_u^* , V_v^* , and V_w^* , the amplitudes of position detection voltages V_{uh} , V_{vh} , and V_{wh} outputted from the position detection voltage generator 14, and then outputs the changed position detection voltages V_{uh2} , V_{vh2} , and V_{wh2} . The changed position detection voltages V_{uh2} , V_{vh2} , and V_{wh2} outputted from the position detection voltage changer 34 are added to the fundamental voltages V_u^* , V_v^* , and V_w^* by the adder 41.

[0121] In the case of the configuration according to the seventh embodiment (FIG. 20), when the values of the voltage commands V_{up}^* , V_{vp}^* , and V_{wp}^* are close or identical to each other, it is extremely difficult to identify the phase in which a rotary electric machine current that is identical to the DC bus current is flowing, and consequently a current detection period extends. In addition, there may be a possibility of occurrence of a current detection error. In order to solve this problem, in the above eighth embodiment, it is configured such that the position detection voltages V_{uh} , V_{vh} , and V_{wh} each have three values, i.e., $+V_h$, $-V_h$, and 0, whereby the rotary electric machine currents can be calculated based on the DC bus current. On the other hand, in the ninth embodiment, in order to address the problem more dynamically than in the eighth embodiment, the amplitude of the position detection voltages V_{uh} , V_{vh} , and V_{wh} outputted from the position detection voltage generator 14 is changed based on the fundamental voltages V_u^* , V_v^* , and V_w^* . The operating principle will be described below.

[0122] FIG. 25 is an explanatory diagram showing an operation of the position detection voltage changer 34. FIG. 25(a) shows output waveforms of the position detection voltages V_{uh} , V_{vh} , and V_{wh} outputted from the position detection voltage generator 14, and FIG. 25(b) shows output waveforms of the changed position detection voltages V_{uh2} ,

Vvh2, and Vwh2 outputted from the position detection voltage changer 34. It is noted that the position detection voltages Vuh, Vvh, and Vwh shown in FIG. 25(a) have the same waveforms (cycle $T_{hv} = 6n \cdot T_c$, $n = 1$) as the position detection voltages Vuh, Vvh, and Vwh shown in FIG. 12, respectively, and thus, K1 to K3 shown in FIG. 12 correspond to K1 to K3 shown in FIG. 25, respectively.

[0123] When the position detection voltages Vuh, Vvh, and Vwh shown in FIG. 25(a) outputted from the position detection voltage generator 14 are directly superimposed on the fundamental voltages V_u^* , V_v^* , and V_w^* without being changed through the position detection voltage changer 34, the resultants have waveforms shown in FIG. 25(c), which are the same as the waveforms shown in FIG. 21(a)

[0124] In FIG. 25(c), among the voltage commands V_{up}^* , V_{vp}^* , and V_{wp}^* which are obtained by superimposing the position detection voltages Vuh, Vvh, and Vwh on the fundamental voltages V_u^* , V_v^* , and V_w^* , respectively, V_{up}^* and V_{wp}^* are close to each other in an interval K1. Accordingly, the period of a switch interval T2 is reduced, and it becomes impossible to identify the phase in which a rotary electric machine current that is identical to the DC bus current is flowing. In addition, in an interval K2, V_{vp}^* and V_{wp}^* are close to each other, and thus the period of a switch interval T5 is reduced, and it becomes impossible to

identify the phase in which a rotary electric machine current that is identical to the DC bus current is flowing.

[0125] Thus, in the ninth embodiment, calculating in advance the periods of the switch intervals T_1 , T_2 , and the like of the position detection voltages V_{uh} , V_{vh} , and V_{wh} , based on the fundamental voltages V_u^* , V_v^* , and V_w^* , the position detection voltage changer 34 checks whether or not there is a state where V_{up}^* , V_{vp}^* , and V_{wp}^* are close or identical to one another, and thus the periods of the respective switch intervals T_1 , T_2 , and the like is reduced, and consequently it becomes impossible to identify the phase in which a rotary electric machine current that is identical to the DC bus current is flowing (hereinafter referred to as an unidentifiable state).

[0126] The above unidentifiable state indicates a state where the period of each of the switch intervals T_1 , T_2 , and the like is shorter than a calculation time of the rotary electric machine current calculation means 30. In addition, the period of each of the switch intervals T_1 , T_2 , and the like is proportional to the difference in values of the voltage commands V_{up}^* , V_{vp}^* , and V_{wp}^* . Thus, it is possible to obtain the period of each of the switch intervals T_1 , T_2 , and the like from the sums of the fundamental voltages V_u^* , V_v^* , and V_w^* and the position detection voltages V_{uh} , V_{vh} , and V_{wh} , respectively (= voltage commands V_{up}^* , V_{vp}^* , and

Vwp*).

[0127] Therefore, when the period of each of the switch intervals T1, T2, and the like obtained through calculation is unidentifiable, the position detection voltage changer 34 changes, in each switching cycle Tc, a value of an amplitude of the position detection voltages Vuh, Vvh, and Vwh by an amount of ΔV so as to avoid the unidentifiable state, thereby outputting the changed position detection voltages Vuh2, Vvh2, and Vwh2.

10 [0128] The position detection voltage changer 34 changes a value of the position detection voltages Vuh, Vvh, and Vwh in a subsequent switching cycle such that the value changed in the preceding switching cycle is restored by an amount of ΔV , thereby outputting the changed position detection voltages
15 Vuh2, Vvh2, and Vwh2. FIG. 25(d) shows changes in the voltage commands Vup*, Vvp*, and Vwp* of the respective phases in the case where the values of the position detection voltages Vuh, Vvh, and Vwh are changed in the above-described manner. The value for changing the position detection
20 voltages Vuh, Vvh, and Vwh is calculated and obtained using Formula (15) below so that the period of each of the switch intervals T1, T2, and the like can be secured to be such a period that enables identification of the phase in which a rotary electric machine current that is identical to the DC
25 bus current is flowing, that is, so that the period is equal

to or more than the calculation time by the rotary electric machine current calculation means 30.

[0129]

[Formula 15]

$$\Delta V \geq K_t \cdot \Delta V_p \quad (15)$$

where, ΔV : change amount of position detection voltage

K_t : proportional constant

5 [0130] In the case of FIG. 25(c), for example, the position detection voltage changer 34 obtains, through calculation, the period of each of the switch intervals T1 and T2, in advance, and determines whether or not the switch interval T2 is unidentifiable. When it is determined that
10 the switch interval T2 is unidentifiable as it is, in order to avoid the unidentifiable state, as indicated as an interval K1 in FIG. 25(d), the value of the position detection voltage V_{wh} of the W-phase is lowered by an amount of ΔV expressed in Formula (16) in accordance with Formula
15 (15).

[Formula 16]

$$\Delta V = K_t \cdot (V_{up}^* - V_{wp}^*) \quad (16)$$

20 [0131] In the interval K2 of the subsequent switching cycle, the value of the position detection voltage V_{wh} of the

W-phase is raised by the amount of ΔV . As shown in FIG. 25(c), in the interval K2, V_{vp}^* and V_{wp}^* are close to each other, which leads to an unidentifiable state. Thus, the position detection voltage V_{wh} of the W-phase is raised, in the interval K2, by the amount of ΔV which is the amount of change performed in the interval K1. Accordingly, it is possible to avoid the unidentifiable state in the interval K2 shown in FIG. 25(d).

[0132] In an example shown in FIG. 25(d), the position detection voltage V_{wh} of the W-phase is changed by the amount of ΔV in the intervals K1 and K2. However, a similar effect can be obtained from a case where the position detection voltage V_{wh} of the W-phase is not changed, but the position detection voltage V_{uh} of the U-phase is changed by the amount of ΔV , or a case where the values of the position detection voltage V_{wh} of the W-phase and the position detection voltage V_{uh} of the U-phase are changed (by an amount of $\Delta V/2$, respectively, for example) so as to be distanced from each other. In this case, however, there may be a case where V_{vp}^* and V_{wp}^* are kept close to each other in the interval K2, and thus, it is further necessary to change the position detection voltage V_{vh} or V_{wh} of the V-phase or the W-phase.

[0133] As above described, in the ninth embodiment, the position detection voltage changer 34 is arranged between the position detection voltage generator 14 and the adder 41, and

adder 41, and with the position detection voltage changer 34, the difference in the voltage commands V_{up}^* , V_{vp}^* , and V_{wp}^* of the respective phases is estimated based on the values of the fundamental voltages V_u^* , V_v^* , and V_w^* . Based on the
5 estimated difference in the respective phases, whether or not the unidentifiable state is present is determined, and when there is a possibility that the unidentifiable state will occur, the amplitudes of the position detection voltages V_{uh} , V_{vh} , and V_{wh} outputted from the position detection voltage
10 generator 14 are changed. Accordingly, it is possible to calculate the rotary electric machine currents based on the DC bus current without deteriorating the driving performance of the rotary electric machine 1, and a further dynamic solution can be achieved as compared to the case of the
15 eighth embodiment. Further, since only the amplitudes of the position detection voltages V_{uh} , V_{vh} , and V_{wh} are changed without changing the fundamental voltages V_u^* , V_v^* , and V_w^* , it is possible to calculate the rotary electric machine currents based on the DC bus current I_{dc} .

20

INDUSTRIAL APPLICABILITY

[0134] The present invention is applicable to a controller of a rotary electric machine such as an induction machine, a synchronous machine, or the like, and is capable of
25 performing rotation control by obtaining rotor position

information without using a rotor position sensor.

The embodiments of the invention in which an exclusive property or privilege is claimed are defined as follows:

1. A controller of a rotary electric machine performing rotation control of the rotary electric machine, comprising:

current detection means for detecting rotary electric machine currents flowing to the rotary electric machine;

position estimation means for estimating a rotor position in accordance with the rotary electric machine currents detected by the current detection means;

control means for outputting voltage commands in accordance with the rotor position estimated by the position estimation means;

pulse-width modulation means for outputting logic signals which are pulse-width modulated based on the voltage commands from the control means and on a switching cycle used for pulse-width modulation control; and

voltage application means for applying voltages to the rotary electric machine in accordance with the logic signals outputted by the pulse-width modulation means, wherein

the voltage commands outputted by the control means are obtained by superimposing, on fundamental voltages for driving the rotary electric machine, position detection voltages which each have a cycle equal to m times (m is an integer of three or more) of the switching cycle and which are different in phase among respective phases.

2. The controller of the rotary electric machine according to claim 1, wherein

the control means includes:

a position detection voltage generator for generating the position detection voltages; and

an adder for superimposing the position detection voltages outputted by the position detection voltage generator on the fundamental voltages and for outputting resultants as voltage commands to the pulse-width modulation means.

3. The controller of the rotary electric machine according to claim 1, wherein the current detection means is replaced with bus current detection means for detecting a bus current flowing between the voltage application means a DC voltage source supplying DC power to the voltage application means, and with rotary electric machine current calculation means for calculating the rotary electric machine currents flowing to the rotary electric machine in accordance with the bus current detected by the bus current detection means, and with both or either of the logic signals and the voltage commands.

4. The controller of the rotary electric machine according to claim 3, wherein the position detection voltages generated by the position detection voltage generator have at least three amplitudes during a period of the switching cycle.

5. The controller of the rotary electric machine according to claim 3, wherein the control means includes a position detection voltage changer for changing the amplitudes of the position detection voltages generated by the position detection voltage generator in accordance with the fundamental voltages, and generates changed position detection voltages to be outputted to the adder.

6. The controller of the rotary electric machine according to claim 2, wherein a cycle of each of the position detection voltages outputted by the position detection voltage generator is set to be $6n$ times (n is a natural number) of the switching cycle.

7. The controller of the rotary electric machine according to claim 1, wherein the position estimation means extracts, from the rotary electric machine currents, position detection alternating currents which are obtained by superimposing, on the fundamental voltages, the position rotary electric machine in accordance with the rotor position estimated by the position estimation means, and for causing the position detection voltage generator to stop generating the position detection voltages when the rotation speed calculated by the speed calculation unit is equal to or greater than a predetermined value.

8. The controller of the rotary electric machine according to claim 7, wherein

the position estimation means includes:

a three-phase/two-phase converter for performing three-phase/two-phase conversion of rotary electric machine currents of three phases, the currents flowing to the rotary electric machine;

a Fourier transformer for extracting the position detection alternating currents from two phase currents which are outputted by the three-phase/two-phase converter;

a multiplier for calculating squared value from each of the position detection alternating currents of two phases extracted by the Fourier transformer; and

a position calculation unit for outputting the rotor position in accordance with respective outputs by the multiplier.

9. The controller of the rotary electric machine according to claim 2, wherein the control means has a speed calculation unit for calculating a rotation speed of the rotary electric machine in accordance with the rotor position estimated by the position estimation means, and for causing the position detection voltage generator to stop generating the position detection voltages when the rotation speed calculated by the speed calculation unit is equal to or greater than a predetermined value.

10. A controller of a rotary electric machine performing rotation control of the rotary electric machine, comprising:

current detection means for detecting rotary electric machine currents flowing to the rotary electric machine;

position estimation means for estimating a rotor position in accordance with the rotary electric machine currents detected by the current detection means;

control means for outputting voltage commands in accordance with the rotor position estimated by the position estimation means;

pulse-width modulation means for outputting logic signals which are pulse-width modulated based on the voltage commands from the control means and on a switching cycle used for pulse-width modulation control; and

voltage application means for applying voltages to the rotary electric machine in accordance with the logic signals outputted by the pulse-width modulation means, wherein

the voltages outputted by the voltage application means are obtained by superimposing, position detection voltages which each have a cycle equal to m times (m is an integer of three or more) of the switching cycle and which are different in phase among respective phases.

FIG.2

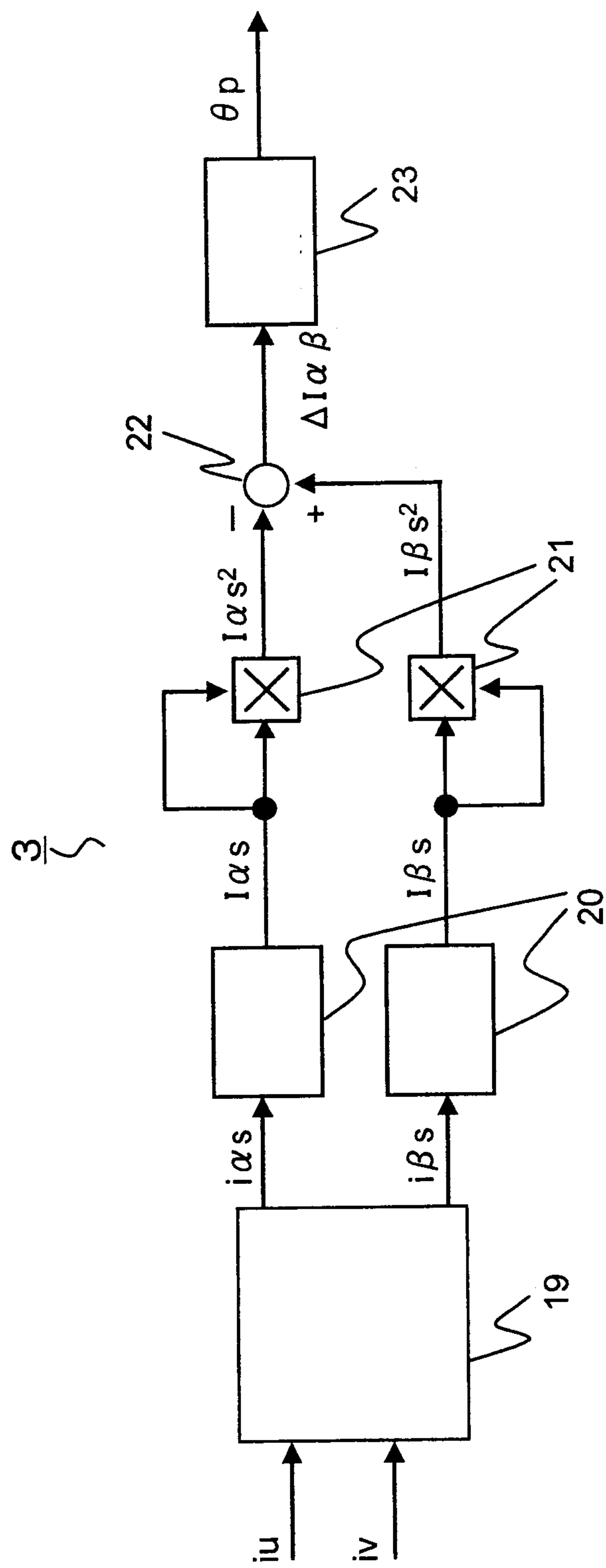
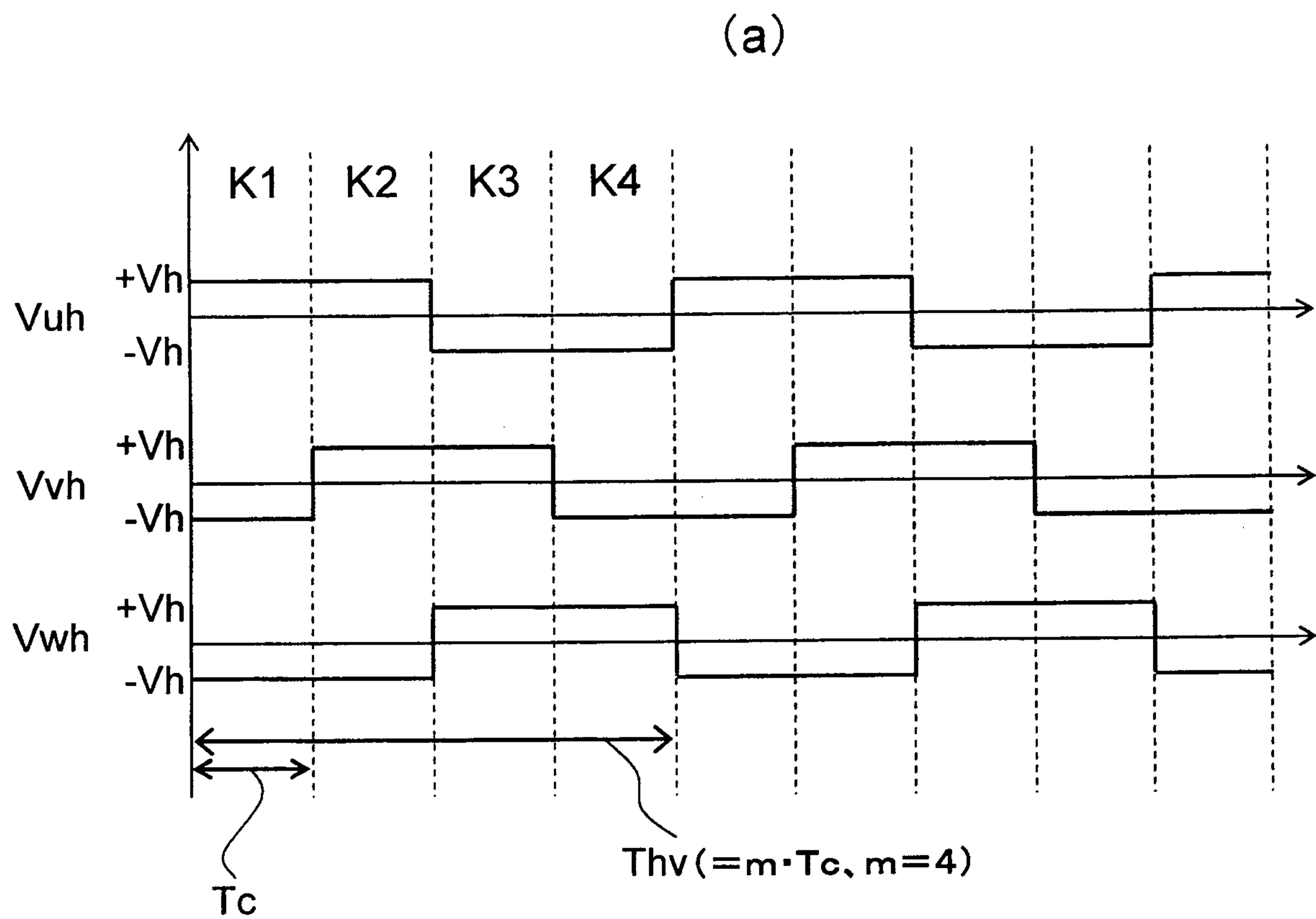


FIG.3



(b)

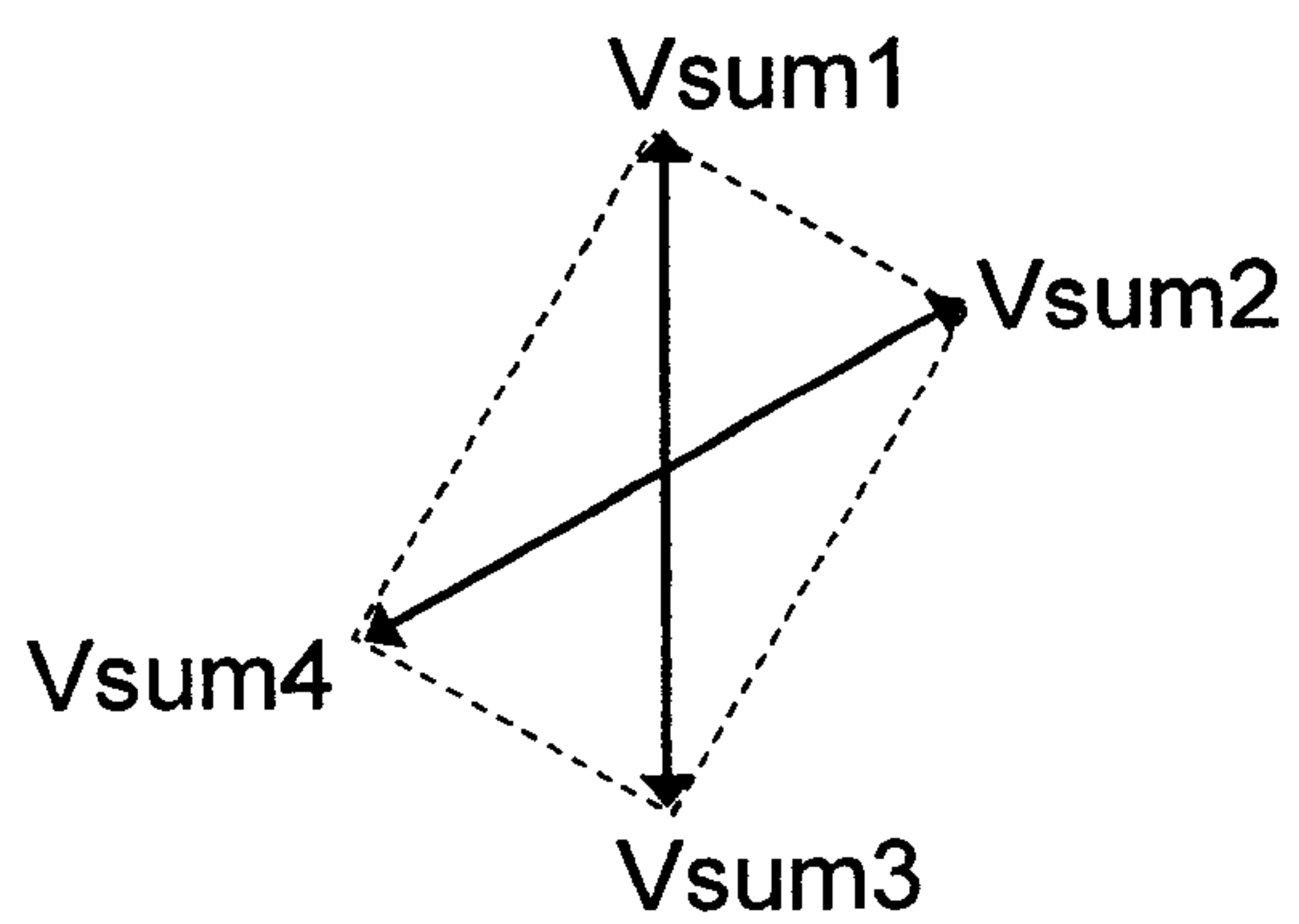


FIG.4

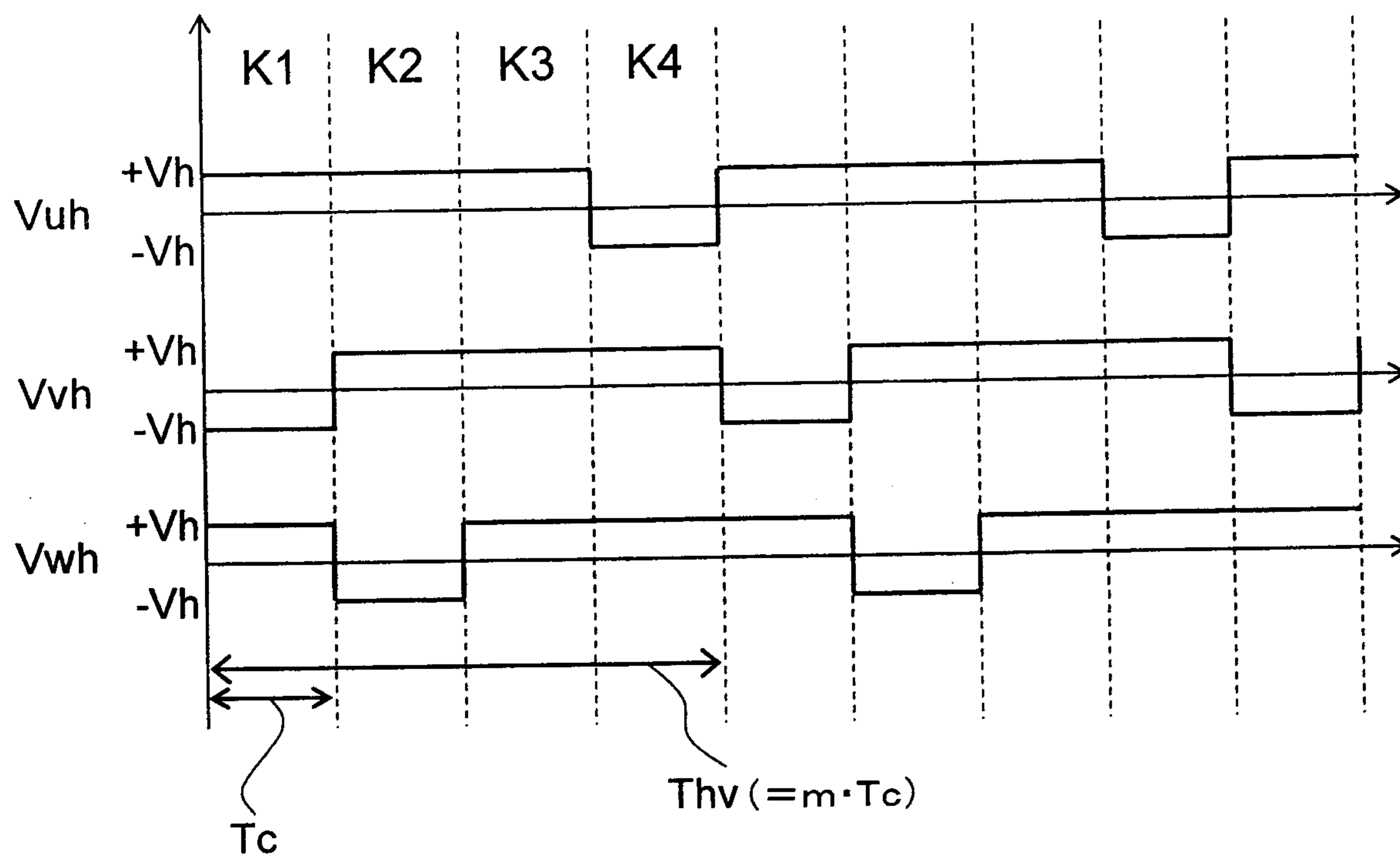


FIG.5

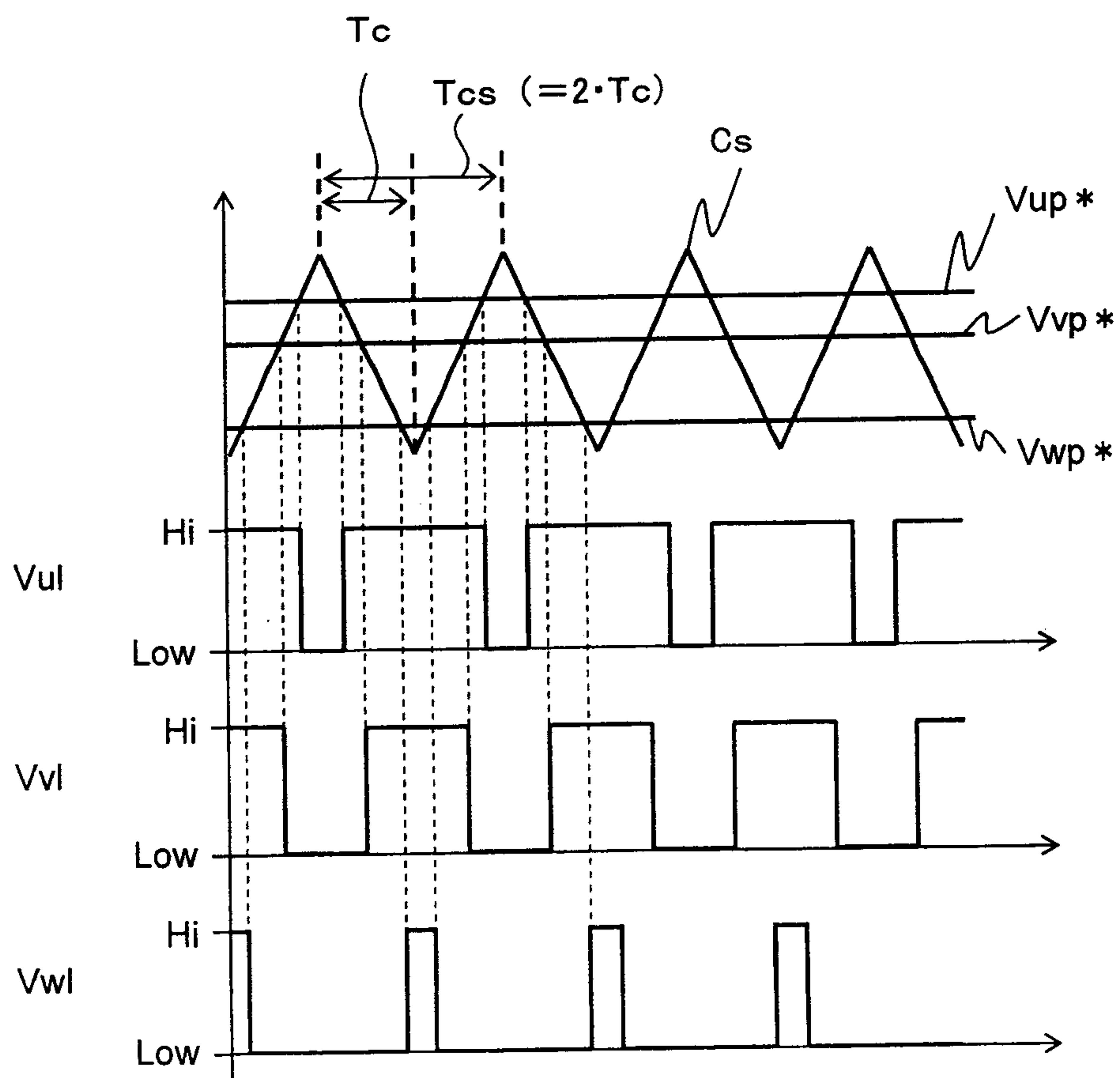


FIG.6

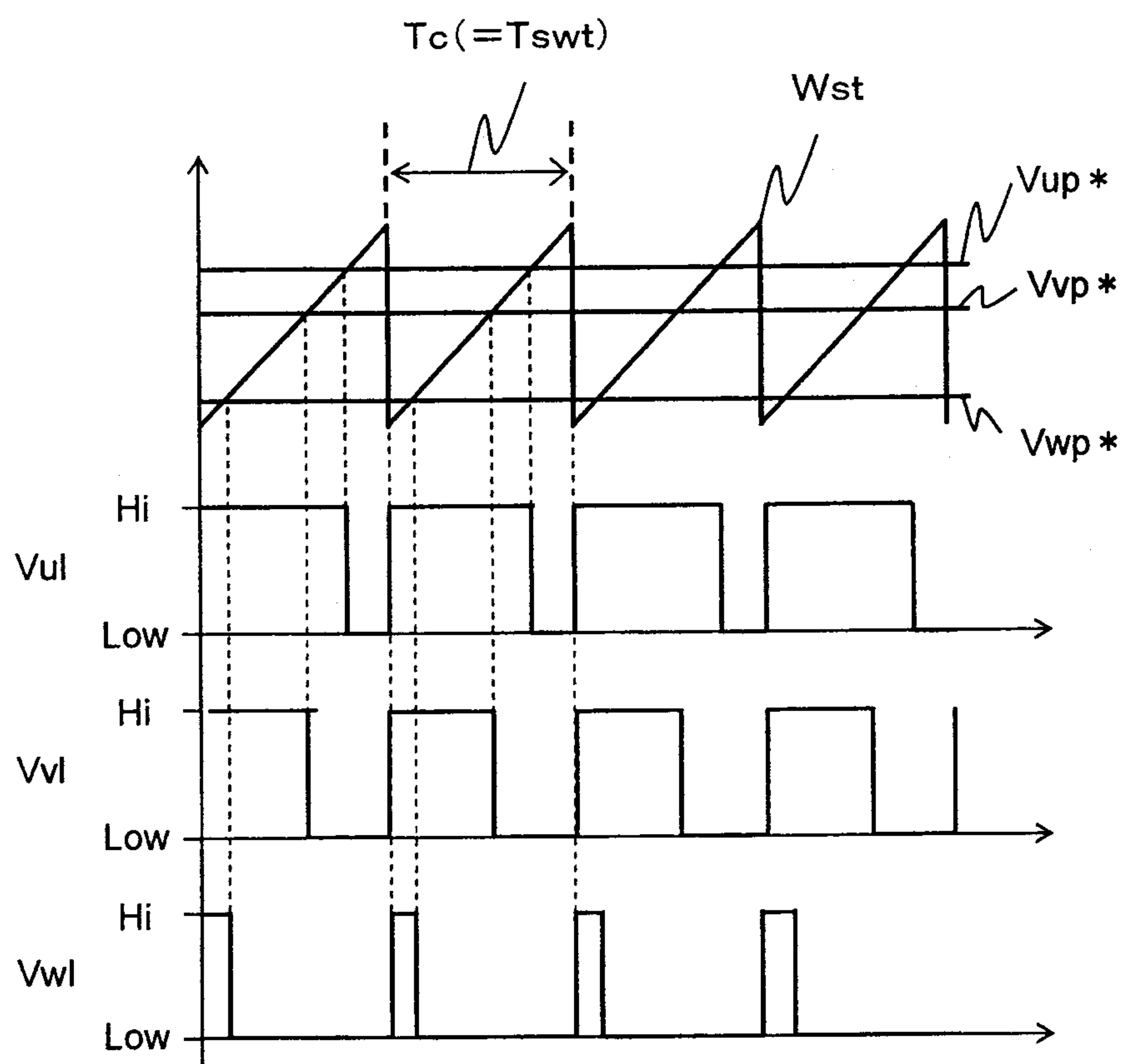


FIG.7

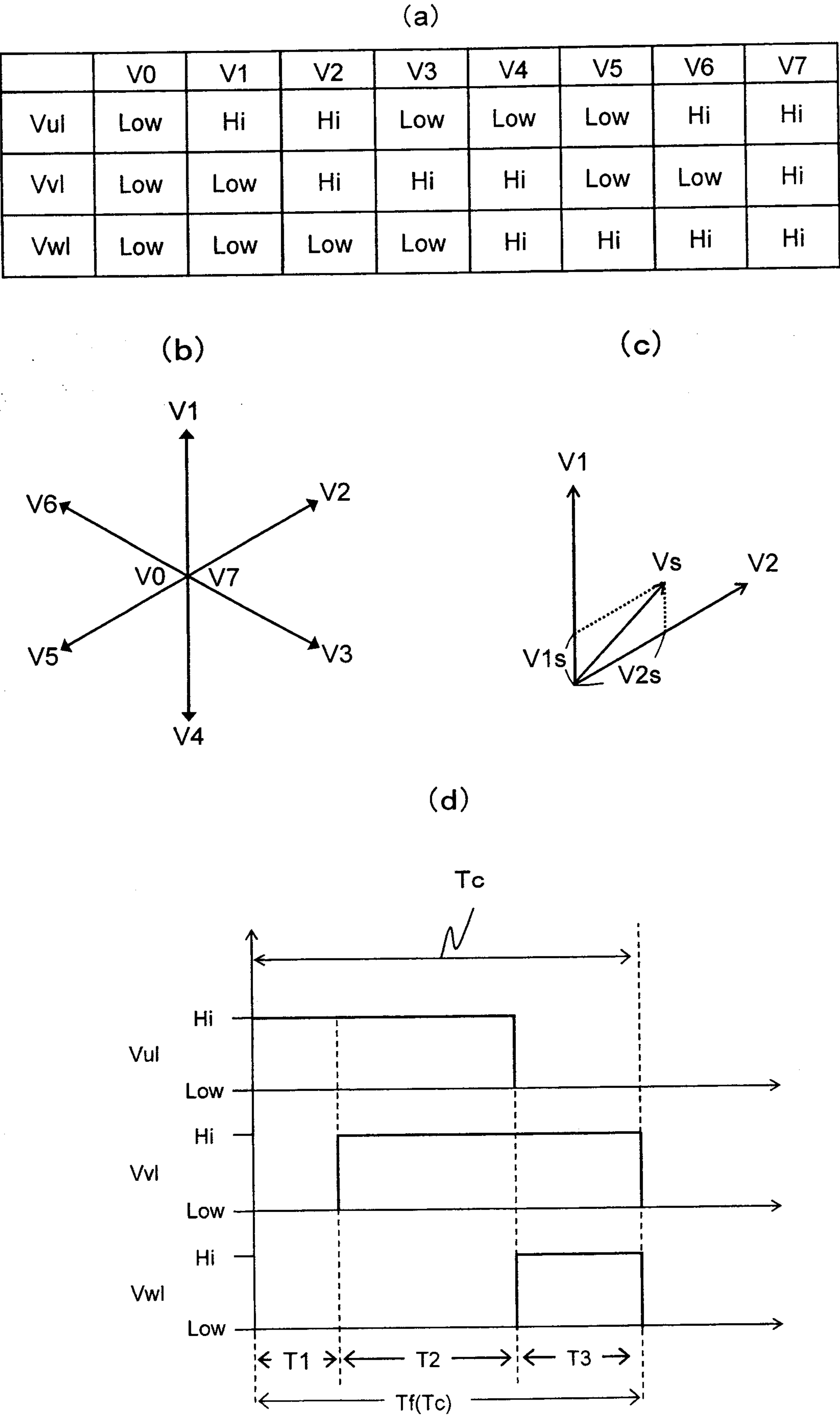


FIG.8

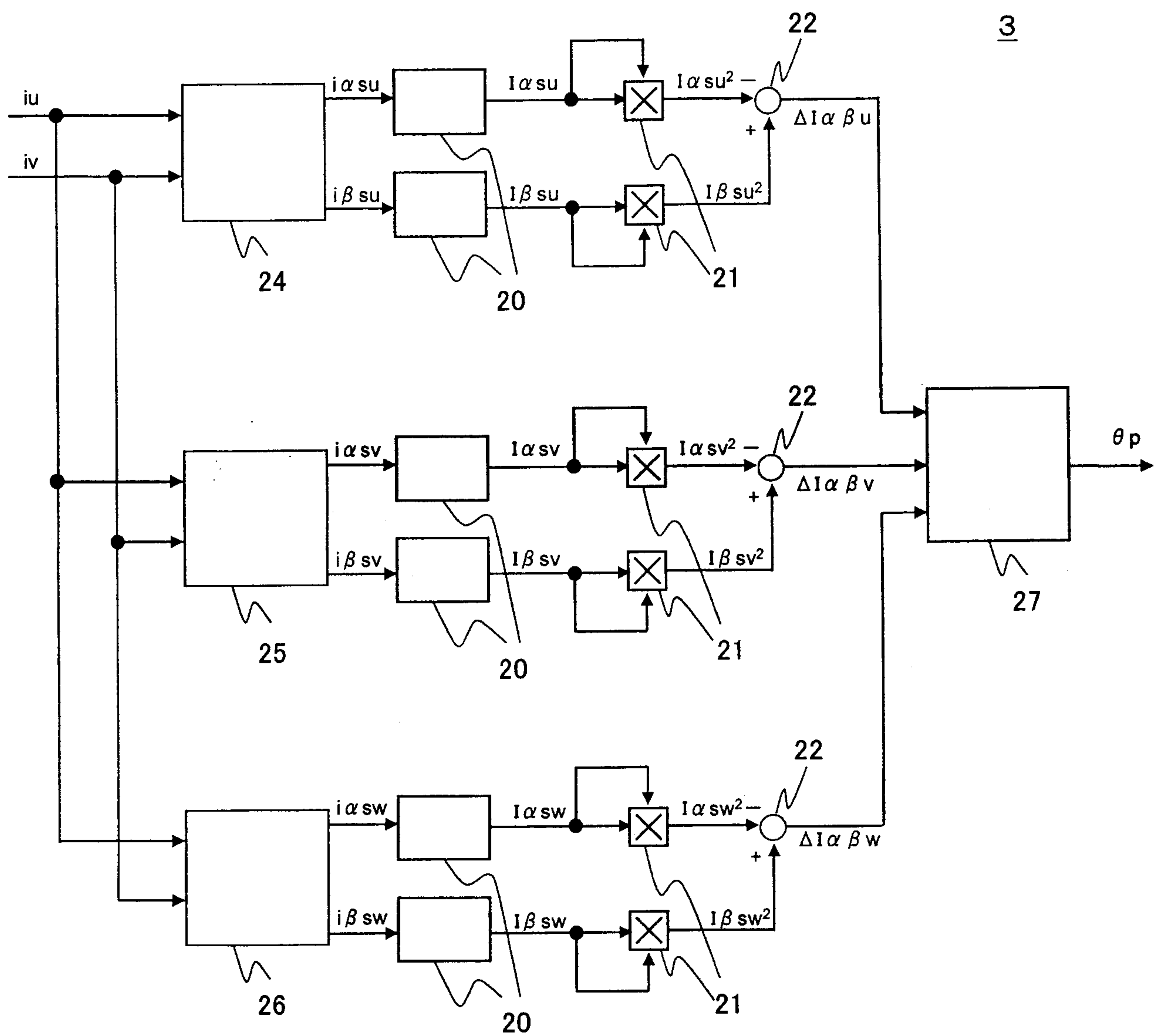


FIG.9

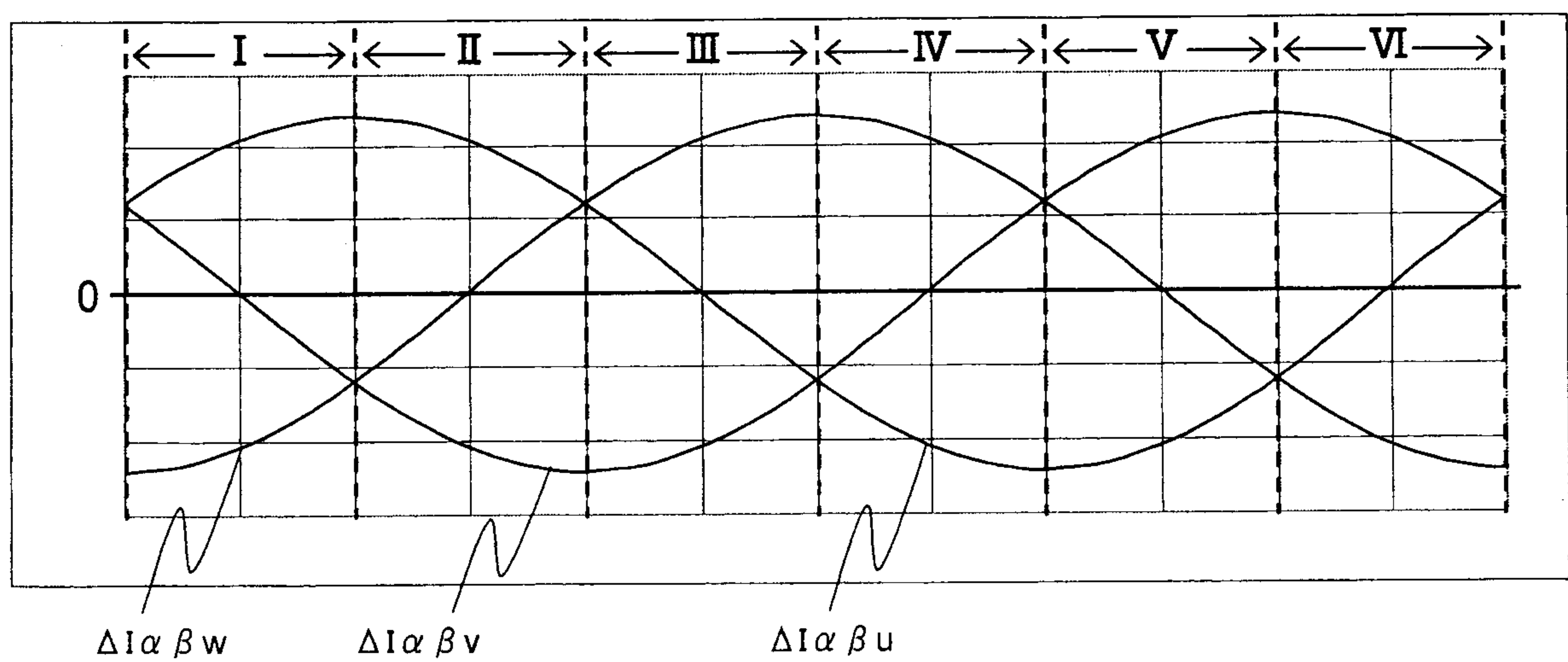
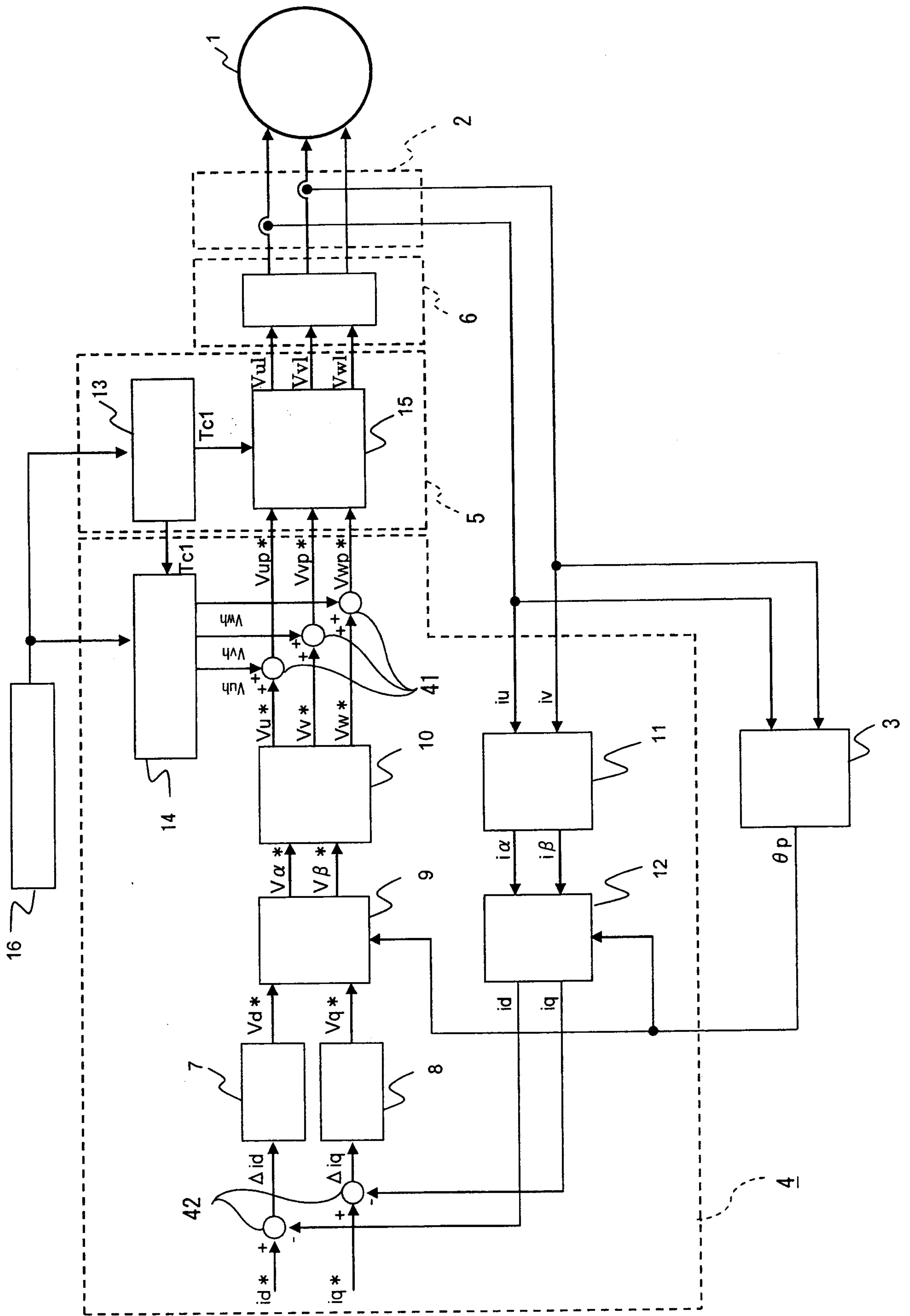


FIG.10



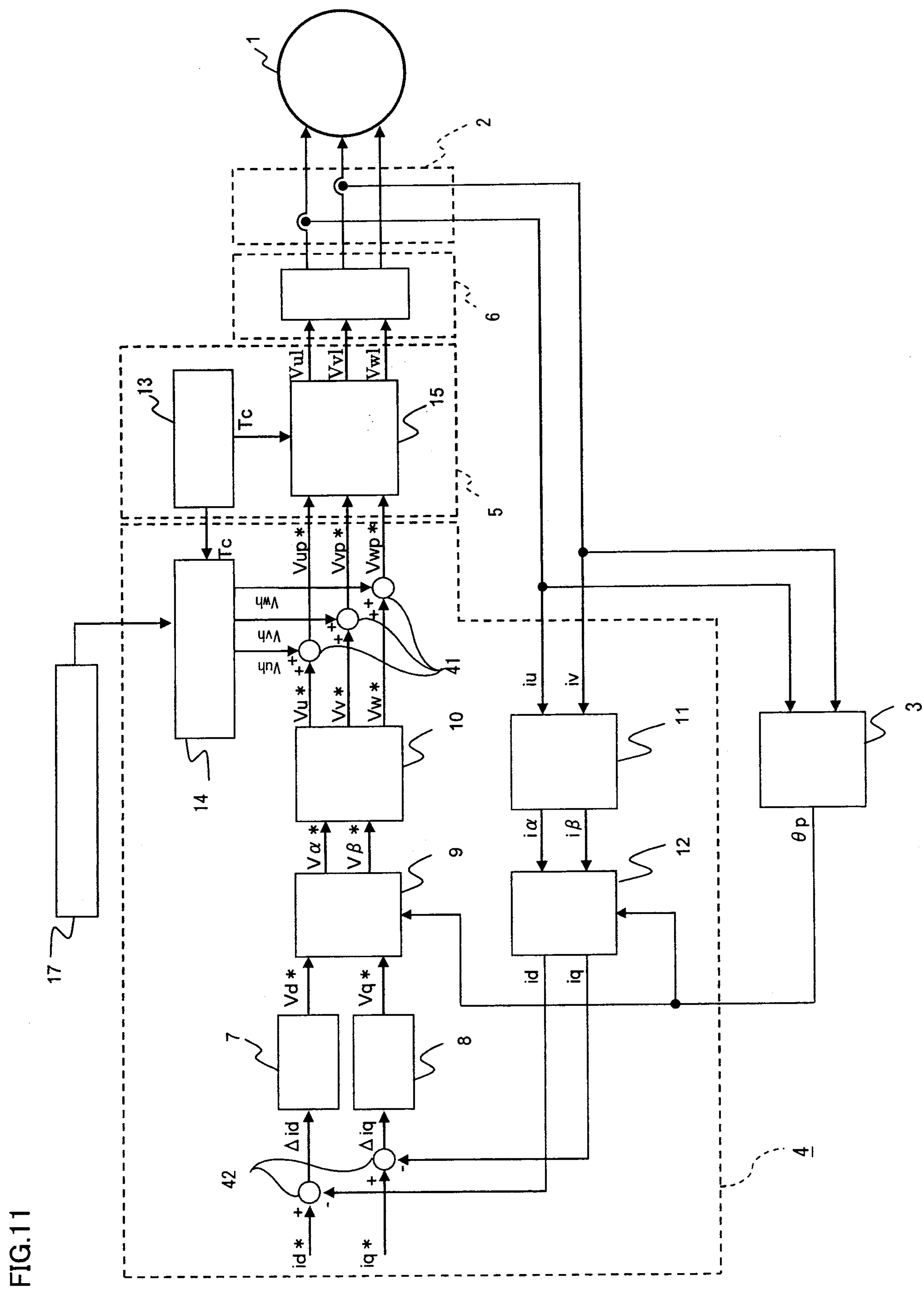


FIG.12

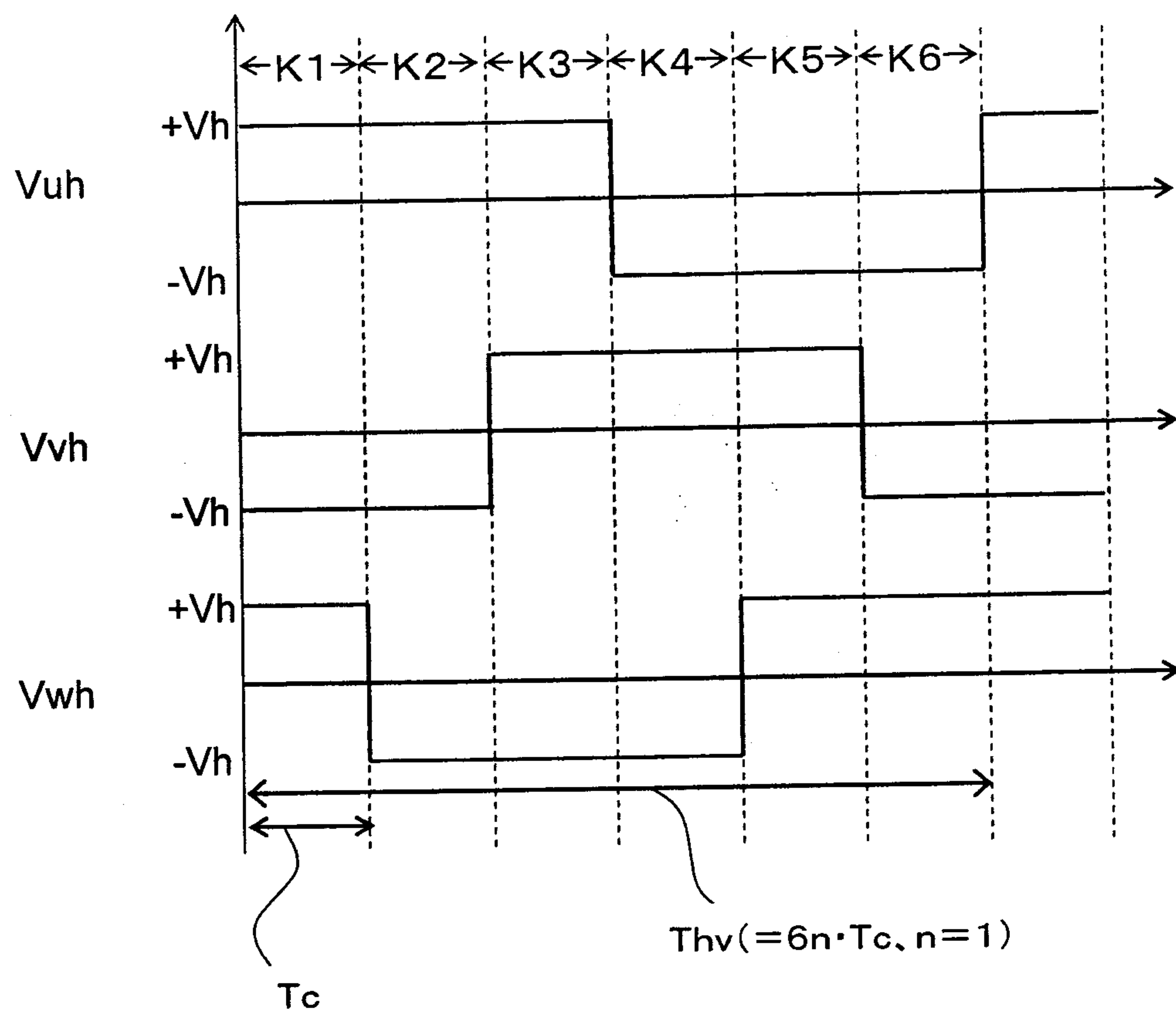


FIG. 13

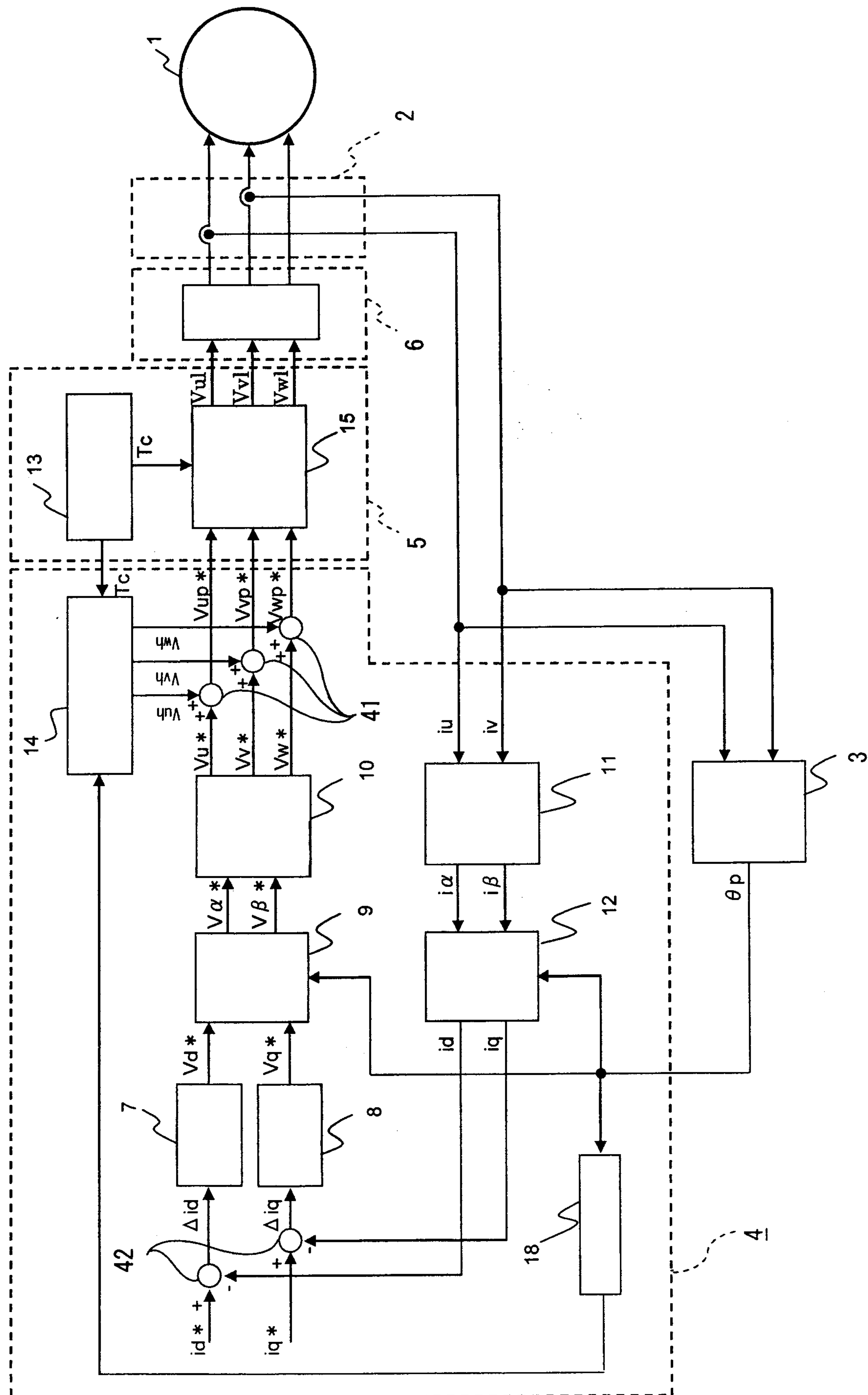


FIG.14

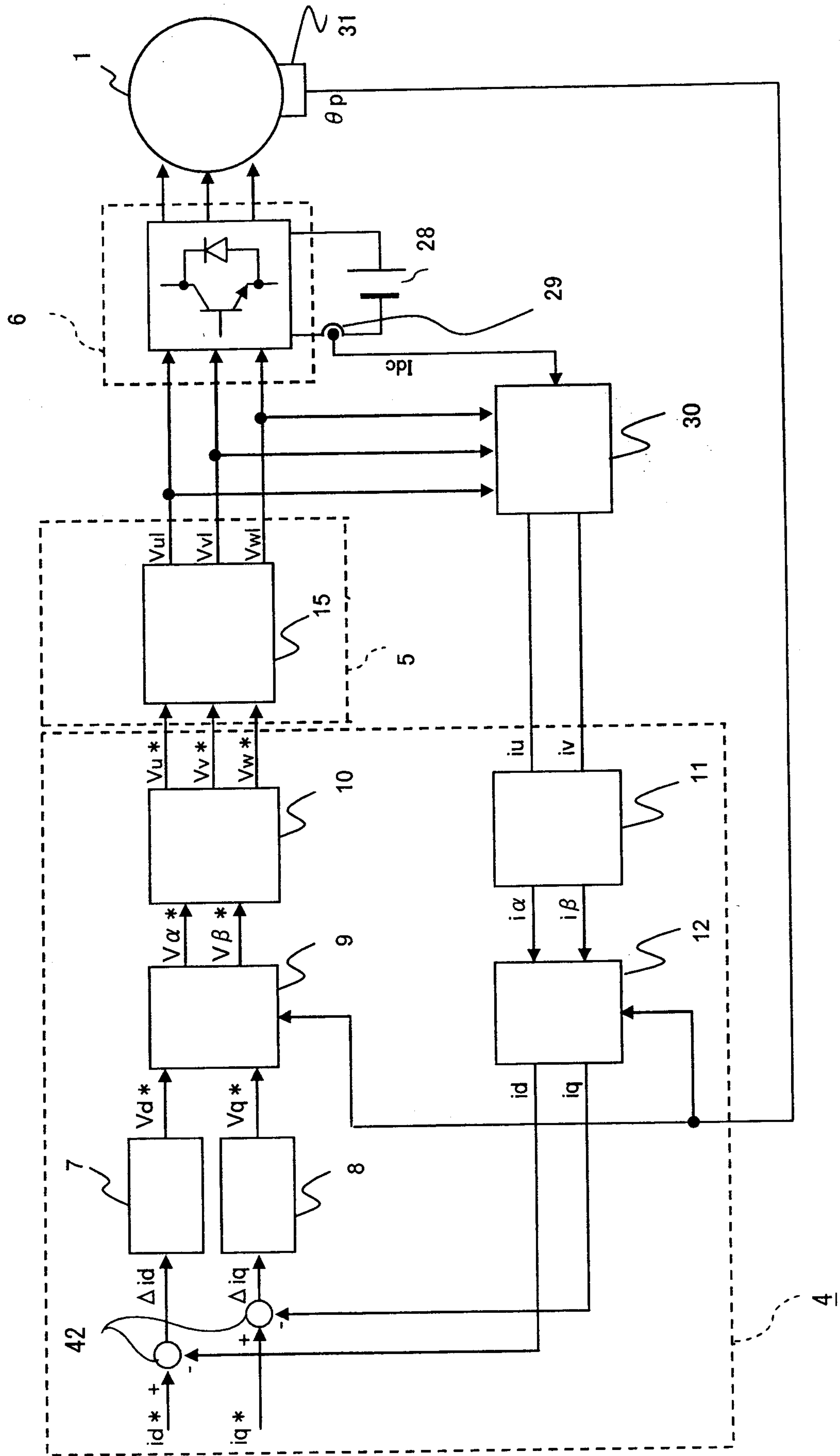


FIG.15

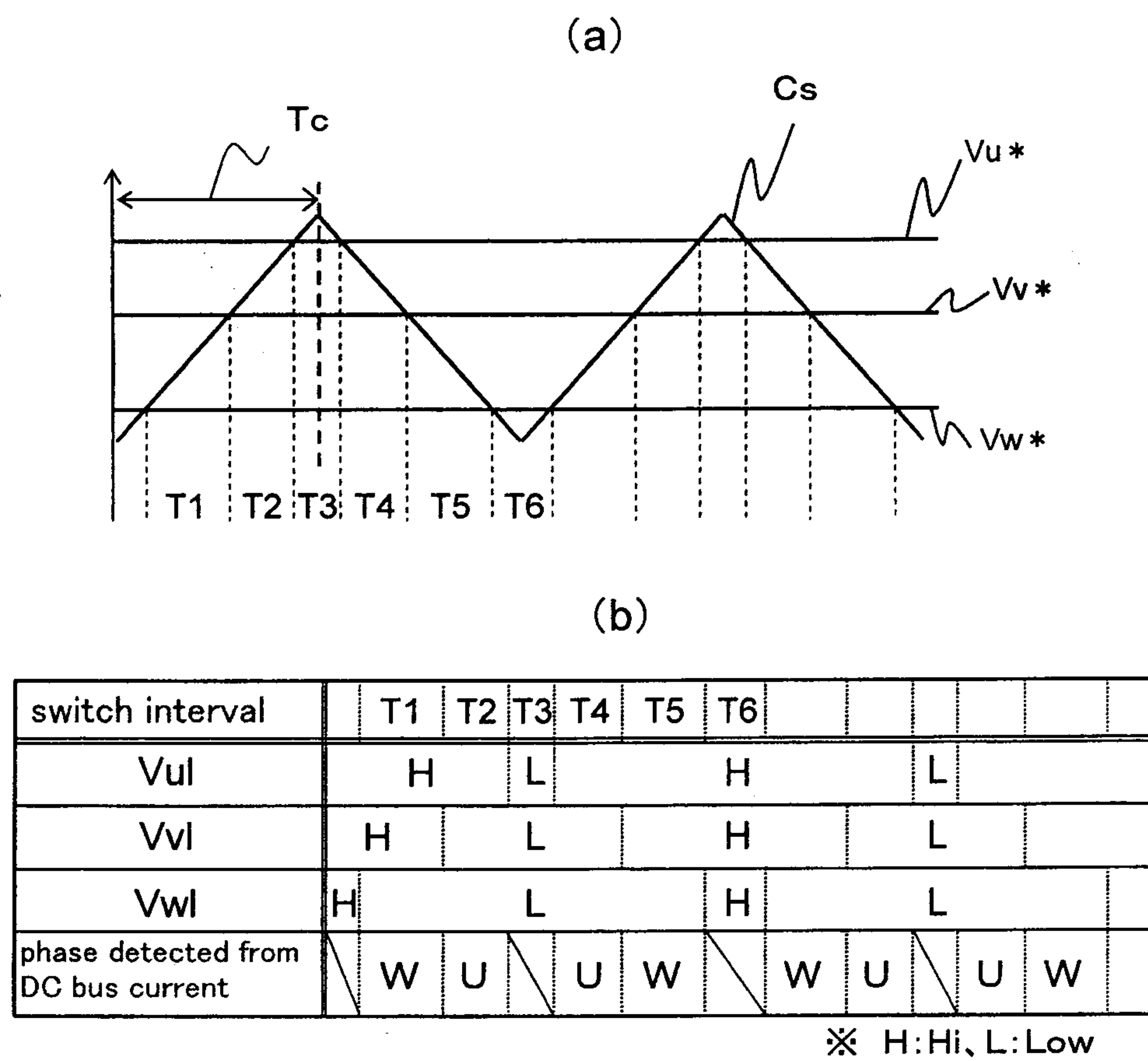


FIG.16

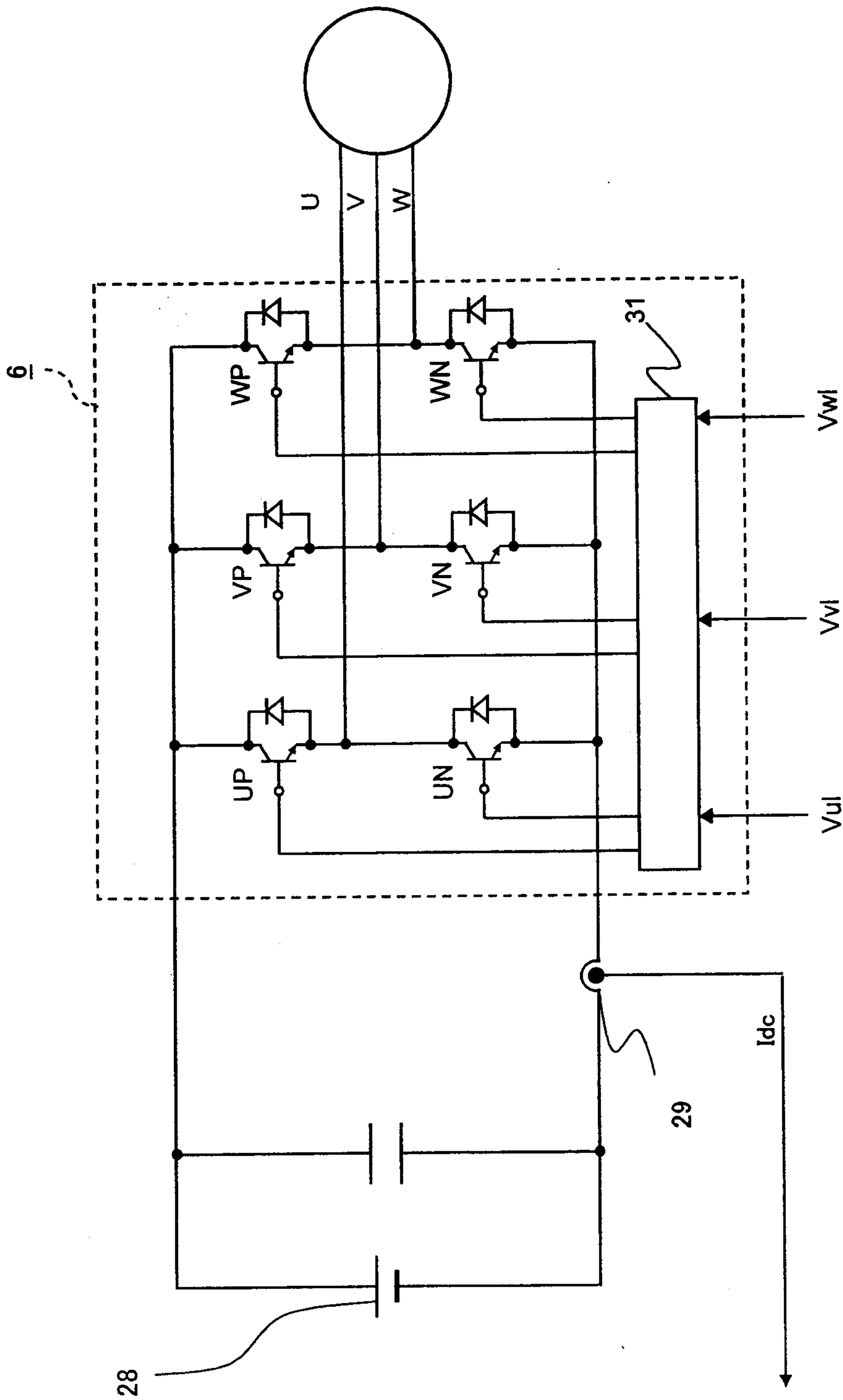


FIG.17

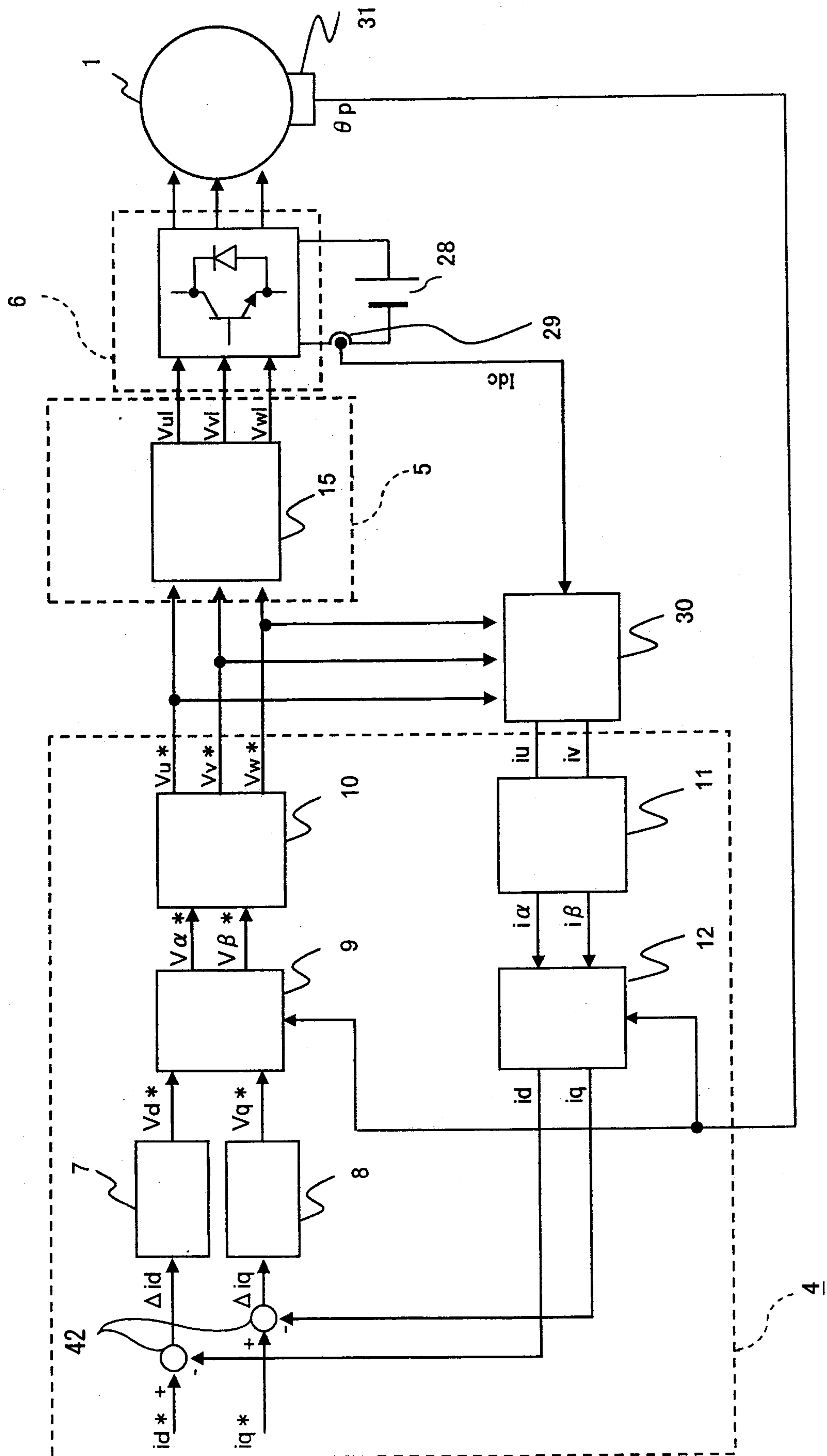


FIG.18

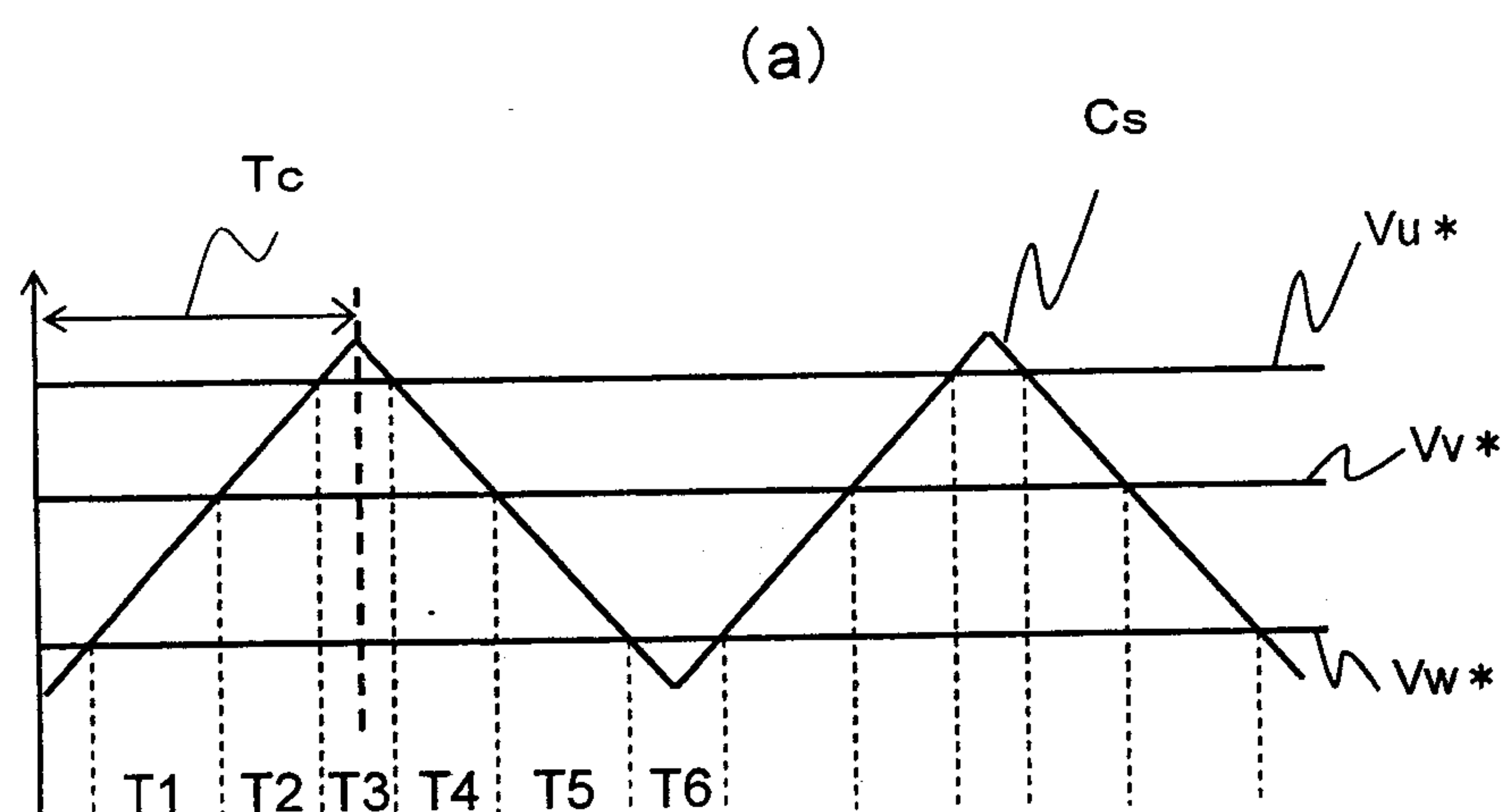


FIG.19

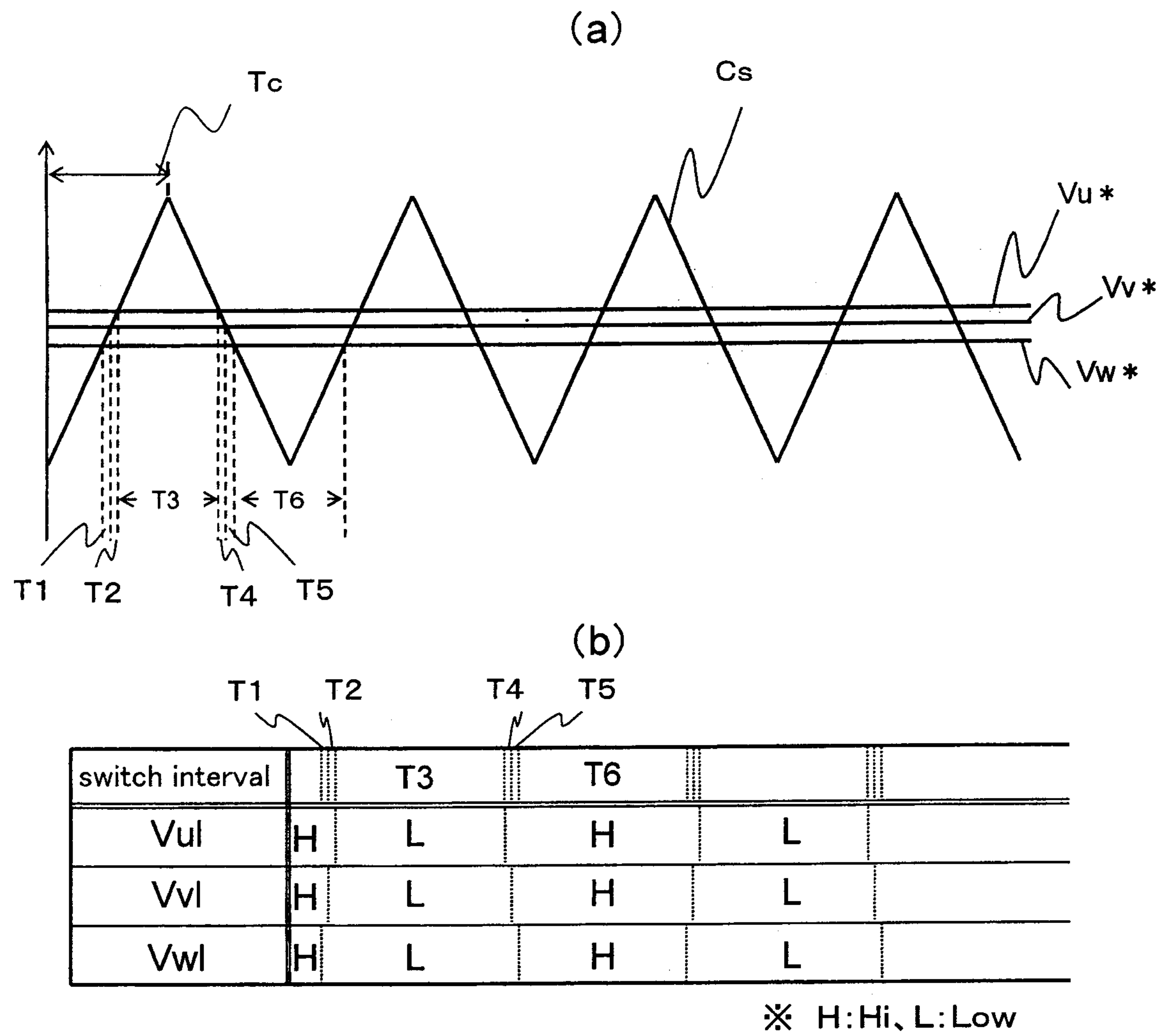


FIG.20

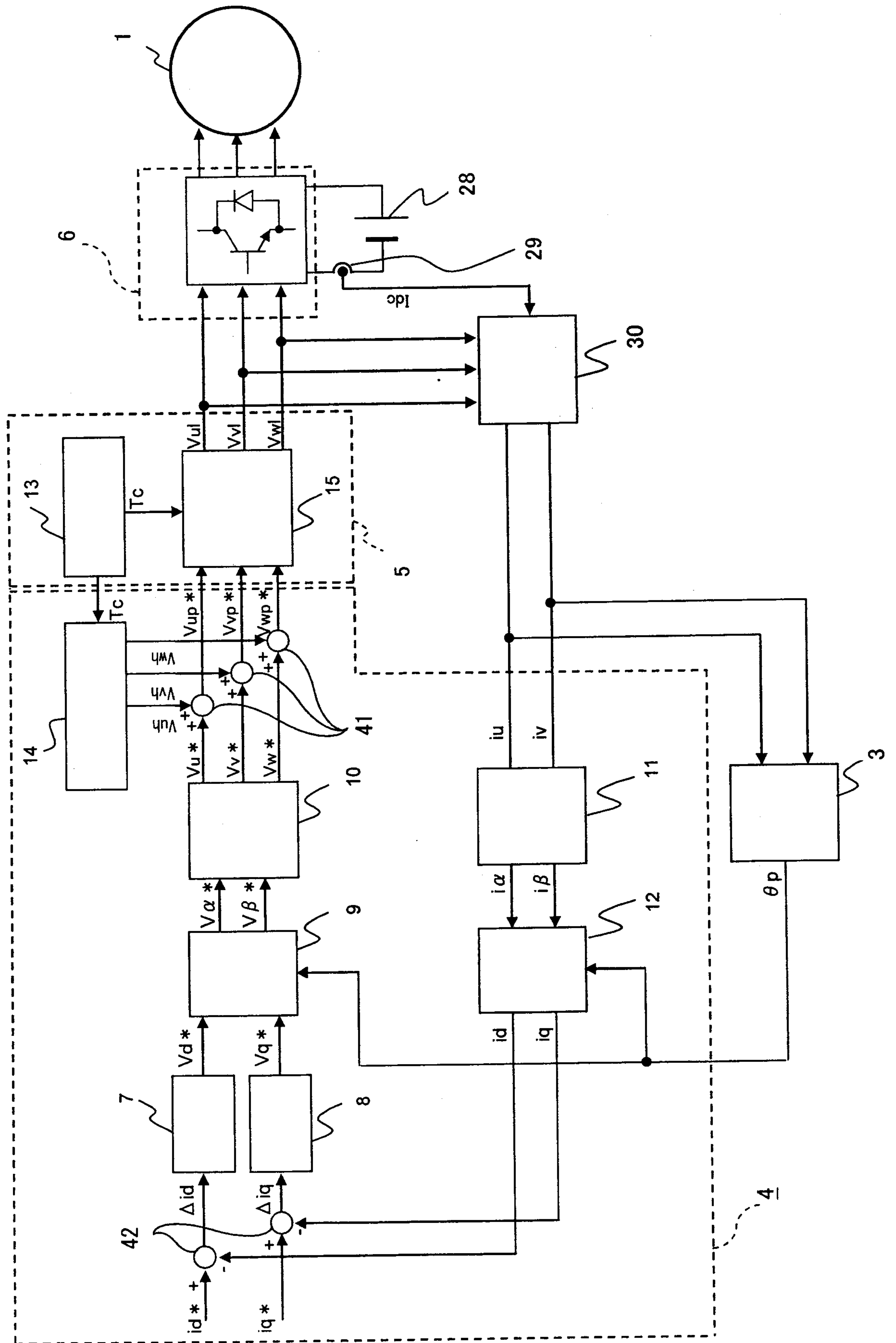


FIG.21

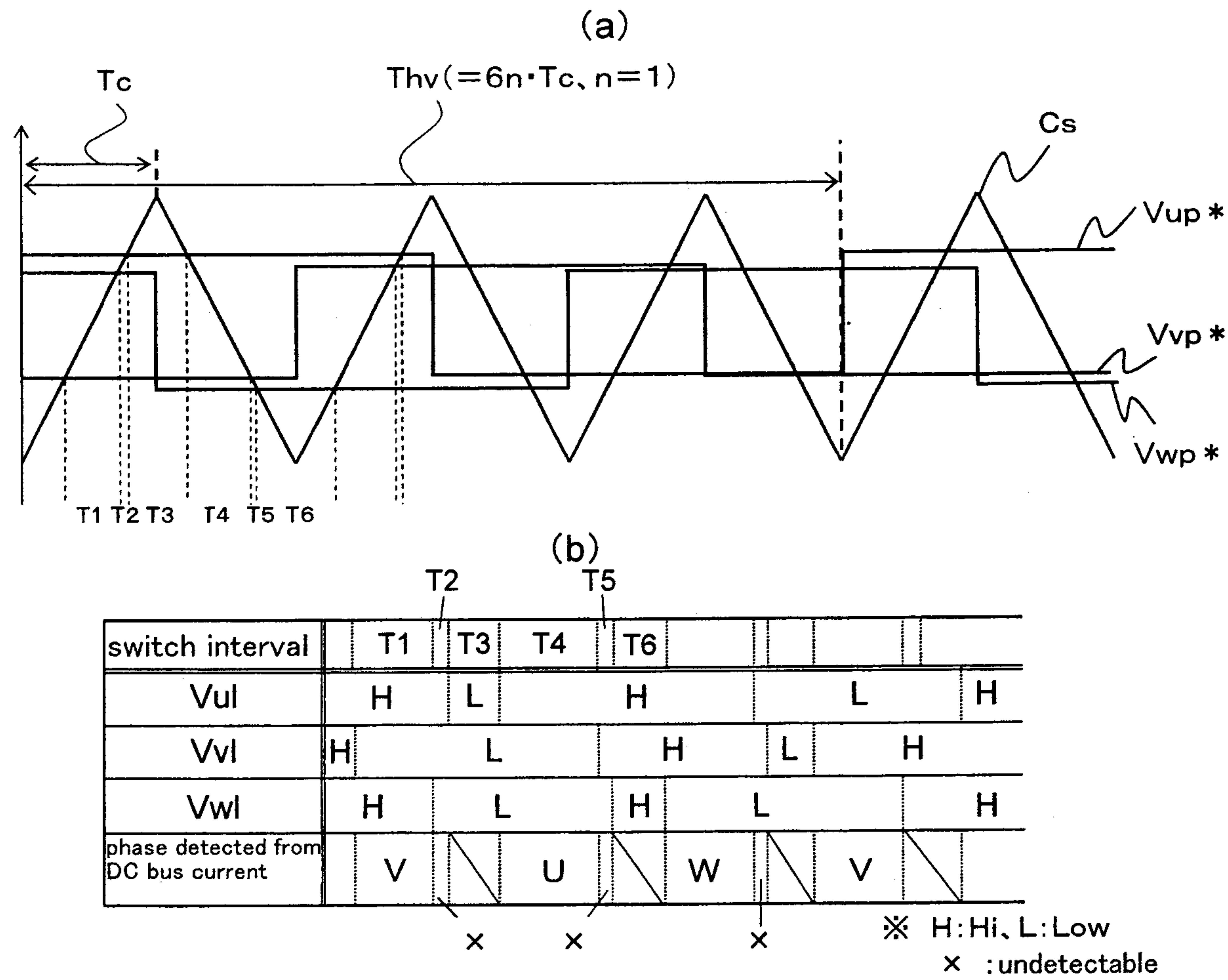


FIG.22

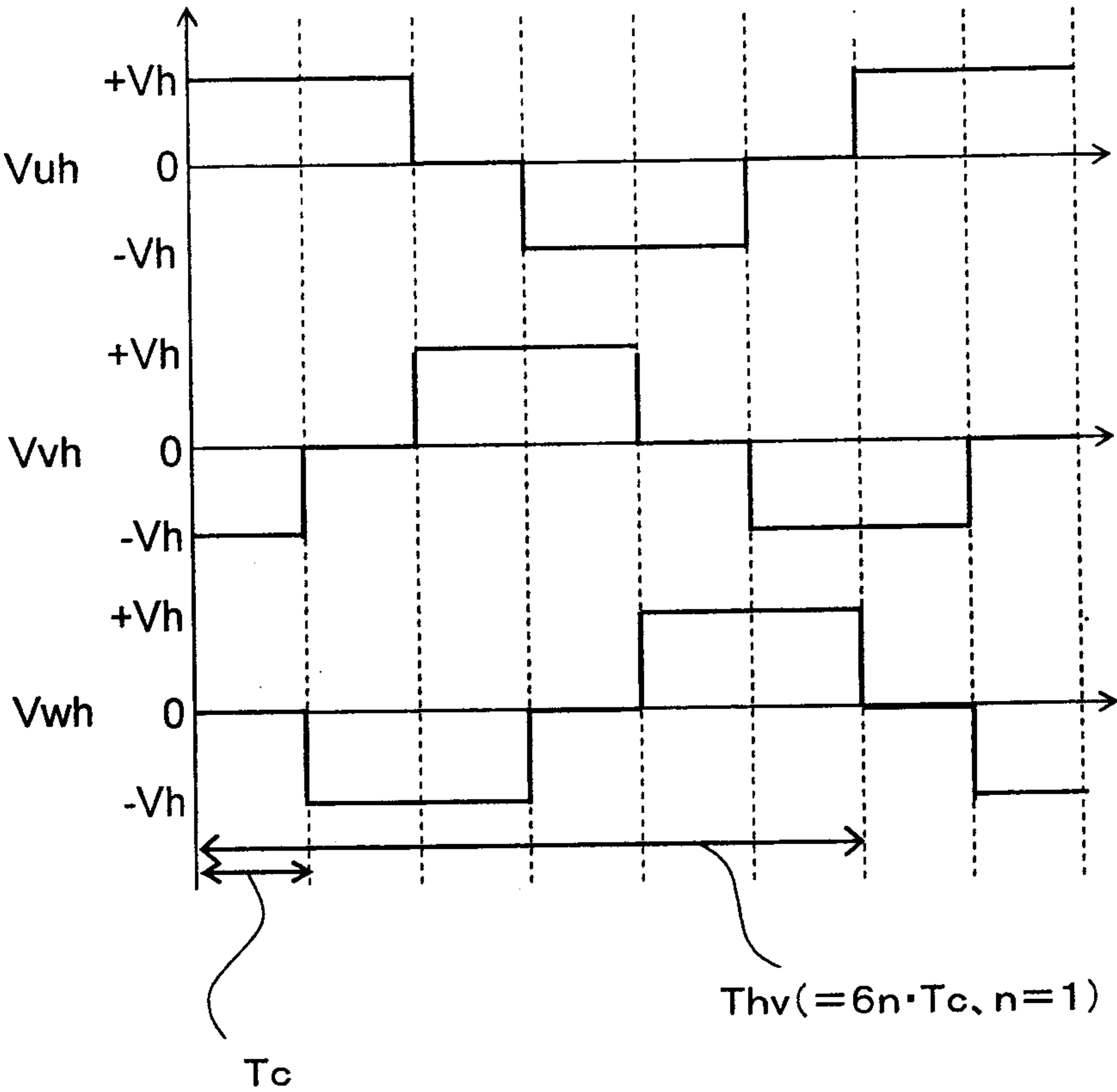
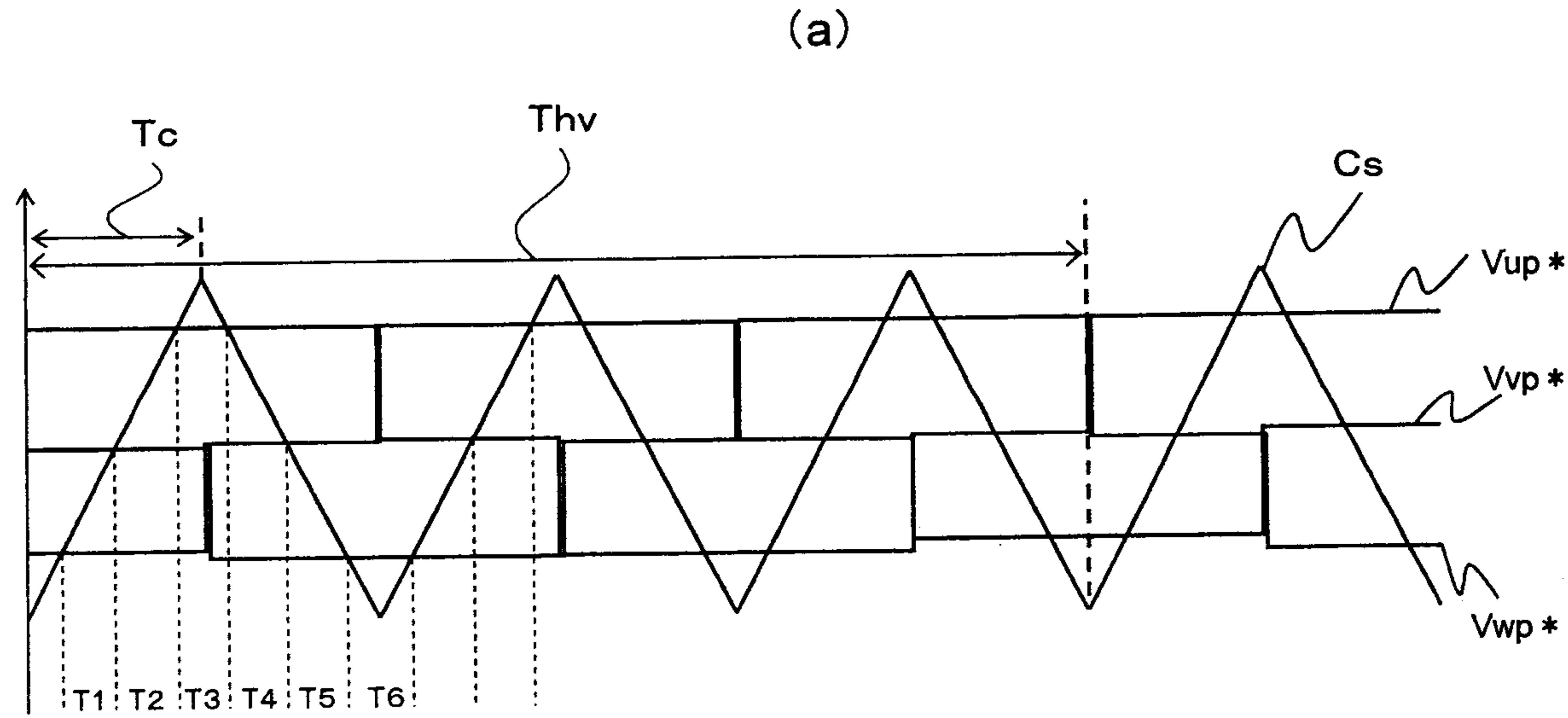


FIG.23



(b)

switch interval	T1	T2	T3	T4	T5	T6				
V_{ul}	H		L		H				L	
V_{vl}	H		L		H			L	H	
V_{wl}	H		L		H		L			
phase detected from DC bus current	V	U	/	U	W	/	W	V	/	V

※ H:Hi, L:Low

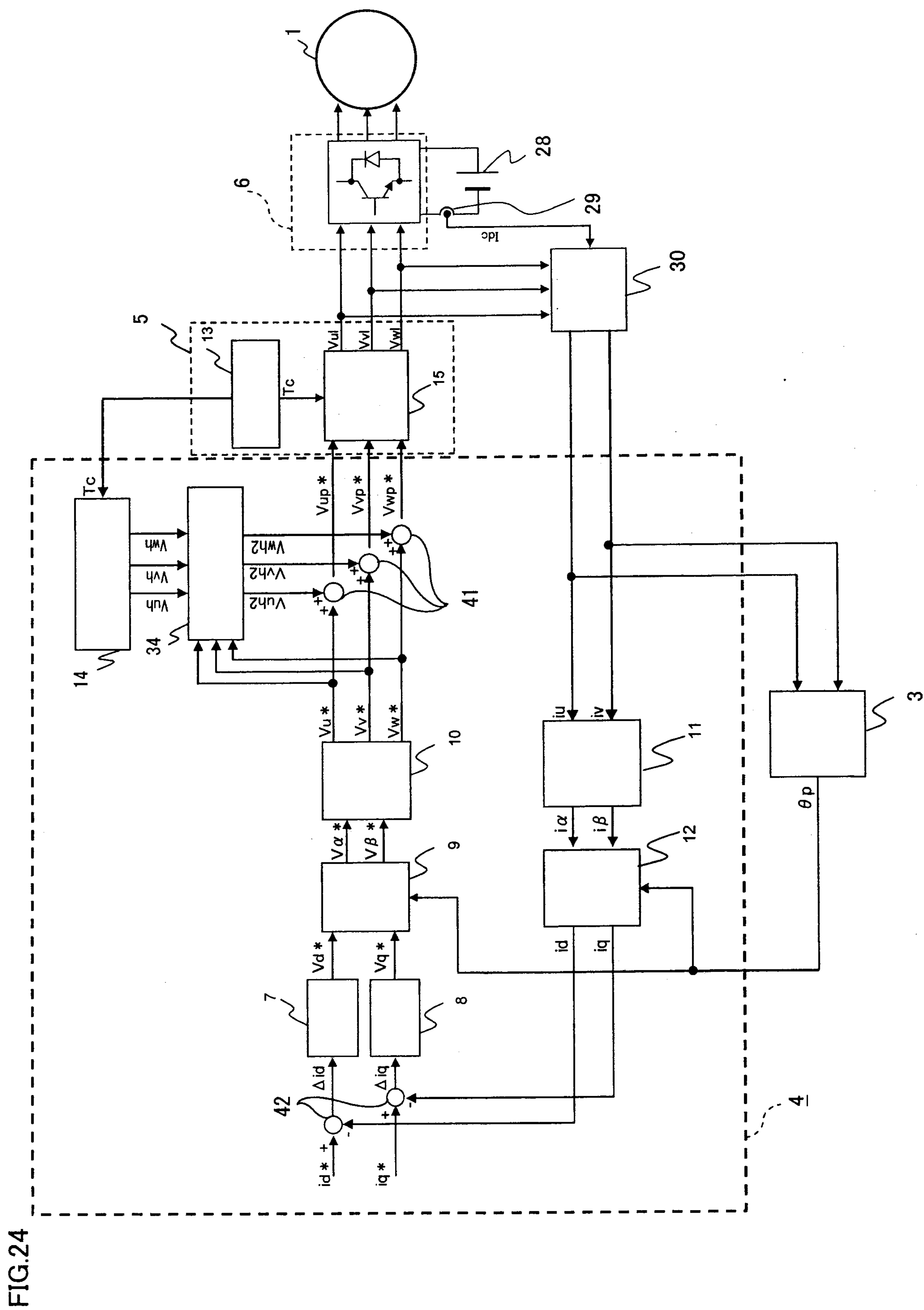
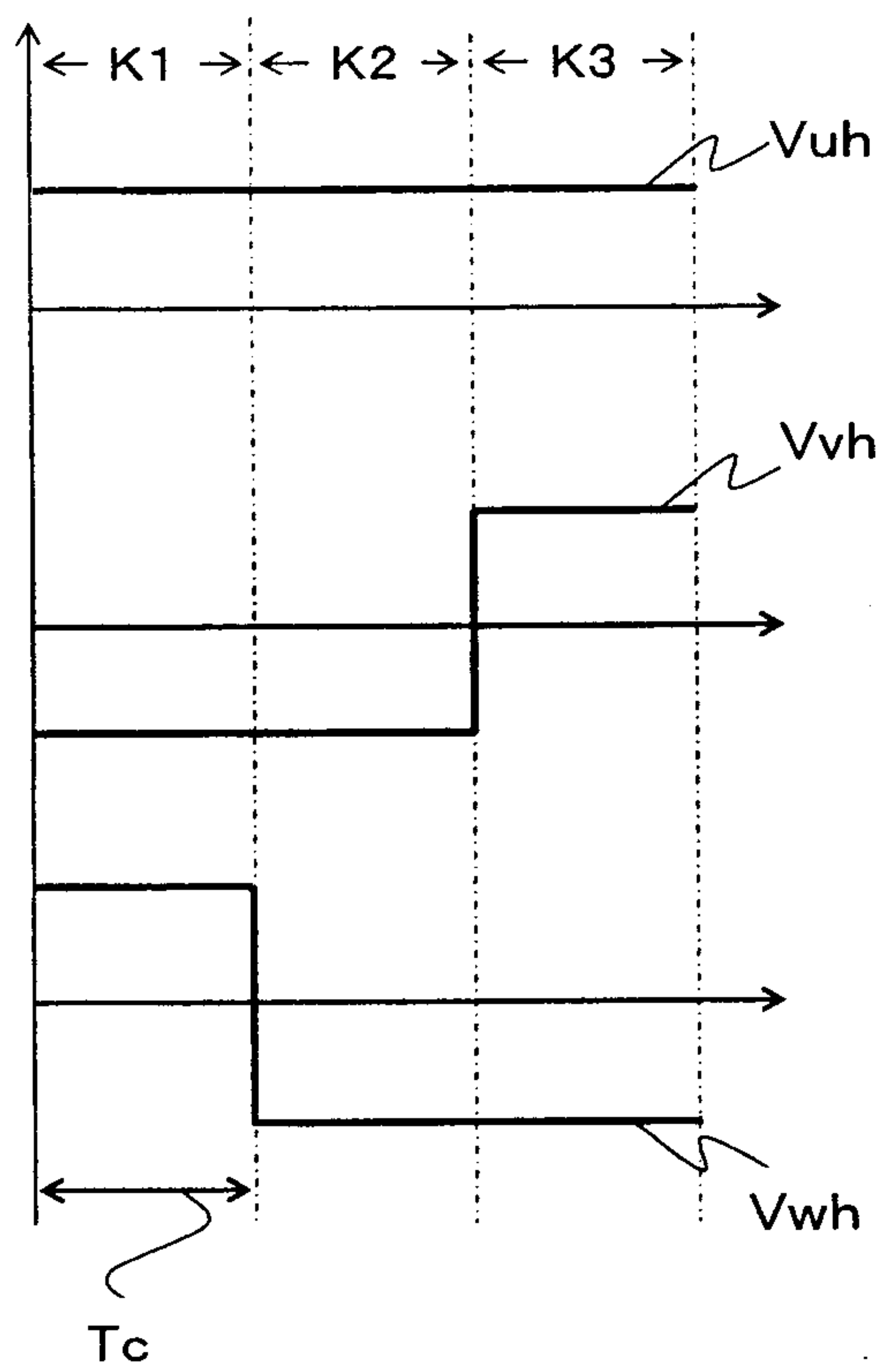
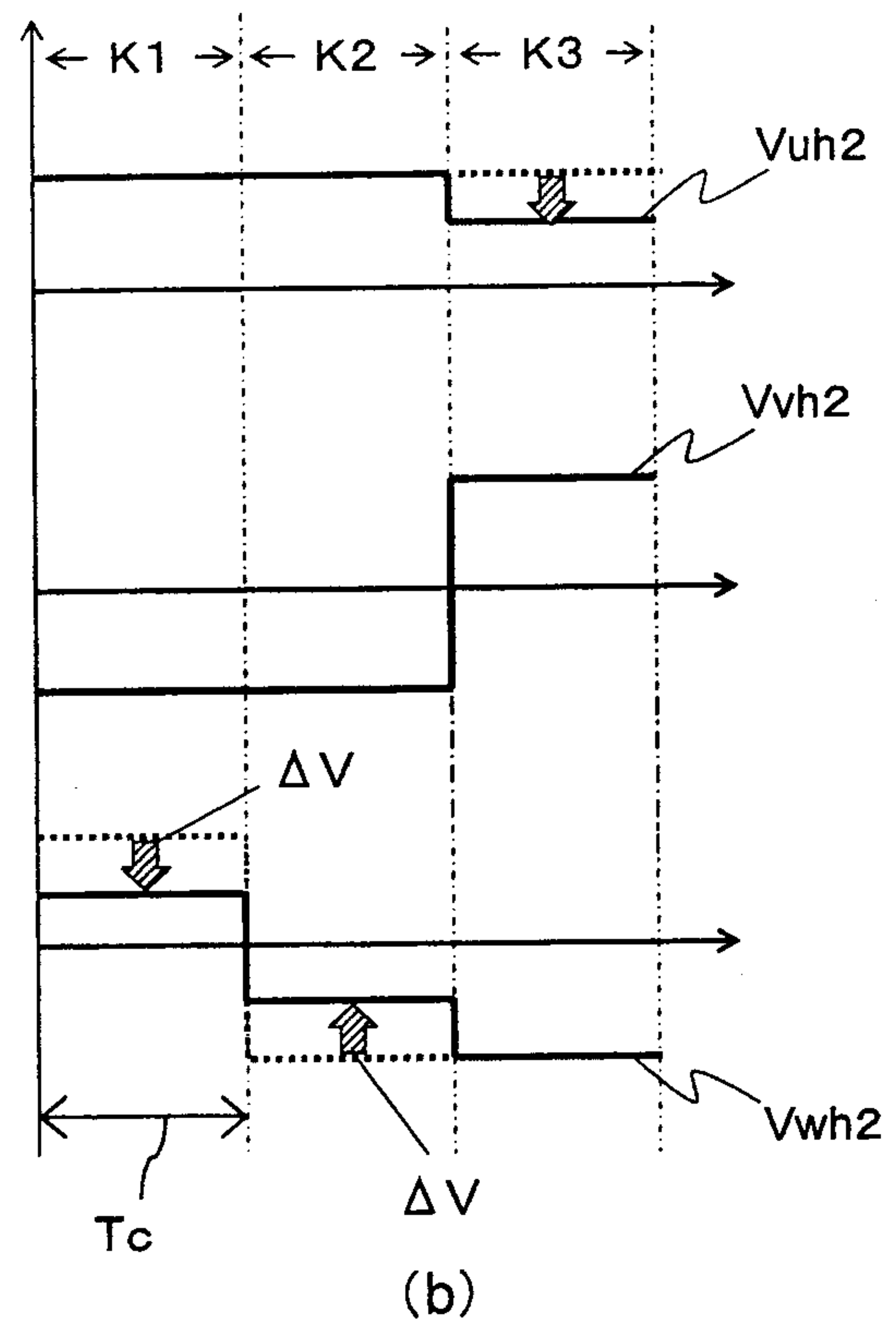


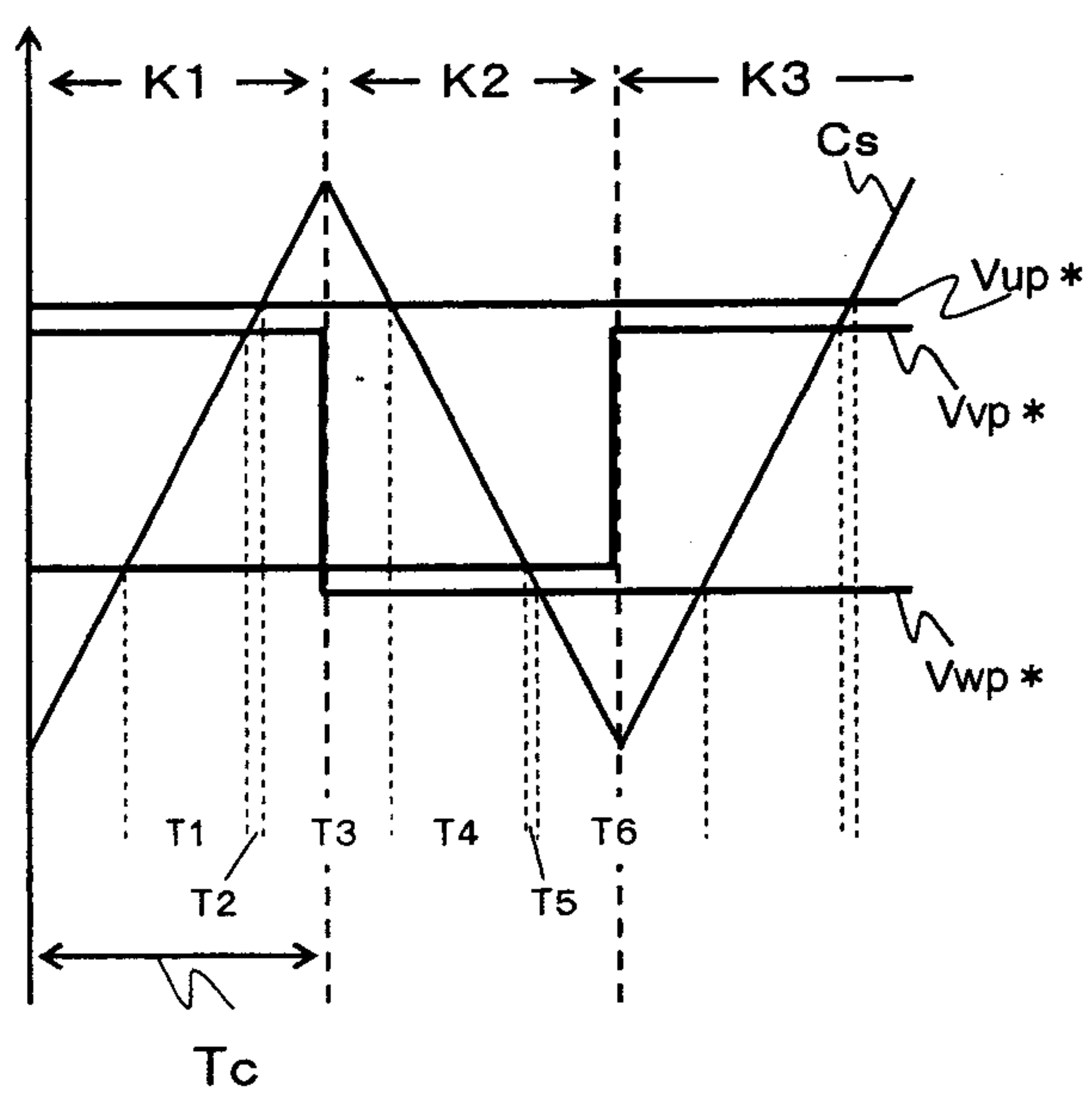
FIG.25



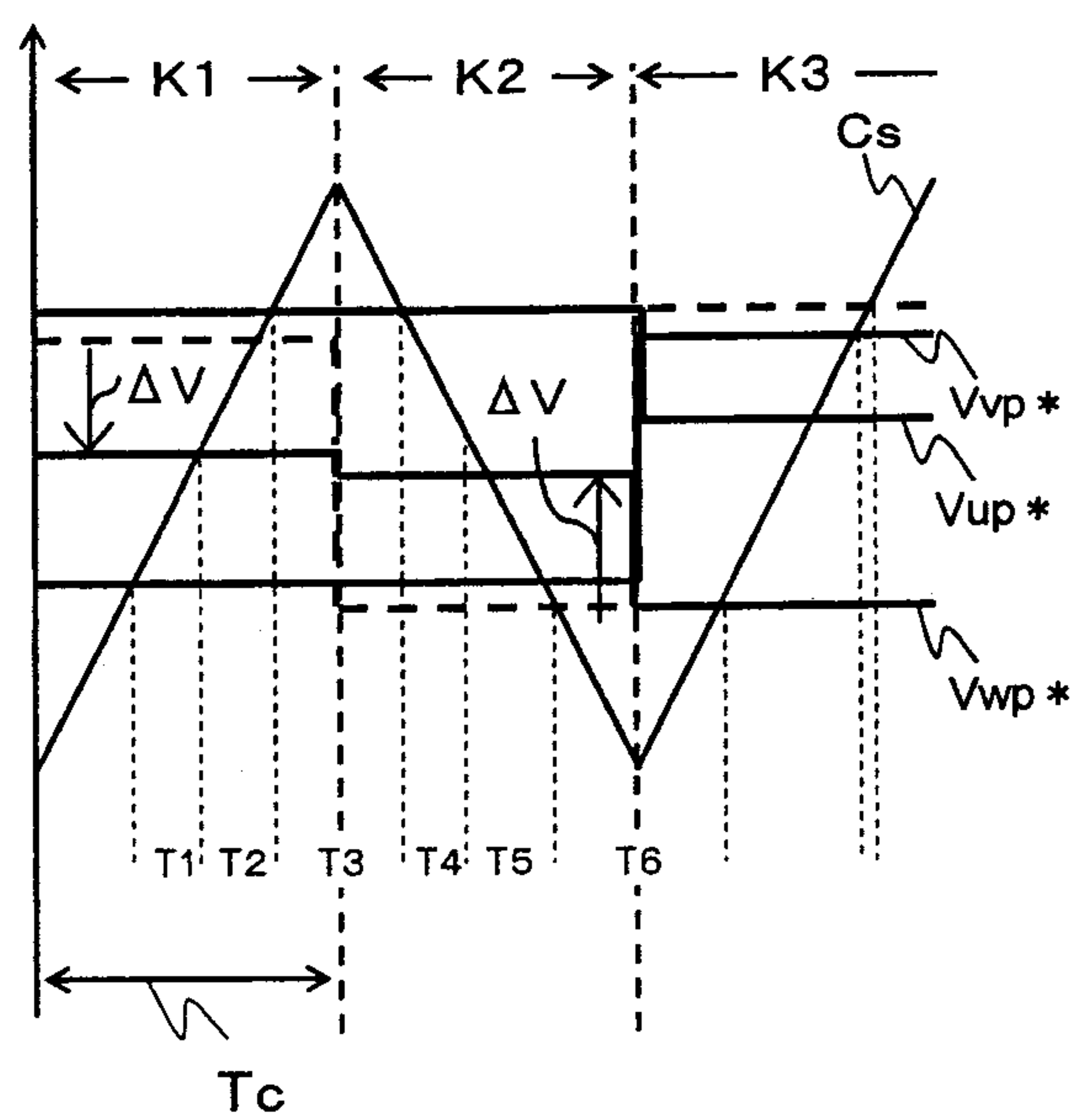
(a)



(b)



(c)



(d)

