

METHOD AND APPARATUS FOR CONTROLLING THE CONTROL
VOLTAGE OF A THREE-PHASE INVERTER SUPPLYING
AN A.C. MOTOR.

5 The present invention concerns a method and an apparatus for controlling the control voltage of a three-phase inverter supplying an a.c. motor.

10 The frequency-controlled a.c. motor is the most advanced design, for instance, in lift use. With frequency control, the efficiency is high at all motor speeds, and the mains power factor is nearly 1. Frequency control is appropriate for both geared and gearless lifts, and at all speeds. Moreover, a simple and moderately priced squirrel cage motor can be used for the motor. In lift use, an inverter, implemented with transistors is best suited for frequency control because it is possible with transistors to achieve the highest switching frequency among existing power electronics components. GTO thyristors may also be contemplated because they have approximately equal
15 switching times, but mains current switching is more complicated than with transistors because of the required switching guards.

20 If in the inverter, pulse width modulation is applied with a comparator, by comparison of sinusoidal and triangle voltages without feedback, the current
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which the inverter supplies to the motor is not sufficiently sinusoidal, for instance for lift use, because in the rectified intermediate voltage circuit, from which the three-phase a.c. voltage supplying the motor is obtained by rectification of the three-phase mains with the inverter, the voltage is not constant. Also, the semiconductor switch does not follow the control without experiencing delay. A third factor causing an error is that of the differential voltage which is caused by the difference in the voltage across the power electronics component in use as a semiconductor switch, compared with the voltage occurring with the other direction of current flow when the diode which lies in parallel with the semiconductor switch is conducting. In practice, the errors give rise to vibration in the motor, which for instance in lift operation impairs the performance of the lift and causes discomfort to the passengers.

At present, current feedback is a procedure known in the state of the art in inverter technology as a method for improving the curve shape. The drawback of current feedback is slow response. This is caused by the fact that in current feedback the motor inductances introduce time constants. The control loop is as a rule slower the greater the number of time constants. Moreover, current measuring elements

are expensive because they are required to be able to measure also direct current.

With the aid of the present invention, it is possible to eliminate the above-mentioned drawbacks.

5 A method of the present invention for controlling the control voltage of a three-phase inverter supplying an a.c. motor is characterised in that the control voltage of each phase of the inverter's pulse width modulator is controlled by a voltage regulator, and
10 that the control voltage obtained from the output of the voltage regulator is produced from an actual value voltage formed from the output voltage of each inverter phase and from a reference voltage. Since in controlling the inverter, voltage control is employed
15 instead of current control, faster control is achieved since, unlike current control, voltage control involves no delay caused by inductive phenomena.

In an advantageous embodiment of the method of the invention, an actual value voltage is formed from the
20 output voltage of each inverter phase and, in order to constitute a synthetic zero level, there is combined with the voltage measured at the output, an a.c. voltage varying at a frequency three times the basic frequency, said a.c. voltage being obtained by
25 combining the positive and negative voltages of the pulsating d.c. voltage obtained by full-wave rectification of the three-phase voltage.

In an advantageous embodiment of the method of the invention the control voltage, obtained at the output of the voltage regulator of each phase, is formed from the actual value voltage, formed from the output
5 voltage of each inverter phase, and from the reference voltage, in that from the actual value voltage and the reference voltage is formed their difference, which is amplified and superimposed on the reference voltage.

In an advantageous embodiment of the method of the invention, the inverter is a transistor inverter in
10 which the transistors, serving as semiconductor switches, are controlled for producing the output voltages of the transistor inverter.

In another advantageous embodiment of the invention, the inverter is a GTO thyristor inverter in
15 which GTO thyristors, serving as semiconductor switches, are controlled for producing the output voltages of the GTO thyristor inverter.

The invention also provides an apparatus for
20 performing the foregoing method wherein, for controlling the control voltage of the pulse width modulator in one inverter phase, there is provided an actual value voltage forming circuit in which from the voltage measured at the inverter output can be
25 established as an actual value voltage, and a reference voltage forming circuit in which, from the

actual value voltage and the reference voltage, there can be formed the control voltage for the pulse width modulator.

5 In an advantageous embodiment, the actual value voltage forming circuit comprises a summing unit, combining the positive voltage and negative voltage of a pulsating d.c. voltage obtained by full-wave rectification of the three-phase supply voltage, and a
10 summing unit combining the voltage measured at the inverter output and the a.c. voltage obtained as described.

In another advantageous embodiment, the control voltage forming circuit comprises a differential unit comparing the actual value voltage and the reference
15 voltage, an amplifier integrating said difference, and a summing unit enabling the differential obtained as described to be superimposed on the reference value to become a control voltage taking into account the instantaneous state of the a.c. motor.

20 In another advantageous embodiment, the inverter is a transistor inverter in which transistors serve as controlled semiconductor switches in the power stage.

In another advantageous embodiment, the inverter is a GTO thyristor inverter in which GTO thyristors
25 serve as controlled semiconductor switches in the power stage.

When the voltage regulator of the invention is used, the ripple of the voltage is, due to the synthetic zero level, less of a detriment than in the case when a sinusoidal voltage is formed with reference to the mains zero. Moreover, in the voltage regulator of the invention, the differential signal produced from the actual value and reference value voltages is amplified and superimposed on the reference voltage. By the superpositioning principle, faster control is achieved than by carrying the entire voltage control through the integrating amplifier of the regulator.

The invention is described further hereinafter, by way of example only, with reference to the accompanying drawings, in which:

Fig.1 is a circuit diagram of one embodiment in accordance with the present invention;

Fig.2 illustrates the formation of the synthetic zero level; and

Fig.3 shows an a.c. motor drive comprising a three-phase transistor inverter with voltage regulators according to the invention.

In the following the operation of the voltage regulator 1 of the invention working in phase A is described with the aid of Figs. 1, 2 and 3. The voltage regulators in phases B and C are similar to

the voltage regulator 1 in phase A. Fig.3 illustrates an a.c. motor drive in which a transistor inverter provided with voltage regulators 1 of the invention is employed. The inputs of the voltage regulator 1 are a voltage V_a , measured at the inverter output with the measuring element 8, and a reference voltage V_a^* . The forming of the reference voltage represents technology with which a person skilled in the art is familiar and it is not part of the subject matter of the present invention. From the output of the voltage regulator 1, a control voltage V_a' for a pulse width modulator 2 is obtained. The pulse width modulator 2 controls through a delay circuit 3 and a control means 4 a transistor T1 in a main circuit 6 of the inverter. Transistors T1 to T6 supply an a.c. motor 7. Power returning from the motor goes to a resistor R2.

The structure of the voltage regulator 1 is shown in Fig.1. The voltage regulator comprises an actual value voltage forming circuit 9 and a circuit 10 forming the control voltage V_a' of the pulse width modulator. In the actual value voltage forming circuit 9, a summing unit 11 produces a synthetic zero level. The synthetic zero level is obtained by combining a positive voltage pU_1 and negative voltage nU_1 of the pulsating d.c. voltage, appearing across a capacitor C4 and which has been obtained by full-wave

rectification, with a diode rectifier bridge 5, of the three-phase mains, which have the phase voltages U_R ; U_S and U_T , to become the a.c. voltage V_0 . The positive voltage pU_1 , the negative voltage nU_1 and the a.c. voltage V_0 formed of these are depicted in Fig.2. In a summing unit 12, the synthetic zero level a.c. voltage V_0 is combined with the voltage V_a measured at the inverter output.

In the pulse width modulator control voltage forming circuit 10, a differential unit 13 forms the difference between the actual value voltage and the reference voltage V_a^* , said difference controlling an integrating amplifier 14. The differential unit 13 comprises a summing unit with one of its two inputs negative. The gain of the amplifier 14 can be changed with the aid of a trimmer T_{M1} . In the summing unit 15, the reference voltage V_a^* and the correction component produced from the difference of the reference voltage V_a^* and the actual value voltage are superimposed to become the control voltage V_a' of the pulse width modulator.

In order that the desired pulse width modulation might be obtained, the modulator 2 has to be controlled with this voltage. The modulator 2 comprises a triangular wave generator 16 and a comparator 17. The triangular wave generator 16 is

common to all phases A, B and C. The modulating digital signal is obtained at the output A and its complementary signal, at the output A'. The signal A controls the transistor T1 of the inverter, and the
5 signal A' controls the transistor T2.

It is necessary in this context to take into consideration the effect of storage time. That is, when the base current is removed from a transistor carrying a current, the transistor remains conductive
10 for about another twenty microseconds. During that time the transistor operating as the pair to the other must not be opened, as a short-circuit would otherwise occur. The transistor ceases to be conductive only after the charge on the base has dissipated. In
15 Fig.3, an asymmetric delay 3 has been introduced in the control of the transistor T1 with the aid of a hysteresis gate 18 so that the other transistor T2 might not open before the transistor T1 has ceased to conduct. The delay provided by this circuit is
20 determined by the product of resistor R1 and capacitor C1. The diode D1 is needed in order that there might be no delay in the switch-off operation.

The control means 4 for the transistor T1 has two floating power sources. A negative supply is required
25 in order to provide a powerful negative base current for rapid switch-off. The two floating voltages are

produced with rectifier diodes D2 to D9 and filtering capacitors C2 and C3. The power supply of the control means 4 is a high-frequency chopper power supply 19, the secondary of its transformer TR1 having enough windings to provide the requisite floating power supplies. Energy is supplied from the transformer TR1. An optoisolator 20 supplies the end stage transistors T7 and T8 by way of the resistor R3. The latter transistors constitute a dual emitter follower circuit.

The diode D10 is a so-called Baker diode. It prevents the power transistor proper, T1, from becoming saturated. This reduces and stabilizes the storage time. Furthermore, the switch-off power of the transistor is reduced due to the diode. The resistor R3 is needed for the Baker diode D10 to operate correctly. The control signal of the control means is inserted at the point a. The point O/E represents the ground of the oscillator electronics. The diode D11 is the protective diode for the optoisolator 20.

The power supply of the main circuit 6 of the four-quadrant transistor inverter is in the present instance obtained by full-wave rectification of the phase voltages UR, US and UT of the three-phase mains with the diode bridge 5. In this way, a fixed

intermediate voltage is produced across the capacitor C4. From the intermediate voltage is produced, by pulse width modulation, a three-phase voltage UA, UB and UC with controlled frequency and amplitude. This
5 controlled three-phase power controls the motor 7. The diodes D12 to D17 are zero diodes constituting current paths for inductive currents while the transistor connected in parallel with the diode is switched off. The braking energy goes to the braking
10 resistance R2 controlled by the braking transistor T9.

It is obvious to a person skilled in the art that various embodiments of the invention are not restricted to the example presented in the foregoing, but may vary within the scope of the claims to be
15 presented below. In addition to a transistor inverter implemented with transistors, a GTO thyristor inverter using GTO implemented thyristors is an example of another possible application of the voltage regulator of the invention.

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CLAIMS

1. A method for the control of the control voltage of a three-phase inverter supplying an a.c. motor, wherein the power stage of said inverter is implemented using semiconductor switches, and wherein
5 the output voltage of each inverter phase in said voltage control is measured, the method comprising controlling the control voltage of a pulse width modulator in each phase of the inverter with a voltage regulator, and forming a control voltage obtained at
10 the output of said voltage regulator from an actual value voltage, formed from the output voltage of each inverter phase, and from a reference voltage.

2. A method as claimed in claim 1, wherein an actual value voltage is formed from the output voltage
15 of each inverter phase and wherein, in order to constitute an artificial zero level, the voltage measured at the output is combined with an a.c. voltage which varies at a frequency three times the basic frequency, this a.c. voltage being obtained by
20 combining the positive voltage and the negative voltage of a pulsating d.c. voltage, produced by full-wave rectification of a three-phase voltage.

3. A method as claimed in claim 1 or 2, wherein the control voltage obtained at the output of the



voltage regulator of each phase is formed from the actual value voltage formed from the output voltage of each phase and the reference voltage, and wherein the difference between the actual value voltage and the reference input voltage is formed and this difference is amplified and superimposed on the reference value.

4. A method as claimed in claim 1, 2 or 3, wherein the inverter is a transistor inverter in which a plurality of transistors serving as semiconductor switches are controlled for producing the output voltages of the transistor inverter.

5. A method as claimed in claim 1, 2 or 3, wherein the inverter is a GTO thyristor inverter in which GTO thyristors serving as semiconductor switches are controlled for producing the output voltages of the GTO thyristor inverter.

6. An apparatus for performing the method of claim 1, having an output voltage measuring element, and wherein, for controlling the control voltage of the pulse width modulator in one phase of the inverter, there is provided an actual value voltage forming circuit in which an actual value voltage can be produced from the voltage measured at the inverter output, and a control voltage forming circuit in which the control voltage of the pulse width modulator can be produced from the actual value voltage and the reference voltage.



7. An apparatus as claimed in claim 6, wherein the actual value forming circuit comprises a summing unit combining the positive voltage and the negative voltage of a pulsating d.c. voltage obtained by
5 full-wave rectification of said three-phase voltage and a summing unit which combines the voltage measured at the inverter output with the a.c. voltage thus obtained.

8. An apparatus as claimed in claim 6 or 7,
10 wherein the control voltage forming circuit comprises a differential unit which compares the actual value voltage and the reference voltage, an amplifier which integrates said difference, and a summing unit, with the aid of which the differential thus obtained can be
15 superimposed on the reference value to become a control voltage taking into account the instantaneous state of the a.c. motor.

9. An apparatus as claimed in claim 6, 7 or 8, wherein the inverter is a transistor inverter in which
20 the controlled semiconductor switches in the power stage are transistors.

10. An apparatus as claimed in claim 6, 7 or 8, wherein the inverter is a GTO thyristor inverter in which the controlled semiconductor switches in the
25 power stage are GTO thyristors.



11. A method for the control of the control voltage of a three-phase inverter, substantially as hereinbefore described with reference to the accompanying drawings.

5 12. Apparatus for the control of a three-phase inverter, substantially as hereinbefore described with reference to and as illustrated in the accompanying drawings.

