

# Circuit arrangement for powering a two-phase asynchronous motor.

The invention relates to a circuit arrangement for powering a two-phase asynchronous motor comprising two windings which each have one end connected to a first and a third node, respectively, and which both have another end connected to a second node, the nodes each being arranged to receive one of three alternating voltages whose sinusoidal  
5 fundamental waves at least substantially correspond in frequency (fundamental frequency).

Such a circuit arrangement is known from DE-OS 42 32 134. In said circuit arrangement the power dissipation in a switching circuit connected to the third node is reduced so as to permit a more economical dimensioning without a deterioration of the performance, particularly the loadability, in that the alternating voltage to be applied to the  
10 second node assumes constant levels in given periodically recurring time intervals.

US-PS 5,136,216 discloses a drive system for driving a conventional single-phase "PSC" motor by means of a two-phase power source. This motor also comprises two windings which each have one end connected to one node and which have both ends connected to a further node. These nodes receive rectangular signals which are pulse-width  
15 modulated in accordance with a sinusoidal function. The motor can be powered by means of a three-phase inverter generating a two-phase alternating voltage, by means of a single-phase source with a starting capacitor, or by means of a two-phase inverter.

It is an object of the invention to improve a circuit arrangement of the type defined in the opening paragraph so as to obtain an even more significant reduction of  
20 the power dissipated in preferably all the switching circuits connected to the nodes.

According to the invention this object is achieved with a circuit arrangement of the type defined in the introductory part of the main Claim in that

- the second alternating voltages to be applied to the second node has a rectangular waveform of fundamental frequency,
- 25 - the first and the third alternating voltage to be applied to the first and the third node, respectively, are given such a lead and such a lag as regards the phases of their sinusoidal fundamental waves that the resulting voltages across the windings have a phase angle relative to one another which corresponds to the (mechanical) angle between the windings,



- the first and the third alternating voltage each comprise time intervals with constant (non-modulated) voltage values and time intervals which are positioned symmetrically in time relative thereto and in which the voltage is pulse modulated with a given duty cycle and with a switching frequency which is high relative to the fundamental frequency,
- only the first or the third alternating voltage in each time interval being pulse modulated and the respective other (third or first) alternating voltage being constant (non-modulated), and the duration of the time intervals with a pulse modulated voltage as well as the duty cycle in each of these time intervals being determined in accordance with a desired amplitude ratio between the voltages across the windings.

The duty cycle is defined as the ratio of the duration of the appearance of a positive voltage within one period of the switching frequency to the overall duration of this period of the switching frequency.

15 In comparison with the state of the art the circuit arrangement in accordance with the invention makes it possible to obtain a significant reduction of the number of switching edges of the alternating voltages to be applied to the nodes. Since each switching edge, i.e. each switching event in this alternating voltage, is attended with losses in the switching circuits causing these switching events, a reduction of the number of switching events in each period of the fundamental wave also means a reduction of the power dissipation. The reduction of the thermal load obtained by means of the invention makes it possible to obtain a simpler and cheaper dimensioning of the circuit arrangement, particularly of said switching circuits. The required waveforms of the alternating voltages on the nodes can then be generated by simple means. By a suitable dimensioning of the time intervals with a constant and with a pulse-modulated voltage, i.e. of voltage values and of the duty cycle, the phase relationships and amplitudes of the voltages across the windings can readily be adapted to the design characteristics of different motors to be powered. Motors having similar windings as well as motors having different windings can be powered in a simple manner.

30 Preferably, the duty cycles in every two symmetrically positioned time intervals of the first or the third alternating voltage in which the voltage is pulse modulated are selected to be one another's complement of 1. The sum of such complementary duty cycles is then 1.

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These values of the duty cycle can be generated simply by inverting a rectangular signal having one of the desired duty cycles. The duty cycle is then preferably constant in the individual time intervals of the pulse-modulated voltage. Close approximations to sinusoidal waveforms of the voltages across the windings with acceptable harmonic contents can then be obtained by means of a very simple pulse-width modulation, fundamental waves which are  $90^\circ$  phase-shifted being formed in the special case.

In a preferred embodiment of the circuit arrangement in accordance with the invention the time intervals with a constant voltage and those with a pulse modulated voltage form a time pattern with a frequency (basic pulse train frequency) which is an integral multiple of the fundamental frequency, and the alternating voltages are derived from a logic combination of a signal having said basic pulse train frequency and a switching signal having the switching frequency and having a desired duty cycle as stated above. The waveform with the basic pulse train frequency can then dictate the speed of the motor in an advantageous manner and can also be incorporated simply in an electronic commutation controlled by the angle of rotation. The switching frequency, however, is preferably constant independently of the operating condition of the motor to be powered.

Further advantageous embodiments are defined in the subsidiary Claims.

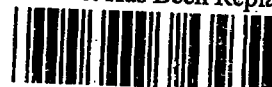
Some exemplary embodiments of the invention are shown in the drawings and will be described in more detail hereinafter. In the drawings:

Fig. 1 is a schematic circuit diagram of a circuit arrangement for powering a motor having two windings by means of a three-phase power inverter,

Fig. 2 shows some signal waveforms for an example of a power supply of a motor having symmetrical windings, and

Fig. 3 shows similar signal waveforms for an example of the power supply of a motor having asymmetrical windings.

Fig. 1 is a schematic circuit diagram for a circuit arrangement by means of which a two-phase asynchronous motor can be powered advantageously in accordance with the diagrams of Figs. 2 and 3. This circuit arrangement comprises a direct voltage source 1, which for simplicity is shown in Fig. 1 as a series arrangement of two sources which each supply a direct voltage  $U_q$  and whose node is coupled to ground 2. On its terminals 3 and 4 the direct voltage source 1 supplies a positive voltage  $U_Q$  and a negative voltage  $-U_Q$  relative to ground potential (potential on 2). The direct voltage source 1 may comprise a mains rectifier, a switched-mode power supply, a battery or the like.



Ends of three switch sections 5, 6 and 7, which each comprise two series-connected switch stages 8, 9; 10, 11 and 12, 13, respectively, are connected to the terminals 3, 4 of the direct voltage source 1. In the example shown in Fig. 1 each of the switch stages 8 to 13 comprises a field-effect transistor whose source-drain path forms a current path for the currents to be applied to the two-phase asynchronous motor. For this purpose the drain terminal of the field-effect transistor of the first switch stage 8, 10 or 12 is connected to the positive terminal 3 of the direct voltage source 1 and the source terminal of the field-effect transistor of the second switch stage 9, 11 or 13 is connected to the negative terminal 4 of the direct voltage source 1 in each of the switch sections 5, 6 and 7, respectively. Moreover, in each of the switch sections 5, 6 and 7 the source terminal of the field-effect transistor of the first switch stage 8, 10 or 12 is connected to the drain terminal of the field-effect transistor of the associated second switch stage 9, 11 or 13. The last-mentioned connection forms a first, second and third node 14, 15 and 16, respectively. A first winding 17 of the two-phase asynchronous motor is connected between the first node 14 and the second node 15 and a second winding 18 of this motor is connected between the second node 15 and the third node 16. The first winding 17 may be a main winding and the second winding 18 may be an auxiliary winding or the other way round; however, the two windings may also be dimensioned identically.

The switch sections 5, 6 and 7 serve to apply three alternating voltages  $U_1$ ,  $U_2$  and  $U_3$ , respectively, to the nodes 14, 15 and 16, respectively. In Fig. 1 these voltages are shown relative to ground. The difference between the first alternating voltage  $U_1$  on the first node 14 and the second alternating voltage  $U_2$  on the second node 15 forms a voltage  $U_A$  across the first winding 17, and the difference between the third alternating voltage  $U_3$  on the third node 16 and the second alternating voltage  $U_2$  on the second node 15 forms a voltage  $U_B$  across the second winding 18. Currents  $I_A$  and  $I_B$  flow through the windings 17 and 18, respectively.

The gate terminals of the first and the second switch stages 8, 9; 10, 11 and 12, 13 of the switch sections 5, 6 and 7, respectively, are connected to one another via an inverter 19, 20 and 21, respectively. In operation control signals  $S_1$ ,  $S_2$  and  $S_3$  can be applied to the gate terminals of the second switch stages 9, 11 and 13, respectively. These signals control the first and the second switch stage 8, 9; 10, 11 and 12, 13, respectively, in an opposite sense, so that the nodes 14, 15 and 16 can be connected selectively to the first terminal 3 or the second terminal 4 of the direct voltage source 1. By an appropriate control





with the control signals S1, S2 and S3 different waveforms are generated for the alternating voltages U1 to U3.

The diagram in Fig. 2 shows waveforms of a number signals in a circuit arrangement as shown in Fig. 1 in a first example of an operating situation. The windings 17 and 18 are dimensioned identically and are arranged to be  $90^\circ$  shifted relative to one another. Accordingly, they are powered with voltages UA and UB which are shifted through  $90^\circ$  relative to their fundamental wave. In Fig. 2 these signals have been plotted particularly in relation to one period of this fundamental wave.

Fig. 2a shows a signal having a frequency corresponding to four times the fundamental frequency and having a rectangular waveform. The frequency of this signal SG is referred to as the basic pulse train frequency; the signal may consequently be referred to as the basic pulse train.

Fig. 2b) shows diagrammatically a switching signal represented as a rectangular waveform with the switching frequency and with a given duty cycle. In contrast with the basic pulse train frequency, which directly dictates the motor speed, the switching frequency of the switching signal PWM is constant in all operating situations of the motor and is high relative to the basic pulse train frequency. The control signals S1 to S3 shown in Figs. 2c) to 2e) are derived from the basic pulse train SG and the switching signal PWM by logic operations. The state or waveform of each of the control signals S1 to S3 then changes on a rising switching edge of the basic pulse train SG. For example, the first control signal S1 assumes a high value between the first two rising edges of the basic pulse train SG in the first time interval corresponding to a motor phase between  $0^\circ$  and  $90^\circ$ . In the second time interval corresponding to a motor phase between  $90^\circ$  and  $180^\circ$  the first control signal S1 is pulse modulated in accordance with the switching signal PWM and in the third time interval it assumes a constant unmodulated low level. In the fourth time interval corresponding to a motor phase of  $270^\circ$  to  $360^\circ$  the control signal is again pulse modulated, the duty cycle of this pulse modulation in the last-mentioned time interval and the duty cycle in the second time interval (between  $90^\circ$  and  $180^\circ$ ) being related to one another as complements of 1. These two time intervals with a pulse-modulated waveform of the first control signal S1 are symmetrically positioned in time relative to the first time interval (between  $0^\circ$  and  $90^\circ$ ) in which the first control signal S1 assumes a constant high level. This becomes apparent when the signal waveforms are extended beyond the shown period of the fundamental wave.

The third control signal S3 has a similar waveform. However, it has a phase lead of  $90^\circ$  with respect to the first control signal S1, referred to the fundamental



frequency. Conversely, the second control signal has only a rectangular waveform with the fundamental frequency, its phase being centered relative to the phases of the fundamental waves of the first and the third control signal S1 and S3.

The control signals S1 to S3 generate alternating voltages U1 to U3, which are not shown explicitly in Fig. 2 but whose waveforms correspond directly to those of the control signals S1 to S3. These alternating voltages U1 to U3 give rise to voltages UA and UB across the windings 17, 18 of the motor, whose waveforms are shown in Figs. 2f) and 2g). The waveforms of the voltages UA and UB are similar to one another with a 90° phase shift relative to the fundamental frequency. The described complementary definition of the duty cycles in the individual time intervals result in identical duty cycles in the voltages UA and UB for all the time intervals.

Fig. 2 shows that the second control signal S2 in each period of the fundamental frequency produces only two switching operations and that at any instant (or in any time interval) only one of the other control signals S1 and S3 is pulse modulated. Thus, in comparison with the state of the art the number of switching operations per period of the fundamental frequency is drastically reduced and, consequently, the power dissipation in the switch sections 5, 6 and 7 is reduced considerably. In spite of this, an unrestricted power control between zero load and full load is possible by selection of the duty cycle.

Fig. 3 is a diagram similar to that in Fig. 2 for the operation of a motor with asymmetrical windings 17, 18. In this example the basic pulse train frequency is six times the fundamental frequency; accordingly, the basic pulse train SG shown in Fig. 3a) comprises six rectangular pulses within the period of the fundamental frequency shown in Fig. 3. The amplitude ratio between the voltages UA and UB across the asymmetrical windings 17 and 18 is now, for example:

1 :  $\sqrt{3}$ .

In principle, the control signals 1 to 3 have the same characteristics as those in the case of Fig. 2, i.e. they have the same symmetrical arrangement of pulse modulated and non-modulated time intervals. The fundamental wave of the first control signal S1 has a phase lead of 30° relative to the fundamental wave of the second control signal S2, relative to which the fundamental wave of the third control signal S3 has a phase lag of 60°. Altogether this yields a phase difference of 90° for the fundamental wave between the control signals S1 and S3, which also occurs in the fundamental waves of the voltages UA and UB across the windings 17 and 18, respectively. The total duration of the time intervals in which the voltage UB across the second winding 18 assumes a non-zero voltage value is

larger than the total duration of the comparable time intervals of the voltage UA across the first winding 17 in accordance with the voltage ratio to be obtained.

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CLAIMS:

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1. A circuit arrangement for powering a two-phase asynchronous motor comprising two windings which each have one end connected to a first and a third node, respectively, and which both have another end connected to a second node, the nodes each being arranged to receive one of three alternating voltages (U1, U2, U3) whose sinusoidal  
5 fundamental waves at least substantially correspond in frequency (fundamental frequency), characterized in that
- the second alternating voltages (U2) to be applied to the second node has a rectangular waveform of fundamental frequency,
  - the first and the third alternating voltage (U1 and U3, respectively) to be  
10 applied to the first and the third node, respectively, are given such a lead and such a lag as regards the phases of their sinusoidal fundamental waves that the resulting voltages (UA, UB) across the windings have a phase angle relative to one another which corresponds to the (mechanical) angle between the windings,
  - the first and the third alternating voltage (U1, U3) each comprise time intervals  
15 with constant (non-modulated) voltage values and time intervals which are positioned symmetrically in time relative thereto and in which the voltage is pulse modulated with a given duty cycle and with a switching frequency which is high relative to the fundamental frequency,
  - only the first or the third alternating voltage (U1 or U3) in each time interval  
20 being pulse modulated and the respective other (third or first) alternating voltage (U3 or U1) being constant (non-modulated), and the duration of the time intervals with a pulse modulated voltage as well as the duty cycle in each of these time intervals being determined in accordance with a desired amplitude ratio between the voltages (UA, UB) across the windings.
- 25 2. A circuit arrangement as claimed in Claim 1, characterized in that the duty cycles in every two symmetrically positioned time intervals of the first or the third alternating voltage (U1 or U3) in which the voltage is pulse modulated are selected to be one another's complement of 1.
3. A circuit arrangement as claimed in Claim 1 or 2, characterized in that

the time intervals with a constant voltage and those with a pulse modulated voltage form a time pattern with a frequency (basic pulse train frequency) which is an integral multiple of the fundamental frequency, and the alternating voltages (U1, U2), U3) are derived from a logic combination of a signal having said basic pulse train frequency and a switching signal having the switching frequency and having the desired duty cycle.

4. A circuit arrangement as claimed in Claim 3, characterized in that the basic pulse train frequency is a multiple of the fundamental frequency and the amplitude ratio between the voltages (UA, UB) across the windings is 1:1.

5. A circuit arrangement as claimed in Claim 3, characterized in that  
10 the basic pulse train frequency is six times the fundamental frequency and the amplitude ratio between the voltages (UA, UB) across the windings is  $1:\sqrt{3}$ .

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