

Description

Method and apparatus for reducing harmonics mains-power-supply perturbations of a self-commutated multilevel inverter

5 The invention relates to a method for reducing harmonics mains-power-supply perturbations of a self-commutated multilevel inverter which is clocked at the fundamental frequency and has capacitive storage devices.

10 The structure of a number of self-commutated multilevel inverters which are clocked at the fundamental frequency and have capacitive storage devices is explained in an earlier utility model application with the application number G 94 16 048.1; their method of operation is described in detail. A multilevel inverter
15 of this type is used, for example, in a power factor correction device, which is referred to as "Static Var Generator (SVG)" or as "Advanced Static Var Compensator (ASVC)" or as "Static Condenser (STATCON)".

20 The spectrum of the three-phase inverter output voltage can be varied by selection of the turn-on and turn-off instants of the individual voltage levels of this multilevel inverter. The more voltage levels this multilevel inverter has, the more harmonics in the three-phase inverter output voltage can be suppressed. Thus,
25 for example, the 11th, 13th, 23rd, 25th and 35th harmonic can be suppressed with eleven voltage levels of a twelve-pulse multilevel inverter. Consequently, the lowest harmonic which is then output into a three-phase mains power supply is the 37th harmonic. A multilevel inverter
30 of this type produces an inverter output voltage which has a specific fundamental content.

 The fundamental of the three-phase inverter output voltage defines the terminal voltage of the multilevel

inverter. In practice, this determines the turns ratio of the converter transformer.

Optimum system tuning with minimum harmonics mains-power-supply perturbation consequently exists for
5 an operating point of the multilevel inverter.

If the turn-on and turn-off instants of the individual voltage levels are now altered, then the terminal voltage of the multilevel inverter is also changed. Owing to this change, a mains current flows
10 whose amplitude has increased and whose time characteristic is distorted. Such a current can cause the multilevel inverter to turn off and can thus lead to an abrupt change in the reactive power in the three-phase mains power supply.

15 The object of the invention, then, is to specify a method and an apparatus for reducing harmonics mains-power-supply perturbations of a self-commutated multilevel inverter having capacitive storage devices whereby the problem evinced is solved.

20 This object is achieved according to the invention by means of the features of claim 1 (method) and of claim 4 (apparatus).

By virtue of the fact that, on the one hand, when a predetermined operating point is left, the angular
25 values for turn-on and turn-off instants of the individual voltage levels of the multilevel inverter are calculated for a new determined operating point in dependence on minimum harmonics mains-power-supply perturbations and, on the other hand, the terminal
30 voltage of this multilevel inverter is matched to the changed fundamental amplitude of the inverter output voltage, the amplitude of the mains current and the time characteristic thereof remain approximately unchanged. This eliminates turn-off of the multilevel inverter.

For each newly established operating point of a multilevel inverter, this method can be used to determine angular values for turn-on and turn-off instants of the individual voltage levels of the multilevel inverter for
5 minimum mains-power-supply perturbations and matching change values, with the result that the inverter can remain in operation with reduced harmonics mains-power-supply perturbations.

In an advantageous method, angular values and
10 matching change values are precalculated and stored for a plurality of operating points, with the result that only the new operating point must be determined as a function of measured values that are determined. Optimization with regard to a plurality of operating
15 points takes place off-line.

The apparatus for carrying out the method for reducing harmonics mains-power-supply perturbations of a self-commutated inverter having capacitive storage devices comprises a device for matching the terminal
20 voltage of this multilevel inverter to the altered inverter output voltage and a program for the existent control and regulating device of the inverter. This matching device is arranged between the three-phase outputs of the multilevel inverter and a three-phase
25 mains power supply, a control input and a signaling output of this device being connected to the control and regulating device.

In an advantageous apparatus, the matching device is a component part of an existent converter transformer.

30 In a further advantageous apparatus, the control and regulating device is provided with a respective memory for the angular values and for the matching change values. As

a result, the multilevel inverter can be programmed off-line in a customized manner by exchanging these memories.

Exemplary embodiments of the invention are diagrammatically illustrated in the drawings and are explained in more detail below.

- Figure 1 shows a basic block diagram of a first embodiment of the apparatus according to the invention for a multilevel inverter,
- 10 Figure 2 shows a single-phase equivalent circuit diagram of the block diagram according to Figure 1,
- Figure 3 shows an advantageous embodiment of the multilevel inverter,
- 15 Figure 4 illustrates a conductor neutral point voltage of the two multilevel inverters of the inverter installation according to Figure 3 against time in a diagram,
- Figure 5 illustrating the associated currents against time in a diagram,
- 20 Figure 6 shows, in a diagram, the inverter output voltages referring to the starpoint of the three-phase mains power supply, and
- 25 Figures 7 and 8 show the characteristics of the mains currents, in each case in a diagram.

In accordance with the basic block diagram of Figure 1, the multilevel inverter installation 2 comprises two multilevel inverters 4 and 6, which are linked to one another on the output side via a three-phase drainage coil circuit 8. The three-phase output of the three-phase drainage coil circuit 8 is linked to a three-phase mains power supply 12, to which a further load 14 is connected, via a device 10 for matching the terminal voltage $u'_{R,S,T}$ of the multilevel inverter installation 2 to its variable inverter output voltage $u_{SRR,S,T}$, which is composed of the output voltages

$u_{R01,S01,T01}$ and $u_{R02,S02,T02}$ of the multilevel invertors 4 and 6, respectively. The inverter installation 2 additionally includes a control and regulating device 16, which generates the control signals S_{1v} and S_{2v} for the two multilevel invertors 4 and 6. The structure and the method of operation of the multilevel inverter 4 or 6 having capacitive storage devices 18 and 20 which is used here are described in detail in an earlier utility model application having the application number G 94 16 048.1.

The matching device 10 comprises, for example, a transformer 22 and a tap switch 24 which is connected via a signal line to the control and regulating device 16. This control and regulating device 16 generates, as a function of the status signal S_{Mst} of the tap switch 24 and of measured current and voltage values $i_{R01,S01,T01}$, $i_{R02,S02,T02}$, $i_{R,S,T}$, $u_{R01,S01,T01}$, $u_{R02,S02,T02}$ and $u_{R,S,T}$ of the multilevel invertors 4 and 6 and of the three-phase mains power supply 12, the control signals S_{1v} and S_{2v} of the multilevel invertors 4 and 6, on the one hand, and, on the other hand, an actuating signal S_{St} for the tap switch 24 of the device 10. In order that the burden on the microprocessor of the control and regulating device 16 is reduced, this device 16 is provided with two memories 26 and 28, in which m respective angular values for turn-on and turn-off instants of the m voltage levels of the multilevel invertors 4, 6 and a plurality of respective matching change values are stored for a plurality of operating points of the multilevel invertors 4, 6. By using these memories 26 and 28, the angular values and the matching change values can be calculated and optimized off-line for different installations.

Figure 2 shows a single-phase equivalent circuit diagram of the three-phase apparatus according to Figure 1. The three-phase mains power supply 12 is illustrated by a voltage source 30 which impresses the mains voltage U_N . The multilevel invertors 4 and 6 are likewise illustrated by a voltage source 32, which impresses an inverter output voltage U_{SR} . The three-phase

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drainage coil circuit 8 is replaced by an impedance 34,
whereas the device 10 is illustrated by

a transformer 36 having an adjustable turns ratio $\dot{u}$. The voltage source 32 impresses a voltage U_{SR} for a predetermined operating point. The fundamental of this voltage U_{SR} defines the terminal voltage U'_N of the multilevel inverter installation 2, as a result of which the turns ratio of the transformer 36 is determined. The voltages U'_N and U_{SR} being impressed are coordinated with one another by the selection of the turns ratio. The three-phase terminal voltage U'_N of the inverter installation 2 differs from the inverter output voltage U_{SR} being impressed by the voltage drop ΔU across the impedance 34. If the angular values for turn-on and turn-off instants of the individual voltage levels of the multilevel inverters 4, 6 are then changed, then the inverter output voltage U_{SR} being impressed is also changed. The mains voltage U_N being impressed is constant, with the result that, if the terminal voltage U'_N of the multilevel inverter installation 2 is not matched to the changed inverter output voltage U_{SR} being impressed, the mains current I is changed in accordance with the changing voltage drop ΔU across the impedance 34, with the result that this change in the current I can lead to the turn-off of the multilevel inverters 4, 6.

With the method according to the invention and an apparatus for carrying out this method, it is possible, when changing a predetermined operating point of the inverter installation 2, on the one hand to alter the angular values for turn-on and turn-off instants of the individual voltage levels of the multilevel inverters 4, 6 in such a way that the inverter output voltage U_{SR} has an optimized harmonic spectrum, and, on the other hand, the terminal voltage U'_N of this inverter installation 2 is matched to the changed fundamental amplitude of the inverter output voltage U_{SR} , with the result that the mains current I is changed only insignificantly. That is to say that the harmonics mains-power-supply perturbations of a self-commutated inverter installation 2 can be kept at a minimum for any desired operating point.

Figure 3 shows an advantageous embodiment of the inverter installation 2. Each multilevel inverter 4 and 6 comprises a 6-pulse three-point inverter 38 and in each case two double cascades 40 per phase. The double cascades 40 are each provided with switching devices which are likewise of three-point design. The outputs of the multilevel inverters 4 and 6 are each linked via a power circuit-breaker 42 to a secondary winding 44 and 46, respectively, of a three-winding transformer 48 having the vector group Yyd. The primary winding 50 is connected to the three-phase mains power supply 12. The use of two double cascades 40 and a 6-pulse three-point inverter 38 yields an 11-level inverter 4 and 6. By means of the three-winding transformer 48 having the vector group specified, a 12-pulse 11-level inverter installation 2 is produced from two 6-pulse 11-level inverters 4 and 6. The characteristic harmonics of a 12-pulse inverter installation are the 11th, 13th, 23rd, 25th, 35th, 37th, 47th, 49th, ... harmonics. Each 11-level inverter 4 and 6 additionally enables the suppression of five harmonics. This can be exploited to suppress the 11th, 13th, 23rd, 25th and 35th harmonics. For this purpose, the angular values for turn-on and turn-off instants of the eleven voltage levels of the inverter 4 and 6 are determined in such a way that the 11th, 13th, 23rd, 25th and 35th harmonics of the two 6-pulse inverters 4 and 6 are suppressed. Consequently, the inverter output voltage $u_{R01, S01, T01}$ and $u_{R02, S02, T02}$ of the two 6-pulse inverters 4 and 6 in each case acquires the 5th, 7th, 17th, 19th, 29th, 31st, 37th, 41st, 43rd, ... harmonics. The 5th, 7th, 17th, 19th, 29th, 31st, 41st, 43rd, ... harmonics are eliminated by virtue of the selection of the three-winding transformer 48, with the result that the lowest harmonic which is then output into the mains power supply 12 is the 37th harmonic. The associated mains current $i_{R, S, T}$ is illustrated in a diagram in Figure 7. The conductor neutral point voltage u_{R01} and u_{R02} of the phase R of the 11-level inverters 4 and 6 is illustrated in a diagram in Figure 4. The associated phase currents i_{R01} and i_{R02}

are illustrated in the diagram in Figure 5. The three-phase inverter output voltages $u_{SRR,S,T}$, which are formed from the output voltages $u_{R01,S01,T01}$ and $u_{R02,S02,T02}$ of the multilevel inverters 4 and 6, respectively, and are referred to the starpoint of the three-phase mains power supply 12, are illustrated in the diagram in Figure 6.

As shown by the diagram in Figure 7, a mains current $i_{R,S,T}$ which has the 37th harmonic as the lowest harmonic is obtained with a 12-pulse 11-level inverter installation 2. If the outlay for the multilevel inverter installation 2 were restricted to a 7-level inverter, that is to say a double cascade 40 is dispensed with per phase of the multilevel inverters 4 and 6, then the mains current $i_{R,S,T}$ acquires the 25th harmonic as the lowest harmonic.

If, for example, one of the two 6-pulse 11-level inverters 4 and 6 is omitted, then the 5th, 7th, 17th, 19th, 29th, 31st, ... harmonics can no longer be eliminated with the aid of the three-winding transformer 48 having the vector group specified. That is to say that loss of a 6-pulse inverter element 4 or 6 results in the loss of the 12-pulse nature of the inverter installation 2. If the driving were then not altered, the lowest harmonic in the mains current $i_{R,S,T}$ would then be the 5th harmonic. Consequently, the harmonics mains-power-supply perturbation of the multilevel inverter installation 2 would change abruptly.

If the angular values for turn-on and turn-off instants of the eleven voltage levels of the multilevel inverter 4 or 6 are altered in such a way that the first five harmonics occurring of the 6-pulse 11-level inverter 4 or 6 are suppressed, then the lowest harmonic which is then output into the three-phase mains power supply 12 is the 19th harmonic (Figure 8). That is to say that by changing the angular values for turn-on and turn-off instants for the eleven voltage levels of the inverter element 4 or 6, the harmonics mains-power-supply perturbation

of the 11-level inverter 2 can be significantly reduced. However, this change in the drive level of the multilevel inverter 4 or 6 also effects a change in the fundamental amplitude of the inverter output voltage $u_{SRR,S,T}$. If the terminal voltage $u'_{R,S,T}$ of the inverter installation 2 is then not matched to the change in the inverter output voltage $u_{SRR,S,T}$ being impressed, then the inverter installation 2 turns off on account of an excessively high current I . Matching is carried out by the tap switch 24 of the device 10 or the tap switch 24 is a component part of the three-winding transformer 48. The corresponding actuating signal S_{st} is calculated by the control and regulating device 16 as a function of the actual values present or else is called up from a memory 28 containing precalculated values. The actual status of this tap switch 24 is signaled to the control and regulating device 16 by means of a status signal S_{Mst} . In an advantageous embodiment of the apparatus, the angular values are likewise read out from the memory 26. The actual values present serve to determine the new operating points of the inverter 2.

With the aid of the method according to the invention and the apparatus for carrying out this method, it is now possible to keep the harmonics mains-power-supply perturbations of a self-commutated multilevel inverter which is clocked at the fundamental frequency to a minimum at any time.



Patent claims

1. A method for reducing harmonics mains-power-supply perturbations of a self-commutated multilevel inverter (4, 6) which is clocked at the fundamental frequency and has capacitive storage devices (18, 20), wherein, when a predetermined operating point of this multilevel inverter (4, 6) is left, the angular values for turn-on and turn-off instants of the individual voltage levels of the multilevel inverter (4, 6) are calculated for a newly determined operating point, on the one hand, and, on the other hand, a terminal voltage ($u'_{R,S,T}$) of this multilevel inverter (4, 6) is matched to a change in the fundamental amplitude of the inverter output voltage ($u_{SRR,S,T}$).
2. The method as claimed in claim 1, wherein predetermined angular values for different operating points of the multilevel inverter (4, 6) are stored, are called up as a function of a new operating point and are fed as control signals (S_{1v}, S_{2v}) to the multilevel inverter (4, 6).
3. The method as claimed in claim 1, wherein predetermined matching change values for different operating points of the multilevel inverter (4, 6) are stored, are called up as a function of a new operating point and are fed as actuating signal (S_{St}) to a matching device (10).
4. Apparatus for carrying out the method as claimed in claim 1 for a self-commutated multilevel inverter (4, 6) which is clocked at the fundamental frequency and has capacitive storage devices (18, 20), having a control and regulating device (16), which generates the control signals (S_{1v}, S_{2v}) for the multilevel inverter (4, 6), wherein the multilevel inverter (4, 6) is linked to a three-phase mains power supply (12) by means of a device (10) for matching the terminal voltage ($u'_{R,S,T}$) of said inverter, wherein the control and regulating device (16) is linked



to this device (10) by means of a control line, and wherein the actual current and voltage values ($i_{R01,S01,T01}$, $i_{R02,S02,T02}$, $i_{R,S,T}$, $u_{R01,S01,T01}$, $u_{R02,S02,T02}$ and $u_{R,S,T}$) of the multilevel inverter (4, 6) and of the
5 three-phase mains power supply (12) and a status signal (S_{MSt}) of the matching device (10) are present at the actual value inputs of the control and regulating device (16).

5. The apparatus as claimed in claim 4, wherein the
10 control and regulating device (16) is provided with a memory (26) containing predetermined angular values for different operating points.

6. The apparatus as claimed in claim 4, wherein the
control and regulating device (16) is provided with a
15 memory (28) containing matching change values for different operating points.

7. The apparatus as claimed in claim 4, wherein the
matching device (10) is a component part of a converter
transformer (48) which is linked to the multilevel
20 inverter (4, 6) on the secondary side and to the three-phase mains power supply (12) on the primary side.



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