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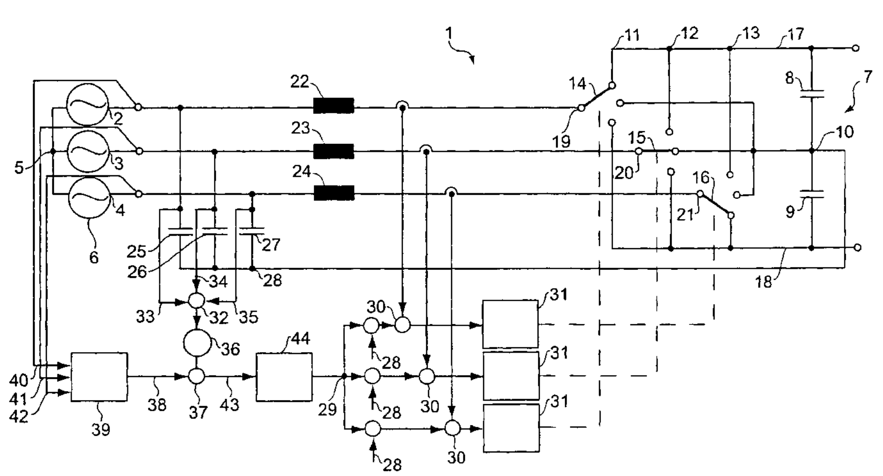
(54) Title: APPARATUS FOR INCREASING THE VOLTAGE UTILIZATION OF THREE-PHASE PWM RECTIFIER SYSTEMS WITH CONNECTION BETWEEN OUTPUT CENTER POINT AND ARTIFICIAL MAINS STAR POINT



(57) Abstract: The invention describes an apparatus for increasing the voltage utilization of a three-phase PWM rectifier system with a star connection of filter capacitors connected to the main phase terminals, where this star point is connected to the output voltage center point. The control of the input currents is done by a current controller in each phase that defines the gate signals for the bridge-leg change-over switches. The phase current reference value that is according to known technology formed by a supervising output voltage controller, is extended according to the invention by adding a phase current reference component that is equal for all three phases. To form this signal, the filter capacitor voltages measured positively against the output voltage center point are added and attenuated by a gain element by a factor of 3. A zero-voltage reference value function generator creates a third harmonic of the main voltages with defined amplitude and phase position according to the main voltages. The output signal of this function generator is compared to the output of the gain element by a subtracting element. The output of the subtracting element is dynamically weighted by a controller which results in the reference current zero-component. The potential of the positive output voltage bus, therefore, according to the time-behavior of the capacitor voltage zero-component reference value increases periodically in the vicinity of the positive maximum of the fundamentals of the rectifier input phase voltages referring to the main star points, while in the vicinity of the negative maximum the potential of the negative output voltage bus is decreased. This results in a virtually higher output voltage available for the formation of the rectifier input phase voltages. Therefore, the degree of modulation can be increased by a factor of 1.15 compared to a filter capacitor voltage-system without zero-component.

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APPARATUS FOR INCREASING THE VOLTAGE UTILIZATION OF THREE-PHASE PWM RECTIFIER SYSTEMS WITH CONNECTION BETWEEN OUTPUT CENTER POINT AND ARTIFICIAL MAINS STAR POINT

BACKGROUND OF THE INVENTION

Field of the Invention

The invention relates to an apparatus for increasing the voltage utilization of three-phase PWM rectifier systems with connection between capacitive output center point and artificial mains star point, that is formed by a star connection of filter capacitors that are connected to the rectifier input terminals.

Description of the Prior Art

According to the current state of technology, three-phase boost-type (characterized by input inductors at the AC-side, as described, for example, in DE 4219222 A1), pulse width modulated (PWM) rectifier systems employ filter capacitors connecting the mains input terminals to the capacitive output center point of the rectifier system in order to decouple the phase current controllers and to filter output voltage common-mode components with switching frequency. This means that the output center point is connected to an artificial mains star point that is formed as star connection of filter capacitors. As a disadvantage, the voltage of the filter capacitors is defined only by the mains phase voltage. Therefore, the output center point and the mains star point show approximately the same electrical potential, and employing the maximum degree of modulation of the rectifier system is only possible if the minimum output voltage is two times the mains phase voltage amplitude. In the case of free output center point (that means no connection to the artificial mains star point), the minimum output voltage for employing maximum modulation index is given by the mains line-to-line voltage amplitude. Employing filter capacitors reduces the voltage utilization of the output voltage of the rectifier system and increases the voltage blocking stress of the power semiconductors, which is especially disadvantageous for rectifier systems with high input voltage.

The present invention provides an apparatus that guarantees maximum utilization of the output voltage of the rectifier system (the maximum degree of modulation) when there is a connection of the output center point to an artificial mains star point that is formed by a star connection of the filter capacitors.

SUMMARY OF THE INVENTION

The present invention provides for the control of a defined potential difference in the form of a third harmonic of the mains phase voltages (a third harmonic of a symmetrical three-phase system shows no phase difference), between the output center point and the mains star point. As result, at every maximum of the fundamental harmonic (with amplitude and phase approximately identical to the according mains phase voltage in case of small inductance of the inductors connected in series on the AC side and/or high switching frequency) of the pulse width modulated rectifier input phase voltages, there is an increase of the electrical potential of the positive output voltage terminal compared to the mains star point and/or a decrease of the electrical potential of the negative output voltage terminal compared to the mains star point. This results in an increase of the degree of modulation by a factor of 1.15. This is equal to the value that can be reached in case of a free output center point (for the same output voltage). The voltage between the filter capacitors and the output center point is measured, and by addition and division by three, the zero-component of this voltage system is found.

A function generator that is synchronized to the mains voltage creates a zero-component voltage reference value, shaped as a third harmonic of the mains phase voltages, with an amplitude of 1/6 of the mains phase amplitude. The zero-component voltage reference value is compared to the measured zero-component of the voltage-system, as described above. The resulting control difference is the input of a zero-voltage controller, the output of this controller is added to the reference phase current values that define the power flow through the rectifier system. The reference phase current values are defined by an accordingly supervising output voltage controller using technology that is standard in the art. The input current control of the rectifier system defines, therefore, the needed load current for the DC output side taken from the AC input side. It also defines a current component flowing through the filter capacitors, that causes the necessary increase and decrease of the electrical potential of the output center point compared to the mains star point. According to standard technology, a control of the symmetry of the partial output voltages can be performed by measuring the asymmetry of the partial output voltages, dynamic weighting of this measured value by a controller, and adding it to the reference value of the zero-component of the filter capacitor voltages.

Because the voltage of the input inductor has no DC component, a positive offset of the filter capacitor reference voltage values (defined positive against the output center point) results in an increase of the average relative time duration, when the bridge-leg change-over switch is switching to the positive output voltage terminal (bus bar) of the rectifier. It also results in a decrease of the average relative time duration, when the bridge-leg change-over switch is switching to the negative output voltage terminal (bus bar) of the rectifier. This results in an increase of the electrical charge of the positive output capacitor and a decrease of the electrical charge of the negative output capacitor. Hence the control of a symmetry of the partial output voltages is now possible.

The application of the invented apparatus is not restricted, however, to a three-phase three-level converter. Accordingly, the apparatus can be employed with two-level converters in similar form, where the artificial star point of the filter capacitors is connected to the positive or negative output voltage terminal. Here, half of the value of the output voltage has to be added to the reference value of the filter capacitor voltages for three-level converters (in case of connection of the artificial capacitor mains star point to the negative output voltage terminal), or half of the value of the output voltage has to be subtracted from the reference value of the filter capacitor voltages (in case of connection of the artificial capacitor mains star point to the positive output voltage terminal). The basic function of the apparatus is not influenced by the change of the reference value.

BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings, which are incorporated in and constitute a part of this specification, illustrate embodiments of the invention and together with the description, serve to explain the principles of the invention.

Fig. 1 shows the basic structure of the power circuit of a three-phase PWM rectifier system with capacitors arranged between the mains input terminals and the output center point, and the extension of the current control of the system according to the invention to increase the degree of modulation, where the part of the phase current controller that is known according to the current known technology is shown in the form of block functions.

Fig. 2 shows the time-behavior (resulting from the invented control of the potential of the output voltage center point) of the potential difference between positive and negative output voltage terminals and the mains star point within one mains period. Also depicted is the fundamental of one rectifier input phase voltage in case of maximum degree of modulation, and the maximum possible fundamental in case of controlling the rectifier system according to current technology.

DETAILED DESCRIPTION OF THE EMBODIMENTS

In the following, the invention is explained with examples and simulation results. These examples are illustrative only, and not limiting of the remainder of the disclosure in any way whatsoever.

Fig. 1 exemplifies one embodiment of the present invention. Specifically, Fig. 1 shows a schematic of a three-phase three-level PWM rectifier system (1). The basic function of the rectifier system is to change a three-phase voltage-system (6), that is symbolized by phase-AC voltage sources (2), (3), (4) with grounded star point (5), into a DC voltage lying across the series connection (7) of two output capacitors (8) and (9) with a center point (10).

According to the state of the art, the rectifier system (1) is formed by three bridge-legs (11), (12), (13) that function with change-over switches (14), (15), (16) between positive output voltage bus (17), output voltage center point (10), and negative output voltage bus (18). The terminals (19), (20), (21) of the switches (14), (15), (16), are connected via the input inductors (22), (23), (24) to the according mains phase terminals (2), (3), (4). Connected to the mains phase terminals (2), (3), (4) there is an arrangement of filter capacitors (25), (26), (27) in star connection, with the artificial star point connected to the output voltage center point (10). For control of the input phase currents of the rectifier system (1), current sensors are connected in series to the input inductors (22), (23), (24). The control difference signals are given by subtraction (30) of the reference phase current components (28) (according to the supervising output voltage controller standard in the art) and a reference value (29) equal to all phases that is defined according to the invention. The control difference signals are the input for the phase current controllers (31), where their output signals control the according bridge-leg change-over switches (14), (15), (16) of the rectifier system. For the formation of the reference value (29) (equal for all three phases) the sum (32) of all the measured (against the output voltage center point (10)) filter capacitor voltages (33), (34), (35) is formed, and attenuated with a factor of three by a gain element (36). Therefore, the output of the gain element (36) represents the actual value of the zero-sequence system of the filter capacitor voltages, and is compared via subtracting element (37) to the output of a function generator (39). The function generator (39) gets the mains phase voltages (2), (3), (4) as input values (40), (41), (42), and creates a third harmonic of the mains voltage with an amplitude of 1/6 (this optimized value is found via calculation) of the amplitude of the mains phase voltage that is in phase with the mains voltages (2), (3), (4). The output (43) of the subtracting element (37) is dynamic weighted by a controller (44) and turned into the invented reference current zero-component (29).

Fig. 2 shows the time-behavior (resulting from the invented control of the potential of the output voltage center point) of the potential difference between positive and negative output voltage terminals and the mains star point within one mains period. Also depicted is the fundamental of one rectifier input phase voltage in case of maximum degree of modulation, and the maximum possible fundamental in case of controlling the rectifier system according to current technology.

To demonstrate the function of the apparatus, the time-behavior (45) of the potential of the positive output voltage bus (17), and the potential (46) of the negative output voltage bus (18) against the mains star point (5) is shown in Fig. 2. Furthermore, the time-behavior (47) of the zero-component of the filter capacitor voltages (33), (34), (35) defined by the invented control is shown for one mains period. The representation of the voltage values is normalized to the half of the value of the output voltage of the rectifier system. Furthermore, shown are the fundamental (48) of a pulse width modulated rectifier input phase voltage (19) (referring to the mains star point (5)) for using the maximum degree of modulation performed according to the state of technology (this means, no zero-components of the filter capacitor voltages), and the maximum possible voltage fundamental (49). For this case also the shown voltages (50) and (51) of the positive and negative output voltage bus referring to the mains star point are valid.

Compared to a zero-component that is defined directly by the duty-cycle, in case of employing the invented control of the zero-component of the filter capacitor voltages, the occurrence of resonance effects between rectifier input inductors and filter capacitors is prevented, and a small control difference between the actual zero-component (the output of the gain element (36)) and the reference value (38) is guaranteed. The reference value and the actual value are assumed to be equal, therefore. Formation of a positive zero-component means (under the assumption of constant output voltage and symmetry of the partial output voltages, which is given in good approximation in practical operation) a decrease of the potential of the output voltage center point (10) referring to the mains star point (5). Accordingly, if a third harmonic of the mains voltage in phase with the mains phase voltages is given, the potential (45) of the positive output voltage bus increases referring to the mains star point in the areas (52), (53), (54) of the positive amplitudes of the fundamentals of the rectifier input phase voltages according to the time-behavior of the zero-voltage reference value. In the areas (55), (56), (57) of the negative maximum of the fundamentals of the rectifier phase input voltages the potential (45) is decreased. Therefore, a virtually higher output voltage for formation of the rectifier input phase voltages is available. The degree of modulation increases by a factor of 1.15 compared to filter capacitor voltage-systems without zero-components (and/or time-independent constant potential (50), (51) of the positive and negative output voltage bus referring to the mains star point (5)) and/or the value of the output voltage of the rectifier can be reduced for given mains voltage.

We claim:

1. An apparatus as shown in Fig. 1 for increasing the voltage utilization of a three-phase PWM rectifier system (1) for changing the three-phase voltage-system (6) with star point (5) into a DC voltage across a series connection (7) of two output capacitors (8) and (9) with capacitive center point (10) that is connected to the star point of a star connection of input filter capacitors (25), (26), (27) connected to the mains terminals (2), (3), (4) that are connected via the rectifier input inductors (22), (23), (24) to the rectifier input side, where the control of the input currents of the rectifier system (1) defines the control difference between the reference phase current (28) (given by a supervising output voltage controller) and the input current of each phase, and this control difference is fed into a current controller (31), where the output signal of the current controller (31) defines the gate signals of the bridge-leg change-over switches (14), (15), (16) of the rectifier system that is characterized by the formation of second phase current reference value (29) equal to all three phases. The filter capacitor voltages (33), (34), (35) are measured positively referring to the output voltage center point (10). The sum (32) of these three voltages is attenuated by a gain element (36) by a factor of 3. The subtracting element (37) forms the difference between the output of the gain element (36) and the output (38) of a zero-voltage reference value function generator (39) in form of a control difference signal (43) of the zero-voltage component of the filter capacitor voltages. The inputs (40), (41), (42) of the zero-voltage reference value function generator (39) are the mains phase voltages (2), (3), (4), and a third harmonic of the mains voltage with an amplitude of 1/6 of the amplitude of the mains phase voltage in phase with the mains phase voltages (2), (3), (4) is created. The output (43) of the subtracting element (37) is dynamically weighted by a controller (44) resulting in the reference current zero-component (29). Therefore, the potential (45) of the positive output voltage bus increases periodically referring to the mains star point (5) in the areas (52), (53), (54) of the positive maximum of the fundamentals of the rectifier input phase voltages (19), (20), (21) according to the time-behavior of the capacitor voltage zero-component reference value (38), and decreases periodically referring to the mains star point (5) in the areas (55), (56), (57) of the negative maximum of the fundamentals of

the rectifier input phase voltages (19), (20), (21). In the vicinity of the maximum of the fundamentals a virtually higher output voltage is available for formation of the rectifier input phase voltages (19), (20), (21). The degree of modulation (that means, the amplitude of the fundamentals of the rectifier input phase voltages (19), (20), (21)) can be increased by a factor of 1.15 compared to a filter capacitor voltage-system without zero-components (and/or time-independent constant potential (50), (51) of the positive and negative output voltage bus referring to the mains star point (5)).

2. Apparatus according to claim 1 for application with three-phase two-level converter systems with a connection between the star point (28) of the filter capacitors (25), (26), (27) and the positive (17) or negative (18) output voltage bus that is characterized by (in case of connection of the star point (28) to the negative output voltage bus (18)) an addition of a voltage value of half the value of the output voltage (the voltage measured between positive (17) and negative (18) output voltage bus bar) to the output (38) of a zero-voltage reference value function generator (39). In case of connection of the star point (28) to the positive output voltage bus (17) a voltage value of half the value of the output voltage (the voltage measured between positive (17) and negative (18) output voltage bus bar) is subtracted from the output (38) of a zero-voltage reference value function generator (39).

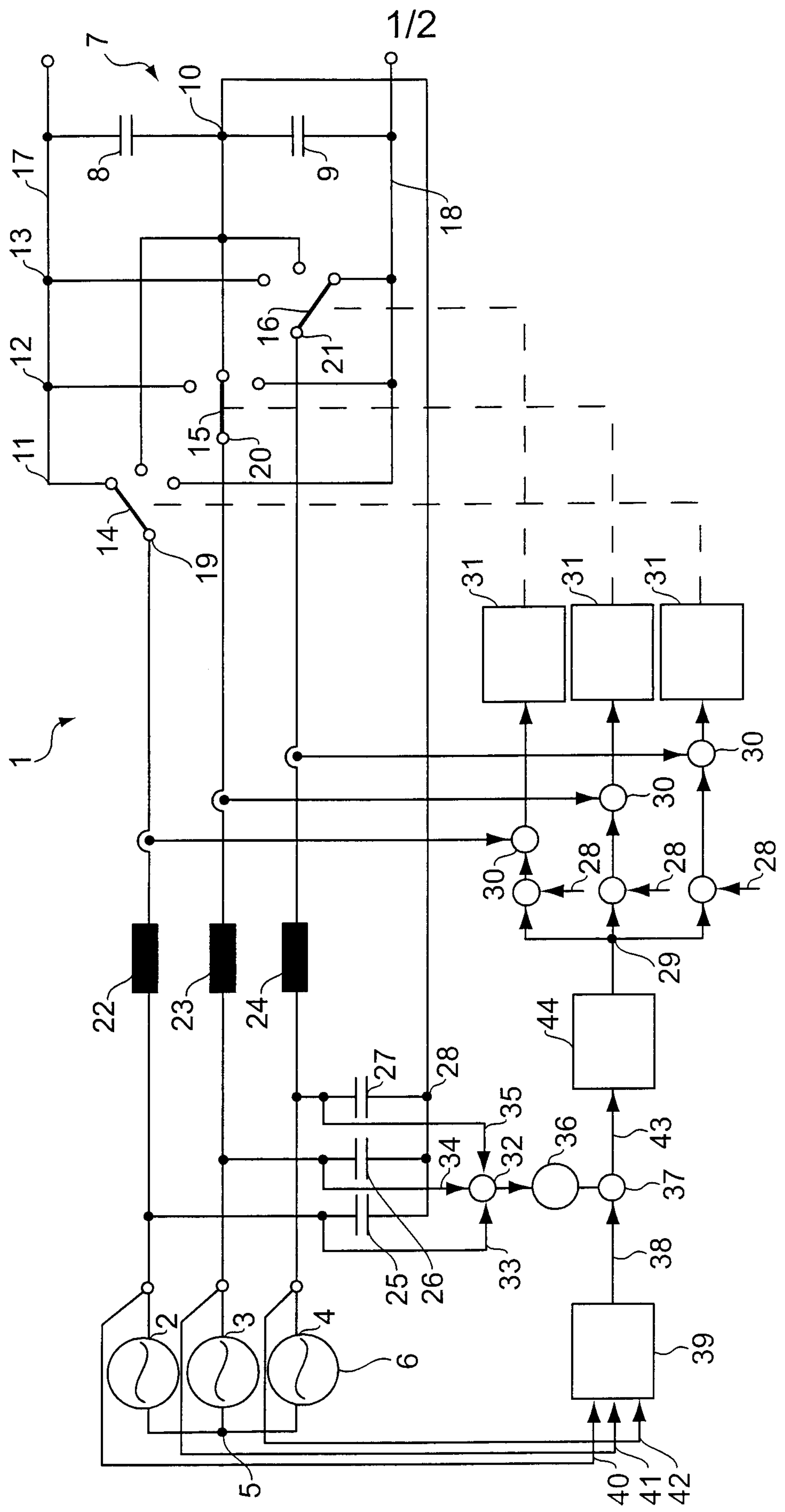
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FIG. 1

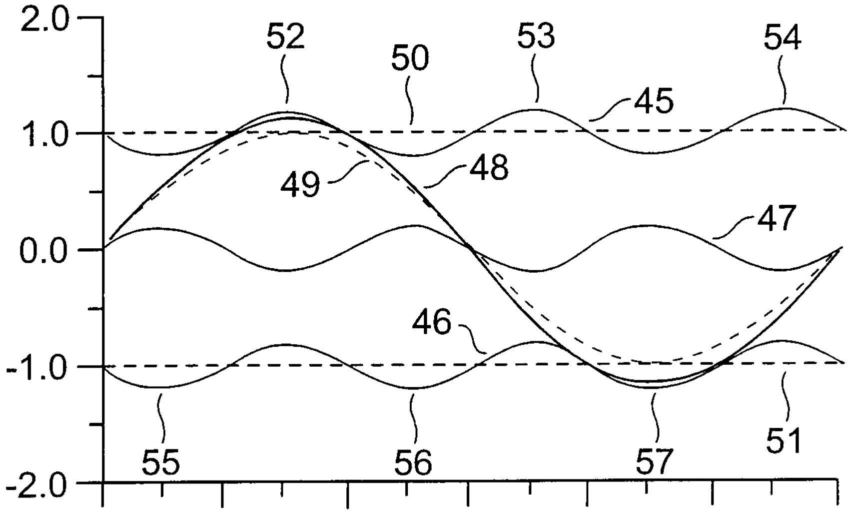

FIG. 2