



RESEARCH ARTICLE

VIENNA RECTIFIER LINE HARMONICS REDUCTION USING DC MOTOR APPLICATION.

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Manuscript Info

Manuscript History

Received: 28 May 2017

Final Accepted: 30 June 2017

Published: July 2017

Abstract

A VIENNA rectifier is a synchronous logic control base three-phase boost unity power factor rectifier that works as an interface to ensure high energy dc-bus voltage. The hybrid control method presents a solution to the control of third harmonic of the neutral-point in a VIENNA rectifier and has been described with a mathematical model. The proposed control method also provides immunity to the influence of changes in the capacitor voltage, voltage stress across the bidirectional switches and reduces switching losses. The feasibility and effectiveness of the proposed strategy has been verified using simulation and experimental results.

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Introduction:-

The term harmonic in its strictest sense describes any member of the harmonic series. The term is employed in various disciplines, including music and acoustics, electric power transmission, radio technology, etc. It is typically applied to repeating signals, such as sinusoidal waves. A harmonic of such a wave is a wave with a frequency that is positive integer multiple of the frequency of the original wave known as fundamental frequency. The original wave is also called as first harmonic, the following harmonics are known as higher harmonics.

Harmonic distortion is described as the interference in an AC power signal created by frequency multiples of the sine wave. Total Harmonic Distortion (THD) is used as a measure of the amount of harmonic distortion in the system.

$$THD = \frac{\sqrt{V_2^2 + V_3^2 + V_4^2 + \dots}}{V_1} \quad (1)$$

Harmonics are caused by non-linear loads, which are loads that draw a non-sinusoidal current from a sinusoidal voltage source. Some examples of harmonic producing loads are electric arc furnaces, static VAR compensators, inverters, DC converters, switch-mode power supplies, and DC and AC motor drives. In the case of a motor drive, the AC current at the input to the rectifier looks more like a square wave than a sine wave. The rectifier can be thought of as a harmonic current over a wide range of power system impedances. The characteristic current harmonics are produced by a rectifier are determined by the pulse number. The following equation allows determination of the characteristic harmonics for a given pulse number:

$$h = kq \pm 1 \quad (2)$$

Where,

h - is the harmonic number (integer multiple of the fundamental)

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k - is any positive integer
q - is the pulse number of the converter

Variable frequency drives also produce harmonic currents at the output of the inverter which are seen by the motor. Most of these harmonics are integer multiples of the inverter operating frequency and not the power supply frequency. Harmonic currents cause problems both on the supply system and within the installation. The problems caused by harmonic currents are overloading of neutrals, overheating of transformers, nuisance tripping of circuit breakers, over-stressing of power factor correction capacitors and skin effect. The problems caused by harmonic voltages are voltage distortion, abnormal operation of induction motors and zero-crossing noise. Hence the mitigation of harmonics should be carried out.

A hybrid control method is a method which combines a dynamic adjustment factor with a voltage deviation control of the split DC link. It is used to suppress the third harmonic fundamental frequency component in the input current and reduce THD. The neutral point current fundamental frequency components are always constants and zero. The neutral-point offset could be eliminated and its fluctuation would be removed by dynamic adjustment factor. The conventional fixed adjustment factor has some difficulty in reducing the low-frequency, neutral-point voltage fluctuations. The hybrid neutral-point control method consists of two parts:

- 1) the actual neutral-point deviation and
- 2) the dynamic adjustment expression.

The hybrid neutral-point compensation components are added to the modulation reference signal to make the neutral-point current work with a zero value, and thus, the neutral-point fluctuation of VIENNA rectifier would be effectively eliminated. Neutral-point fluctuation would become more significant under the abnormal conditions, such as asymmetric capacitor parameters or unbalanced DC-side load, so the additional adjustment coefficient is needed to be introduced in order to restrain the significant influence caused by the abnormal condition.

A grid-connected voltage source Pulse Width Modulated (PWM) rectifier has advantages over a diode bridge rectifier in terms of having a low current THD as well as offering controllable supply-side Power Factor (PF). In comparison with the traditional two- and three-level unidirectional PWM rectifiers, the VIENNA rectifier is reported to have many advantages, including a simple power stage structure and control, low input current harmonics, and low semiconductor device voltage stress. The VIENNA rectifier belongs to the three-level voltage source converter family. The three-level structure results in a low blocking voltage stress on the power semiconductor devices and a small input inductor volume. However, the topology can also cause a significant problem related to the fluctuation of the neutral-point voltage, which can cause unbalanced capacitor voltages, leading to increased stress on semiconductor devices and the generation of low order harmonics in the input voltages and currents.

Johann W. Kolar (1999) [8] based on a comprehensive study of the literature concepts of three-phase rectifier systems with low effects on the mains are classified. Such systems are unidirectional and bidirectional self-commutated converters with impressed output voltage or output current with passive and active filtering. Selected circuit concepts are analyzed concerning the operational behavior and the obtainable quality of the mains current. Furthermore, an evaluation of the rectifier concepts concerning utilization of the power semiconductors, rated power of the inductive and capacitive components and of the realization effort in general is given. Finally, problems of a practical application of high switching frequency PWM rectifier systems and topics of further research are discussed.

Roland Greul (2006) [12] discussed about the three-phase delta-rectifier is formed by a delta-connection of single-phase PWM rectifier modules and has the advantage that it can provide full rated output power in the case of a mains phase loss. In this paper the delta-rectifier, implemented with a standard (two-level and/or three-level) boost converter, is analyzed based on an equivalent star connection. Analysis of the delta-rectifier shows a redundancy in the switching states concerning the input voltage formation. Furthermore, the delta-rectifier has reduced current ripple in the mains phase currents if the modulation is implemented with synchronized PWM. Disadvantage of two-level delta rectifier is the higher voltage stress on the switching devices.

Ali M. Eltamaly (2008) [1] proposed a special issue on three-phase controlled converters have many applications especially in adjustable speed drivers and renewable energy. A three-phase controlled converter is a good option in these applications due to its low cost, simplicity and maintainability with respect to other solutions like a full-bridge insulated gate bipolar transistor converter or a VIENNA rectifier. Line current harmonics in this converter is very

high. Therefore, a harmonic reductions technique is needed to remedy the problem. In this paper, an improved injection current technique is introduced to reduce line current harmonics. The optimal amplitude and phase angle of the injection current for different loads and firing angles have been mathematically determined. Simulation for this technique has been performed by using PSIM simulation program. An experimental prototype has been built to verify the mathematical and simulation results. The simulation and experimental results prove the superiority of this technique in mitigating the requirements for harmonics standards.

G. Tulasi Ram Das (2009) proposed a synchronous logic control based three-phase constant DC-bus voltage. This paper discusses the determination of performance characteristics of VIENNA rectifier topology with the synchronous logic based control. Furthermore this enabled the design and development of a three-phase active converter system that was built and tested with the inputs and output.

Mopari (2010) proposed that this paper presents a closed loop control strategy to eliminate harmonics present at input and output side of rectifier when rectifier operate under unbalance input impedance condition. The unbalance present at input side of rectifier cause even harmonic at DC output side and odd harmonic in the input current as well as it affect the cost of DC side capacitor and AC side filter. To improve the performance of PWM rectifier, variable hysteresis current control technique has been implemented. Hysteresis current controller of variable bandwidth is used to track line current of all the three phases independently.

Existing system of hybrid control method in VIENNA rectifier:-

A grid connected voltage source PWM rectifier has advantages over a diode bridge rectifier in terms of having a low current THD as well as offering controllable supply-side PF. In comparison with the traditional two- and three-level unidirectional PWM rectifiers, the VIENNA rectifier is reported to have many advantages, including a simple power stage structure and control, low input current harmonics, and low semiconductor device voltage stress.

Therefore, the circuit is widely used in telecommunications power systems as well as aircraft and medium-voltage drive systems, where high-power density and low device voltage stresses are required. The VIENNA rectifier belongs to the three-level voltage source converter family. The three-level structure results in a low blocking voltage stress on the power semiconductor devices and a small input inductor volume. However, the topology can also cause a significant problem related to the fluctuation of the neutral-point voltage, which can cause unbalanced capacitor voltages, leading to increased stress on semiconductor devices and the generation of low order harmonics in the input voltages and currents.

A series of suppression methods for neutral-point fluctuation in the VIENNA rectifier has been proposed, and these methods can be classified into the following categories: solutions based on the use of P and N short vectors or redundant switching states, solutions based on the injection of zero sequence or ripple components, solutions with neutral-point voltage error feed forward, where any deviation of the voltage across the two DC-link capacitors is added to the modulation signals to suppress the neutral-point offset. A hysteresis-band-based method was proposed to eliminate the potential effects on the neutral point according to the principle that the P and N short vectors have the opposite effect on neutral-point voltage. However, this method relies on a complicated three-level algorithm.

The neutral-point voltage was balanced by using a proper time weight or distribution of the redundant switching states. The input current would include more harmonics because of the change in the time weight or distribution of the switching states, especially in the operating condition of an asymmetric output load. The zero-sequence components are injected to suppress the neutral-point fluctuation. But the calculation of the zero-sequence components is very complex and difficult to be realized in practice. Constant power control by injecting power ripple was employed to eliminate the twice-fundamental frequency ripple in the DC-link voltage. However, this method does not consider the third-harmonic fluctuation.

A method of zero-sequence component injected carrier based Sinusoidal Pulse Width Modulation (SPWM) is described and this method avoids using the complex three-level Space Vector Pulse Width Modulation (SVPWM) strategy, but a large calculation effort is required for the zero-sequence components. A feed forward control method using neutral-point voltage error with a fixed regulating factor was used to improve the neutral-point performance. However, the selection of adjusting factors lacks theoretical basis and relies on engineering experience. Furthermore, this scheme has some difficulty in reducing the third harmonic fluctuation. Two methods named active and passive voltage-balancing technologies to balance the DC-link capacitor voltages for a multi-pulse rectifier were proposed.

This paper presents a hybrid method combining a dynamic adjustment factor with a capacitance voltage deviation expression to suppress the third-harmonic neutral-point voltage fluctuations in a VIENNA rectifier.

A hybrid method combining a dynamic adjustment factor with a capacitance voltage deviation expression to suppress the third-harmonic neutral-point voltage fluctuations in a VIENNA rectifier is proposed. The circuit comprises a main diode bridge and three bidirectional switches connecting the input phases to the DC-link neutral point. The three active switching units are controlled to ensure sinusoidal input current and a steady DC-link voltage.

The three-phase VIENNA rectifier comprises three single-phase VIENNA rectifiers in a parallel output hence, the equivalent circuit of three-phase VIENNA rectifier also consists of the equivalent model of three single-phase VIENNA rectifiers in a parallel output. The current source is controlled by using a switch, while the capacitor voltage is decided by the equivalent voltage source, including the inductor voltage. However, the inductor voltage is partly decided by the current of current source, so the capacitor voltage is indirectly controlled by the switch, and thus, the neutral-point voltage fluctuation of the DC-link two capacitors is decided by the neutral-point current controlled by the switch. Figure 1 shows the various blocks of the existing VIENNA rectifier and its connections.

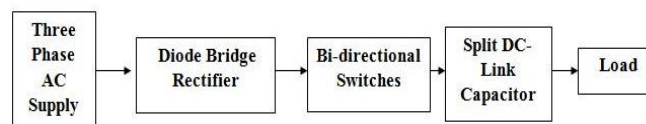


Figure 1:- Block diagram of VIENNA rectifier.

Modified system:-

Figure 2 shows the circuit topology of the non-regenerative three-level VIENNA rectifier. The circuit comprises a main diode bridge and three bidirectional switches connecting the input phases to the DC-link neutral point. The three active switching units are controlled to ensure sinusoidal input current and a steady DC-link voltage. It comprises of a MOSFET in each phase leg of a 1-phase diode bridge. By adjusting the width of the pulse that turns on the MOSFET, corresponding line current is forced to be sinusoidal and in phase with the voltage. When the MOSFET is turned on the corresponding phase is connected, via the line inductor, to the center point between the output capacitors. The phase current rises through the MOSFET during that pulse period charging the capacitor. When the MOSFET is turned off, current tapers through the diode half bridge (upper or lower depending on direction of the current flow).

The system advantages are even in presence of unbalanced mains or only two phases. Total switching losses are reduced by a factor of six, assuming switching frequency.

Simulation:-

The simulation circuit diagram has modified VIENNA rectifier and motor load. The modified VIENNA rectifier has three bidirectional switches and protection for switches using diodes. The motor load used is DC shunt motor and it is a constant speed motor. The speed-torque characteristic of the DC shunt motor is linear in nature.

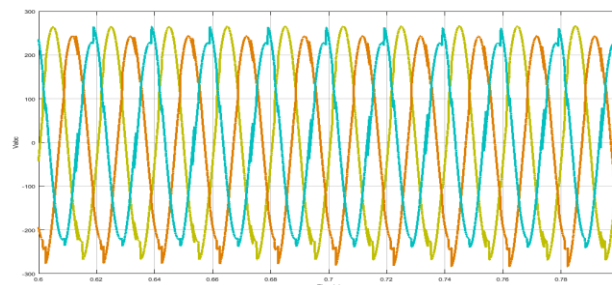


Figure 3:- Input voltage waveform

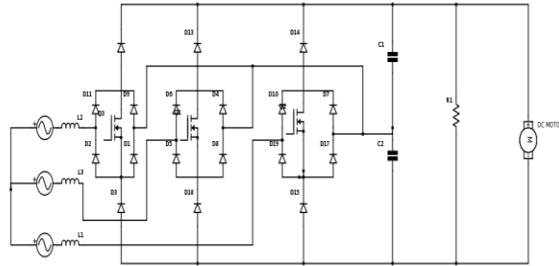


Figure 2:- Circuit diagram of modified VIENNA rectifier

Some of its applications are - a number of industrial, telecom and computing equipments are used such as AC and DC drives, telecommunication power supplies, uninterruptible power supplies, air conditioning units, computer installations, power supplies for all industrial uses such as welding, surface treating, motion control, large appliances and process control, RF transmitters, radar transmitters and repeater stations below 50 KHz. Any malfunction in control circuit does not manifest itself in short circuit of output or PFC front end.

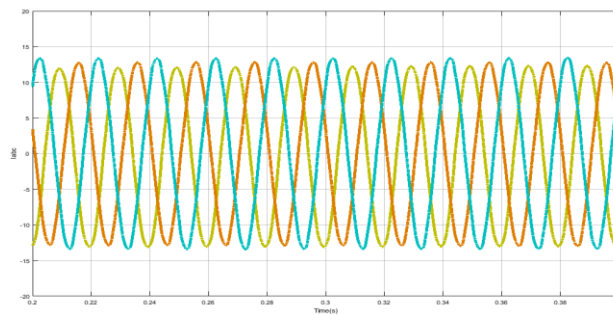


Figure 4:- Input current waveforms

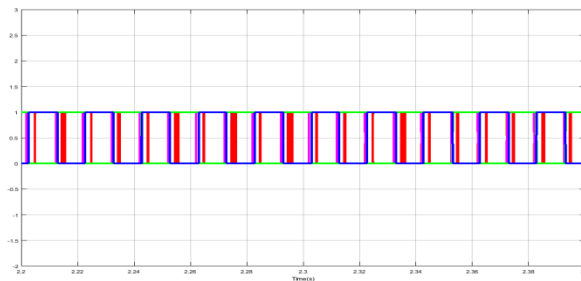


Figure 5:- Gate pulse waveform

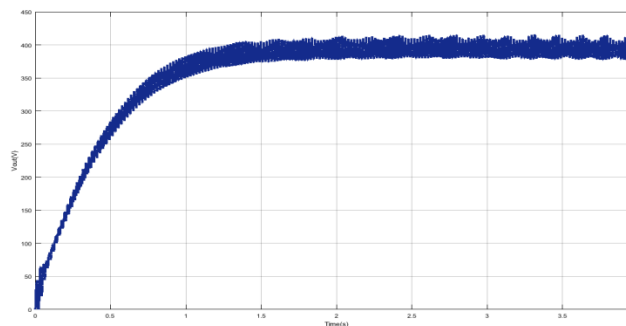


Figure 6:- Output voltage waveform

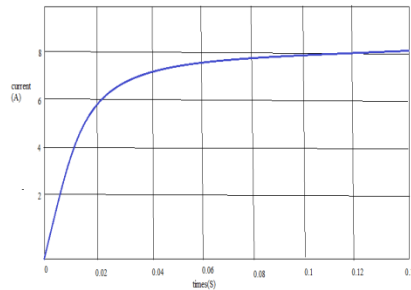


Figure 7:- Output current waveform

Results and discussion:-

The figure 3 illustrates the input voltage waveform. The magnitude of input voltage is 230V. It has three phases a, b, c and phase difference of 120 degree between the two phases. The figure 4 illustrates the input current waveform. In this waveform, the current ranges from 13A to 14A. The figure 5 shows the gate pulse. The gate pulse is generated by PIC microcontroller and pulse generator. The pulses are used to turn on or turn off processes in order to obtain the balanced output voltage across split DC link capacitors. The figure 6 shows the output voltage. The output voltage is summation of capacitor voltage. For the input of 275V, the output voltage obtained is 400V. The figure 7 represents the output current waveform, ranging till 8A.

The hybrid neutral point balancing control method combining a dynamic adjustment factor with a capacitor voltage deviation to solve the problem of neutral-point fluctuation in a vienna-type three-level rectifier. Using a look up table for a capacitor voltage deviation and a dynamic adjustment factor expression in the six input sector, the neutral-point fluctuation can be effectively suppressed, so the influence of DC deviation in the DC-link capacitor voltage can be eliminated. Furthermore, a significant fluctuation of neutral-point voltage caused by abnormal conditions, such as asymmetric capacitors parameters or unbalanced load can be reduced by using the improved hybrid method combining an additional adjustment coefficient. Moreover, the system after being introduced the proposed method still exhibits a low input current THD as well as a high displacement factor and a fast response to load disturbance in addition the algorithm only needs a look up table, effectively removing the need for complex calculations, which makes this method very suitable for practical implementation. It produces ripple voltage when the rectifier is connected with the motor load system.

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