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An improved power quality using multi-pulse AC-DC converters in vector controlled induction motor drives

M.Karthika and K.P.Swaroop

Department of Electrical and Electronics, Shri Vishnu Engineering College for Women, Bhimavaram, A.P.

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ABSTRACT

Power electronic devices are non-linear loads that create harmonic distortion and can be susceptible to voltage dips if not adequately protected. The non linear nature of these switching devices causes harmonic current injection into the ac mains; there by polluting the power quality (PQ) at the point of common coupling (PCC).This power quality (PQ) improvement is achieved by using multi-pulse converters in THREE-PHASE ac-dc converters (ADCs).The proposed multi-pulse ac-dc converter is based on autotransformer configurations and passive tuned filters. The proposed ac–dc converter is able to eliminate lower order harmonics in the ac supply current. The resulting supply current is near sinusoidal in shape with low total harmonic distortion and a nearly unity power factor. The proposed multi-pulse ac-dc converter is designed and the simulation model is developed in MATLAB. It improves the power quality at the ac mains and meets IEEE-519 standard requirements at varying loads.

Introduction

The use of induction motors has increased in industrial applications due to their advantages such as improved efficiency, ruggedness, reliability, and low cost. For variable speed drives, dc motors have been used because of their flexi-ble characteristics. To incorporate the flexible characteristics of a dc motor into an induction motor, vector control technique has been used in many industries.

Various methods based on the principle of increasing the number of pulses in ac–dc converters to mitigate current har-monics. These methods use two or more converters, where the harmonics generated by one converter are cancelled by another converter, by proper phase shift.

These autotransformer based schemes considerably reduce the size and weight of the transformer. Autotransformer-based multi-pulse ac–dc converters have been introduced for reduc-ing the total harmonic distortion (THD) of the ac mains cur-rent. To provide equal power sharing between the diode bridges and to achieve good harmonic cancellation, interphase transformers are needed.

In this paper, the proposed multi-pulse ac-dc converters that are suitable for retrofit applications (where presently 6-pulse converter is being used, as shown inFig.1) are to feed vector controlled induction motor drive (VCIMD).

This proposed multi-pulse ac-dc converter results in the elimi-nation of 5th, 7th, 11th, 13th, and 17th harmonics. It results in near unity power factor operation in the wide operating range of the drive with the THD of ac mains current always less than 5%.

Design of Proposed 12-Pulse and 18-Pulse AC–DC Converters

The design of the suitable autotransformer for these pro-posed multi-pulse ac-dc converters along with the design of a reduced rating passive tuned filter for effective harmonic filter-ing.

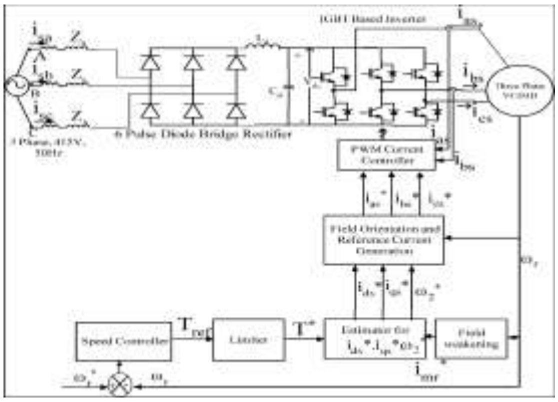

Fig. 1 Six-pulse diode rectifier fed VCIMD

Design of the Proposed 12-Pulse AC–DC Converter:

To design the 12-pulse ac-dc converter, we have to satisfy the mainly two conditions. First, Two sets of balanced three-phase line voltages are to be produced, which are either $\pm 15^\circ$ or $\pm 30^\circ$ out of phase with respect to each other. Second The magnitude of these line voltages should be equal to each other to result in reduced ripple in output dc voltage.

Fig. 3 shows the winding connection diagram of the proposed autotransformer for achieving the 12-pulse rectification.

The number of turns required for and phase shift are calculated as follows. Consider phase "a" voltages as

$$V_a' = V_a + K_1 * V_{ca} - K_2 * V_{bc} \quad (1)$$

$$V_a'' = V_a - K_1 * V_{ab} + K_2 * V_{bc} \quad (2)$$

Assume the following set of voltages:

$$V_a = \angle 0^\circ, V_b = \angle -120^\circ, V_c = \angle 120^\circ \quad (3)$$

Similarly

Tele:
E-mail addresses: karthika.mangamuri@gmail.com

$$V_a' = V\angle +15^\circ, V_b' = V\angle -105^\circ, V_c' = V\angle 135^\circ \quad (4)$$
$$V_a'' = V\angle -15^\circ, V_b'' = V\angle -135^\circ, V_c'' = V\angle 105^\circ \quad (5)$$

Using above equations, K_1 and K_2 can be calculated. These equations result in $K_1 = 0.0227$ and $K_2 = 0.138$ for the desired phase shift in an autotransformer. The phase-shifted voltages for phase "a" are

$$V_a' = V_a + 0.0227V_{ca} - 0.138V_{bc} \quad (6)$$
$$V_a'' = V_a - 0.0227V_{ab} + 0.138V_{bc} \quad (7)$$

Thus, the autotransformer uses two auxiliary windings per phase. A phase-shifted voltage (e.g. V_a') is obtained by Tapping a portion (0.0227) of line voltage V_{ca} and Connecting one end of an approximate 0.138 times of line voltage (e.g., V_{bc}) to this tap.

For the same dc-link voltage as that of a six-pulse diode bridge rectifier, the values of K_1' and K_2' are as $K_1' = 0.0195$ and $K_2' = 0.1402$, where K_1' and are the new constants for achieving the same dc-link voltage as that of the six-pulse diode bridge rectifier.

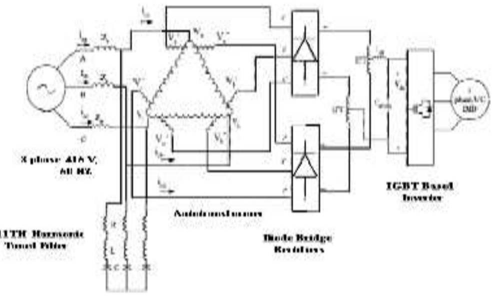

Fig. 2 Autotransformer based proposed 12-pulse converter- (with a phase shift of and) fed VCIMD.

Fig. 2 shows the proposed 12-pulse rectification based harmonic mitigator fed VCIMD.

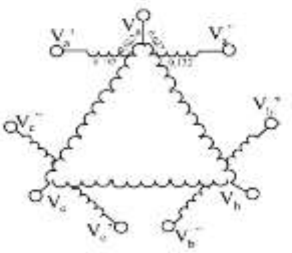

Fig.3. Proposed autotransformer winding connection diagram.

Design of the Proposed 18-Pulse AC–DC Converter:

To design the 18-pulse ac-dc converter, we have to be satisfy the two conditions. First, Two sets of balanced three-phase line voltages are to be produced, which are either +20◦ or +40◦ out of phase with respect to each other. Second, The magnitude of these line voltages should be equal to each other to result in reduced ripple in output dc voltage.

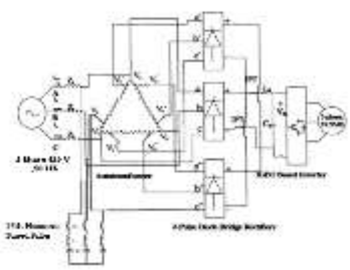

Fig.4. Autotransformer based proposed 18-pulse converter- (with a phase shift of +20° and -20°) fed VCIMD.

The numbers of turns required for +20◦ and phase shift are calculated as follows. Consider phase "a" voltages as

$$V_a' = V_a + K_1 * V_{ca} - K_2 * V_{bc} \quad (8)$$
$$V_a'' = V_a - K_1 * V_{ab} + K_2 * V_{bc} \quad (9)$$

Using above equations, K_1 and K_2 can be calculated. These equations result in $K_1 = 0.0402$ and $K_2 = 0.177$ for the desired phase shift in an autotransformer.

Again, the dc link voltage is higher than that of a 6-pulse ac–dc converter due to the 18-pulse rectification. The values of constants K_1', K_2' and K_3' for retrofit arrangement are calculated, and are given as

$K_1' = 0.0385$, $K_2' = 0.184$ and $K_3' = 0.762$

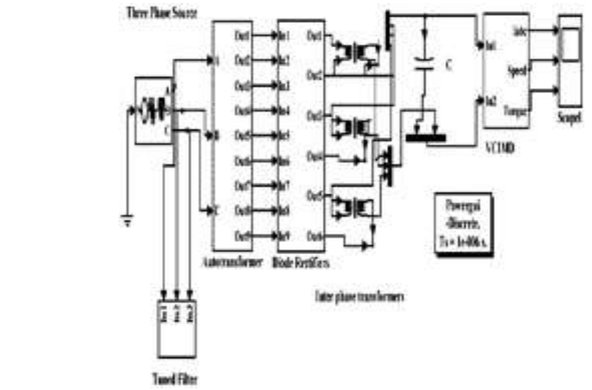

Fig.5.MATLAB block diagram of the proposed harmonic mitigator fed VCIMD.

Vector controlled induction Motor drive

Indirect vector controlling technique is very popular in industrial applications.Fig.1 shows the schematic diagram of an indirect vector controlled induction motor drive (VCIMD).The power circuit consists of a front-end diode rectifier and a PWM inverter with a dynamic brake in the DC link. A hysteresis-band current controller PWM is used. The speed control loop generates the torque component of current.

The speed control range in indirect vector control can easily be extended from stand-still (Zero speed) to the field weakening region. In this case, closed loop flux control is needed. In the constant torque region, the flux is constant. However in the field-weakening region, the flux is programmed such that the inverter always operates in PWM mode.

In the rotor flux oriented reference frame the reference vector i_{ds} (flux component of the stator current) is obtained .

The closed loop PI speed controller compares the reference speed (ω_r^*) with motor speed (ω_r) and generates the reference torque T^*(after limiting it to a suitable value).

The torque component of the stator current reference vector i_{qs} is obtained from the output of the PI controller.

These current components (i_{ds}^* and i_{qs}^*) are converted to stationary reference frame using rotor flux angle calculated as sum of the rotor angle and the value of slip angle.

These currents (i_{ds}^*, i_{qs}^*) in synchronously rotating frame are converted to stationary frame three phase currents (i_{as}^*, i_{bs}^*, i_{cs}^*). These three phase reference currents (i_{as}^*, i_{bs}^* and i_{cs}^*) along with the sensed motor currents (i_{as}, i_{bs} and i_{cs}) are fed to the PWM current controller which provides the gating signals to different switches of VSI to develop necessary voltages. These voltages are being fed to the motor to develop the necessary torque for running the motor at a given speed under given load conditions.

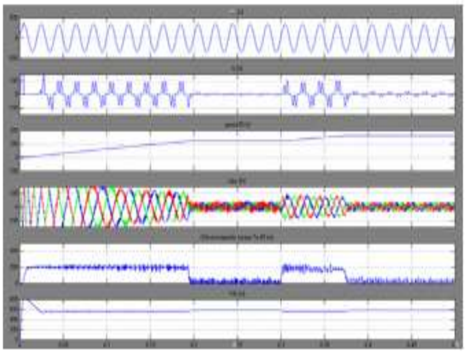

Fig.6. Dynamic response of 12-pulse ac–dc converter based proposed harmonic mitigator fed VCIMD with load perturba-tion.

Results and Discussion

The proposed autotransformer based harmonic mitigators along with the VCIMD are simulated to demonstrate the per-formance of the proposed converter systems. The THD of the ac mains current at full load is 30.10%, which decreases to 65.9% at light load. Moreover, the power factor at full load is 0.933, which decreases to 0. 816 at light load (20% of full load). These results shows the need for improving the power quality at ac mains using some harmonic mitigators which can easily replace the existing 6-pulse converter.

The supply current waveform at full load along with its harmonic spectrum of 12-pulse converter is shown in Fig. 8, and shows that the THD of ac mains current is 4.45%, and the power factor obtained is 0.988.

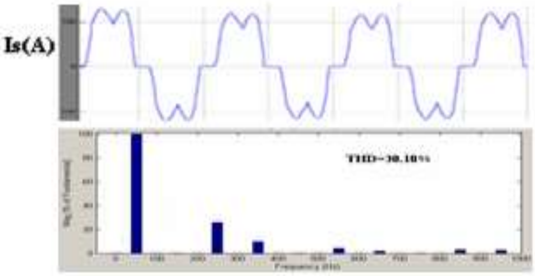

Fig. 7. AC mains current waveform along with its harmonic spectrum at full load in a six-pulse diode bridge rectifier-fed VCIMD.

From these results that the proposed 12-pulse harmonic mi-tigator is able to per-form satisfactorily on VCIMD with power factor always higher than 0.98 and THD of supply current less than 5%.

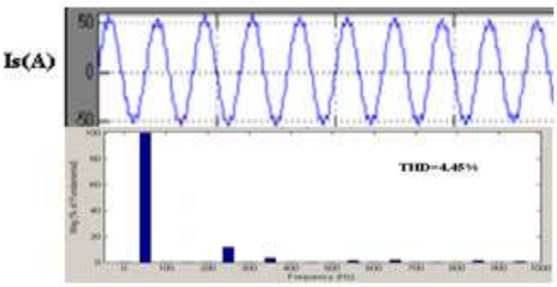

Fig.8. AC mains current waveform along with its harmonic spectrum at full load with 12-pulse ac–dc converter on ac side

However, under light load condition, these power quality indexes start decreasing. which shows that the supply current (I_s) is always less than the converter input current (I_c), thus, showing the effectiveness of the designed passive filter.

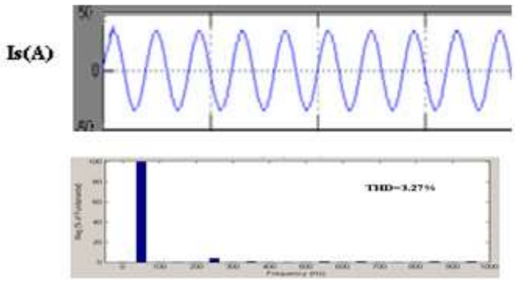

Fig.9. AC mains current waveform along with its harmonic spectrum at full load with 18-pulse ac–dc converter on ac side

The supply current waveform at full load along with its harmonic spectrum of 18-pulse converter is shown in Fig. 9, showing THD of ac mains current as 3.27% and the power factor obtained as 0.982. so that the proposed harmonic mitigator operates satisfactorily under varying load conditions, the load on VCIMD is varied.

From these results that the proposed 18-pulse converter based harmonic mitigator performs well under load variation on VCIMD with a near-unity power factor and THD of supply current always less than 5%.

Conclusion

The proposed harmonic mitigators have been designed, modeled, and developed with variable frequency induction motor drives operating under varying load conditions. The observed performance of the proposed harmonic mitigators has the capability of these converters to improve the power quality indexes at ac Mains in terms of THD of supply current, THD of supply voltage, power factor, and crest factor.

Moreover, the12-pulse-based harmonic mitigator can be used for retrofit applications where load variation is always higher than 50%.

For drives with load variation in wider range, 18-pulse-based harmonic mitigator is able to yield satisfactory performance in terms of near-unity power factor and THD of ac mains current less than 5% limits, thus, satisfying the IEEE Standard 519-1992.

Appendix

Motor and Controller Specifications:

Three-phase squirrel cage induction motor of 30 HP (22 KW), three-phase, four pole, Y-connected, 415 V, 50 Hz, R_s = 0.2511 ohms, R_R = 0.2489 ohms, X_{ls} = 0.439 ohms, X_{lr} = 0.439 ohms, L_m = 0.0591 Henry, J = 0.305 kg·m^2.PI Controller: K_p = 250.0, K_i = 0.01.

Passive Filter Parameters:

$$Z = R + j\left(\omega L - \frac{1}{\omega C}\right),\quad f_n = \frac{1}{\left\{2\pi (LC)^{\frac{1}{2}}\right\}},\quad Q = \frac{X_{ln}}{R} = \frac{X_{cn}}{R}$$

11th harmonic filter: C = 50 μF , L = 1.8953 mH, and R = 0.22 ohms.

17th Harmonic Filter: C = 20 μF, L = 1.75 mH, and R = 0.312 ohms.

Magnetics Ratings:

12-pulse-based converter: Autotransformer rating 12 kVA, interphase transformer 2.7 kVA, passive filter 3 kVA.

18-pulse-based converter: Autotransformer rating 9.8 kVA, Interphase transformer 2.1 kVA, passive filter 1.5 kVA.

Acknowledgement

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