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COMPARATIVE ANALYSIS OF MULTIPULSE AC-DC CONVERTERS IN VCIMD

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ABSTRACT: Power electronic devices are non-linear loads; 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 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 is able to eliminate lower order harmonics in the ac supply current. This paper describes the comparative analysis of different types of multipulse converters in vector controlled induction motor drives (VCIMD). The proposed multi-pulse ac-dc converter is designed and the simulation model is developed in MATLAB.

Keywords: Autotransformer, multi-pulse AC–DC converter, passive filter, harmonic mitigator, power quality improvement and Vector-Controlled Induction Motor Drive (VCIMD).

I.INTRODUCTION

The use of induction motors has been increased in industrial applications due to their advantages such as improved efficiency, ruggedness, reliability and low cost. So for variable speed drives dc motors have been used because of their flexible characteristics [1]. 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 harmonics [2]. These methods use two or more converters where the harmonics generated by one converter are cancelled by another converter through proper phase shift [3].These autotransformer based schemes considerably reduce the size and weight of the transformer. Autotransformer-based multi-pulse ac–dc converters have been introduced for reducing the total harmonic distortion (THD) of the ac mains current [4]. To provide equal power sharing between the diode bridges and to achieve good harmonic cancellation, interphase transformers are needed [5][6].

The proposed multi-pulse ac-dc converters those are suitable for retrofit re to feed vector controlled induction motor drive (VCIMD) [7].This proposed multi-pulse ac-dc converter results in the elimination of 5th, 7th, 11th, 13th, 17th and 21th 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%.

II. DESIGN OF PROPOSED 12-PULSE AND 24-PULSE AC–DC CONVERTERS

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

A. Design Of the Proposed 12-Pulse Ac–Dc Converter:

To design the 12-pulse ac-dc converter, we have to select the mainly two conditions. First condition is, 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. Simulink model of 12-pulse ac–dc converter based proposed harmonic mitigator fed VCIMD is shown in fig-1

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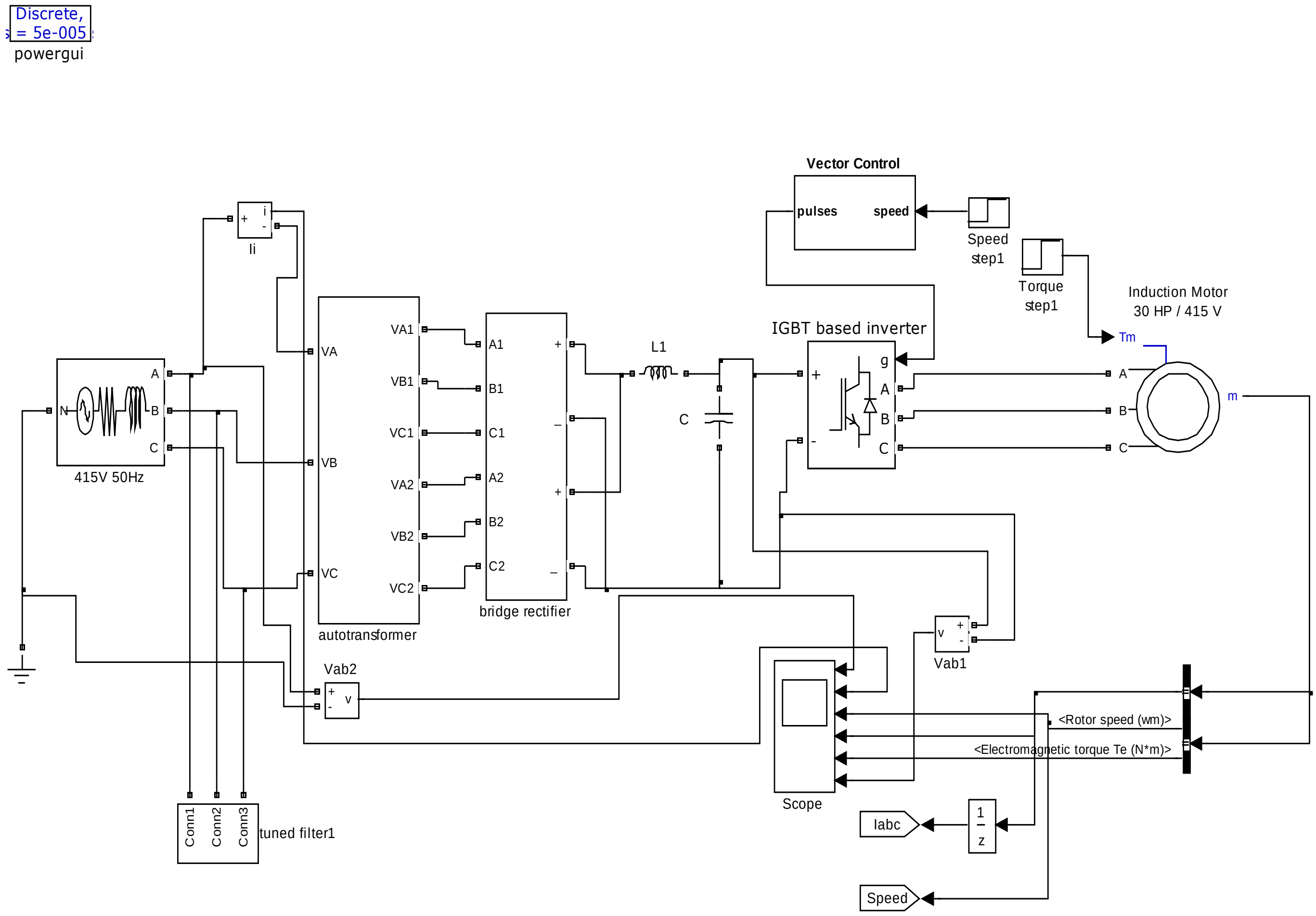

Fig. 1 Simulink model of 12-pulse ac–dc converter based proposed harmonic mitigator fed VCIMD

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

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

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

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

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

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

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.

B. Design Of the Proposed 24-Pulse Ac–Dc Converter:

For achieving the 24-pulse operation, four sets of 3-phase voltages (phase shifted through an angle of +15°) are produced. The number of turns required for achieving these phase shifts among different phase voltages is calculated as follows.

Consider phase 'a' voltages as:

$$V_{a1} = V_a + K_1 * V_{ca} - K_2 * V_{bc} \qquad (8)$$

$$V_{a2} = V_a + K_3 * V_{ca} - K_4 * V_{bc} \qquad (9)$$

$$V_{a3} = V_a - K_1 * V_{ab} + K_2 * V_{bc} \qquad (10)$$

$$V_{a4} = V_a - K_3 * V_{ab} + K_4 * V_{bc} \qquad (11)$$

Where, V is the rms value of phase voltage. Using above equations K1, K2, K3 and K4 can be calculated. These equations result in K1 =0.005706, K2 = 0.07041, K3 =0.0508 and K4 = 0.196375 for the desired phase shift in autotransformer. Simulink model of 24-pulse ac–dc converter based proposed harmonic mitigator fed VCIMD is shown in fig-2

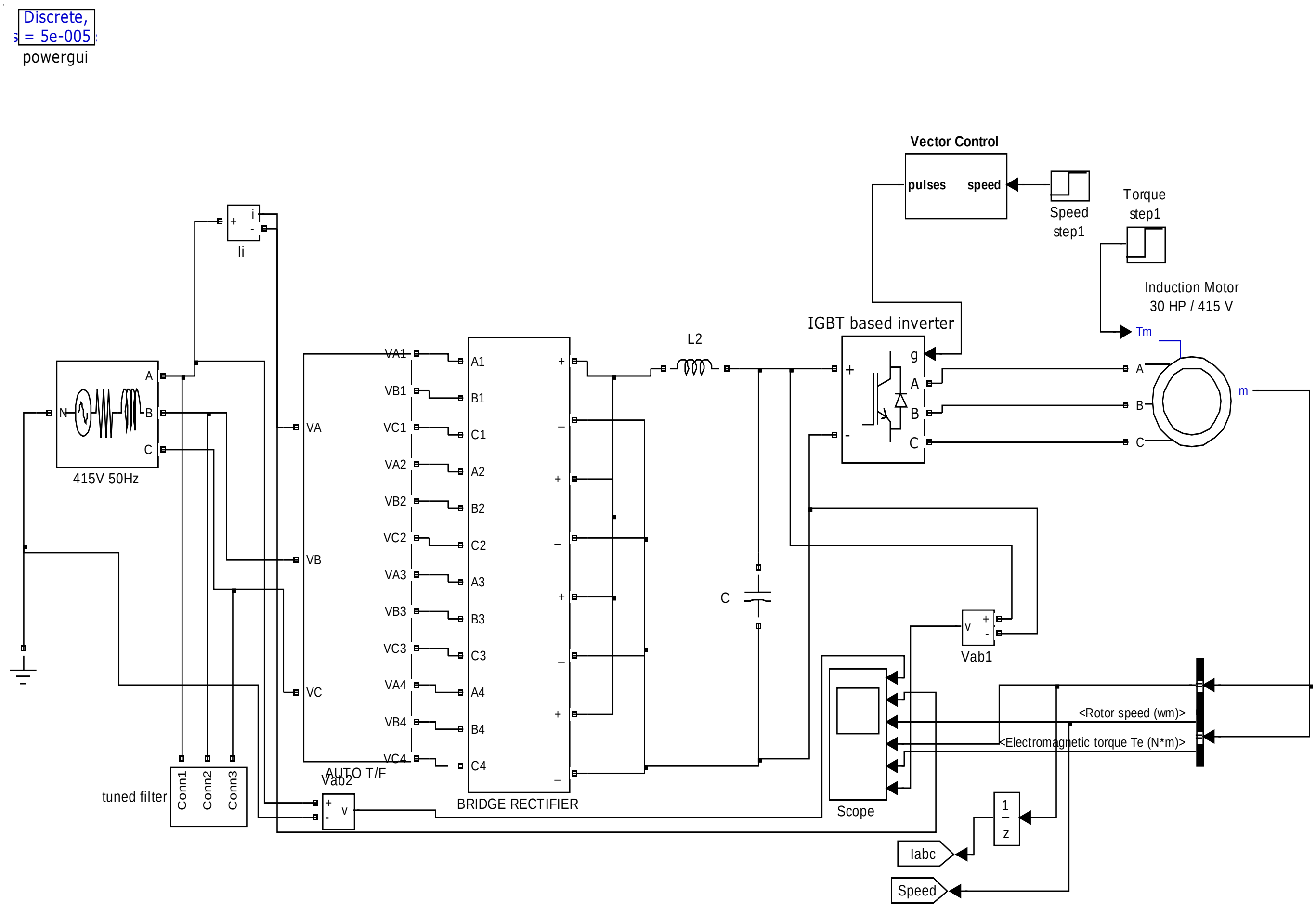

Fig. 2 Simulink model of 24-pulse ac–dc converter based proposed harmonic mitigator fed VCIMD

A phase shifted voltage (e.g. Val) is obtained by tapping a portion (0.005706) of line voltage Vca and connecting one end of an approximately (0.07041) of line voltage (e.g. Vbc) to this tap. Thus the autotransformer can be designed with these known values of winding constants.

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III. VECTOR CONTROLLED INDUCTION MOTOR DRIVE

Indirect vector controlling technique is very popular in industrial applications.Fig.3 shows the MATLAB 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.

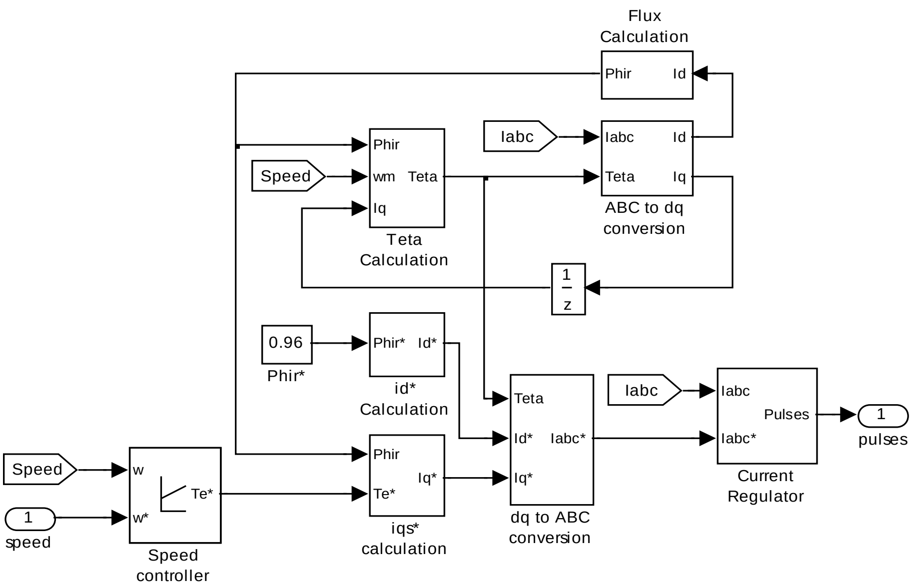

Fig. 3 MATLAB block diagram of VCIMD

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.

IV.RESULTS

The proposed autotransformer based harmonic mitigators along with the VCIMD are simulated to demonstrate the performance 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 and the power factor at full load is 0.933, which decreases to 0. 816 at light load (20% of full load). The supply current waveform at full load along with its harmonic spectrum of 6-pulse converter is shown in Fig. 5, and shows that the THD of ac mains current is 30.10%, these results show the need for improving the power quality at ac mains using some harmonic mitigators which can easily replace the existing 6-pulse converter.

Dynamic response of 12-pulse converter based proposed harmonic mitigator fed VCIMD with load perturbation is shown in Fig. 4, these results shows the improvement of characteristics with respect to 6-pulse converter system in

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terms of THD and power factor.

The supply current waveform at full load along with its harmonic spectrum of 12-pulse converter is shown in Fig. 6, and shows that the THD of ac mains current is 4.45%, and the power factor obtained is 0.988.

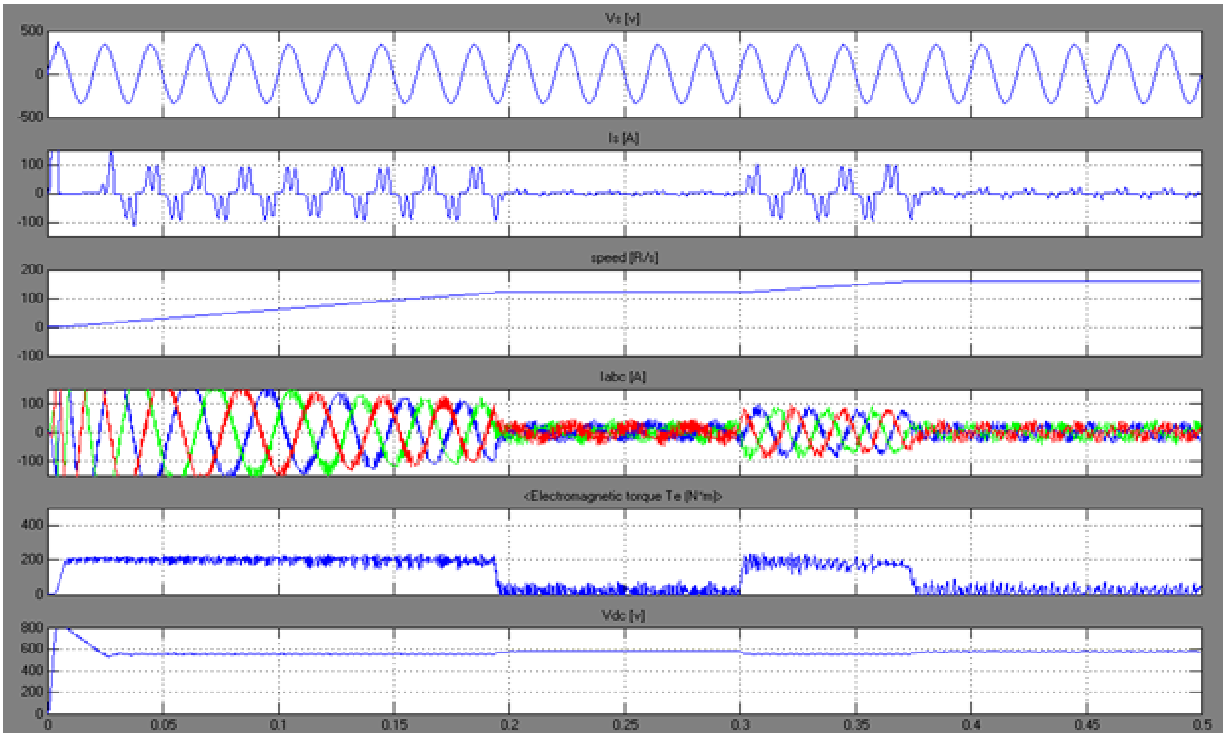

Fig. 4 Dynamic response of 12-pulse ac–dc converter based proposed harmonic mitigator fed VCIMD with load perturbation.

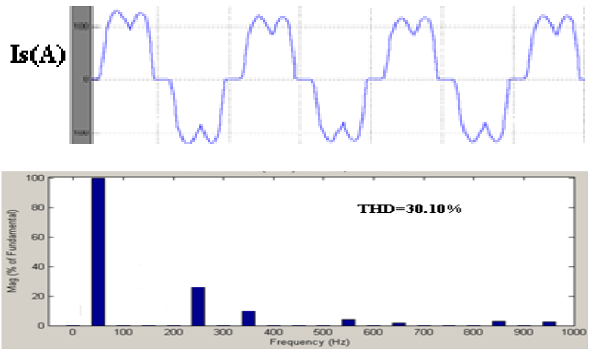

Fig. 5 AC mains current waveform along with its harmonic spectrum at full load in a six-pulse diode bridge rectifier-fed VCIMD.

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

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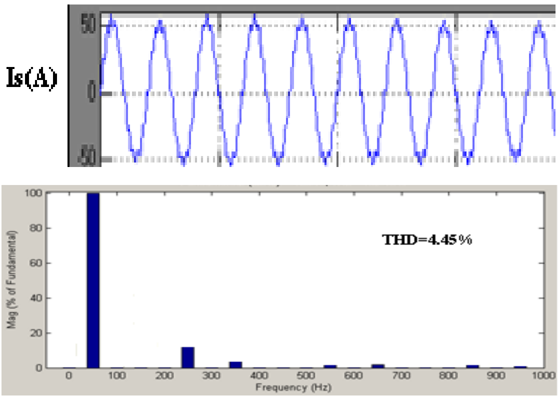

Fig. 6 AC mains current waveform along with its harmonic spectrum at full load with 12-pulse ac–dc converter on ac side.

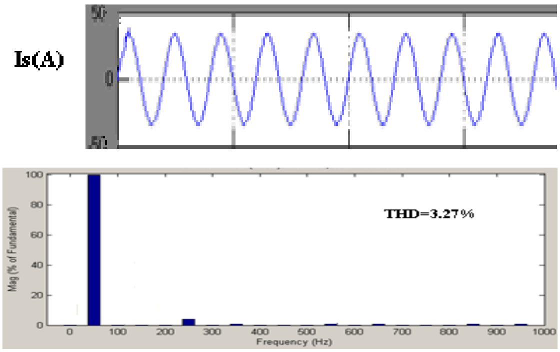

Fig. 7 AC mains current waveform along with its harmonic spectrum at full load with 18-pulse ac–dc converter on ac side.

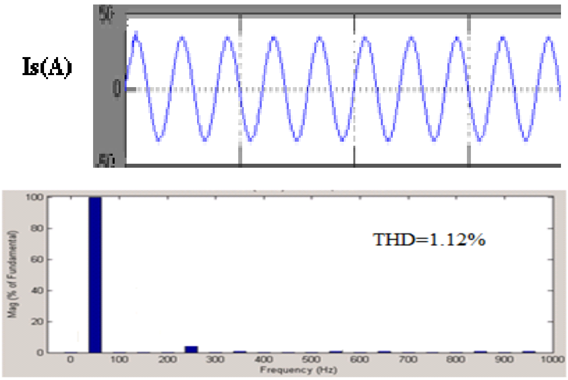

Fig. 8 AC mains current waveform along with its harmonic spectrum at full load with 24-pulse ac–dc converter on ac side.

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Table-1comparison of Power Quality Indexes of A VCIMD Fed from Different Converters

S.No.	ZS	Topology	IS(A)		THD of IS (%)		Distortion Factor (DF)		Displacement Factor (DPF)		Power Factor(PF)		DC Link Voltage (V)	
			Full Load	Light load (20%)	Full Load	Light load (20%)	Full Load	Light load (20%)	Full Load	Light load (20%)	Full Load	Light load (20%)	Full Load	Light load (20%)
1	3%	6-pulse	43.31	10.1	30.9	65.9	0.955	0.835	0.977	0.977	0.933	0.816	545	557
2	3%	12-pulse	42.54	8.84	4.42	8.10	0.999	0.997	0.988	0.947	0.988	0.944	545	563
3	3%	18-pulse	41.60	8.29	3.25	4.60	0.999	0.999	0.983	0.998	0.982	0.998	544	559
4	3%	24-pulse	40.45	7.92	1.12	2.21	0.999	0.999	0.980	0.999	0.992	0.999	540	560

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.
The supply current waveform at full load along with its harmonic spectrum of 18-pulse converter is shown in Fig. 7, 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.

The supply current waveform at full load along with its harmonic spectrum of 24-pulse converter is shown in Fig. 8, showing THD of ac mains current as 1.12% and the power factor obtained as 0.992. So that the proposed harmonic mitigator operates satisfactorily under varying load conditions, the load on VCIMD is varied. Table-1 shows the comparative analysis of different power quality indexes of a VCIMD is fed from 6, 12, 18, 24-pulse converters and it shows the power quality improvement.
From these results that the proposed 24-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%.

IV.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 supply current THD, supply voltage THD, 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 the proposed 24-pulse ac-dc converter results in almost unity power factor in the wide operating range of the drive. Thus the proposed ac-dc converter can easily replace the existing 6-pulse converters without much alteration in the existing system layout and equipments.

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