ISSN-2249 5460

INTERNATIONAL JOURNAL OF MATHEMATICAL SCIENCES, TECHNOLOGY AND HUMANITIES

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International Journal of Mathematical Sciences, Technology and Humanities 118 (2014) 1268 - 1276

POWER QUALITY IMPROVEMENT BY USING PULSE BASED HARMONIC CONVERTER FOR INDUCTION MOTOR DRIVE

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***Abstract*— In this paper, a novel autotransformer based 18-pulse Ac-Dc Converter fed vector controlled induction motor drive is discussed and its Matlab/Simulink model is also given. The procedure for proposed autotransformers shows the flexibility in the design for making it a cost effective replacement suitable for retrofit applications, where presently a six-pulse diode bridge rectifier is used. Using the above designs we can capable to suppress harmonics up to 13th in 18-pulse configuration of the VCIMD. Various simulation results are given for autotransformer and VCIMD in topology C and D. THD analysis at No load and Load is also done. A comparative performance of different ac-dc converters based on eighteen-pulse rectification has also been presented to demonstrate the performance of the proposed AC- DC converter feeding VCIMD.**

Index Terms: *Autotransformer,* ***MATLAB****, Multi-pulse* ***AC-DC*** *converter, power quality, and vector controlled induction motor drive* ***(VCIMD).***

I. INTRODUCTION

With the proliferation of power-electronic converters, the majority of dc drives are being replaced by variable frequency induction motor drives. These variable frequency induction motor drives are generally operated in vector control [1], as it is an elegant way of achieving high performance control of induction motors in a way similar to the dc motor. These vector-controlled induction motor drives (VCIMDs) are fed by an uncontrolled ac–dc converter which results in injection of current harmonics into the supply system. These current harmonics, while propagating through the finite source impedance, result in voltage distortion at the point of common coupling, there by affecting the nearby consumers.

Various methods based on the principle of increasing the number of pulses in ac–dc converters have been reported in the literature to mitigate current harmonics [2]–[4]. These methods use two or more converters, where the harmonics generated by one converter are cancelled by another converter, by proper phase shift. The autotransformer-based configurations [5, 6] provide the reduction in magnetic rating, as the transformer magnetic coupling transfers only a small portion of the total kilovolt-ampere of the induction motor drive. These auto transformer-based schemes considerably reduce the size and weight of the transformer. Autotransformer-based 18-pulse ac-dc converters have been reported for reducing the total harmonic distortion (THD) of the ac mains current. To ensure equal power sharing between the diode bridges and to achieve good harmonic cancellation, this topology needs Inter-phase transformers and impedance matching inductors, resulting in increased complexity and cost. Moreover the dc-link voltage is higher, making the scheme non applicable for retrofit applications.

To overcome the problem of higher dc-link voltage, Hammond [5] has proposed a new topology, but the transformer design is very complex. To simplify the transformer design, Paice [6] has reported a new topology for 18-pulse ac-dc Converters But this topology requires higher rating magnetic, resulting in the enhancement of capital cost. Bhim Singh [9, 11 and 13] also gives various VCIMD model with 862 various autotransformer connections. In this paper, an 18-pulse Ac-Dc converter fed vector controlled induction motor drive (VCIMD) is simulated, which is used a novel autotransformer for 18- pulse production.

In this paper, a 12-pulse and an 18-pulse ac–dc converters that are suitable for retrofit applications (where presently 6-pulse converter is being used, as shown in Fig. 1) are proposed to feed VCIMD. First, a 12-pulse ac–dc converter-based harmonic mitigator is presented, which is able to eliminate 5th, 7th, and 11th harmonics. The same concept has been further extended to achieve 18-pulse ac–dc converter-based harmonic mitigation, which is able to eliminate 9th, 11th, and 13th harmonics.

In the autotransformer, the windings are interconnected such that the kilovolt ampere rating of the magnetic coupling is only a portion of the total kilovolt ampere. These schemes considerably reduce the size and weight of the transformer

The presented techniques for the design of the autotransformer provides flexibility in design to vary the output voltages to make it suitable for retrofit applications (where presently, a six-pulse converter is being used, as shown in Fig.1) without much alterations in the system layout. This topology results in improvement in THD of ac mains current and power factor even under light load conditions.

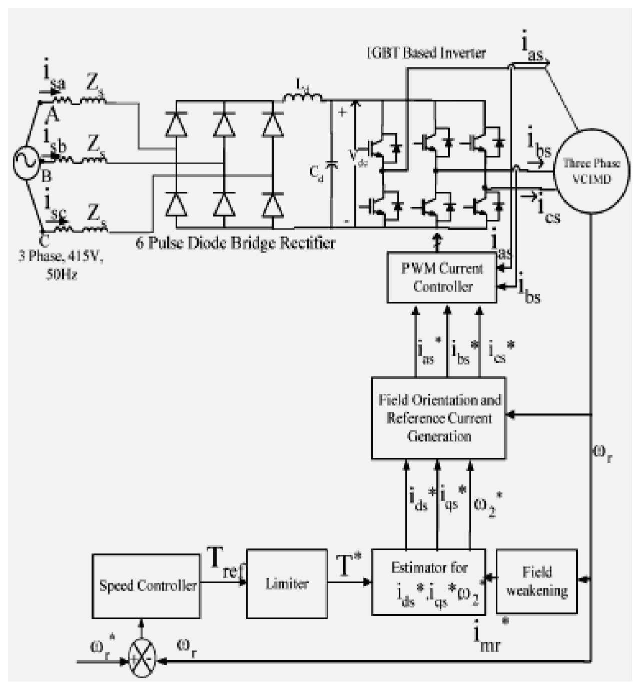

Fig.1 Six-pulse diode bridge rectifier fed vector controlled induction motor drive (Topology 'A').

To ensure equal power sharing between the diode bridges, and to achieve good harmonic cancellation, this topology necessitates the need of inter-phase transformers and impedance-matching inductors resulting in increased complexity and cost. Moreover, the dc-link voltage is higher, making the scheme non-applicable for retrofit applications.

II. PROPOSED 12-PULSE AC–DC CONVERTER BASED HARMONIC MITIGATOR

This section deals with the autotransformer arrangements for 12-pulse ac–dc converter-based harmonic mitigator. Various issues related with suitable autotransformers for these configurations with the reduced KVA rating.

A. Design of the Proposed 12-Pulse AC–DC Converter

Fig. 2 shows the schematic diagram of a VCIMD fed from the proposed harmonic-mitigator-based 12 pulse ac–dc converter. The detailed winding diagram of the autotransformer-based magnetics is shown in Fig. 3, and the vector diagram of the phase voltages is shown in Fig. 4.

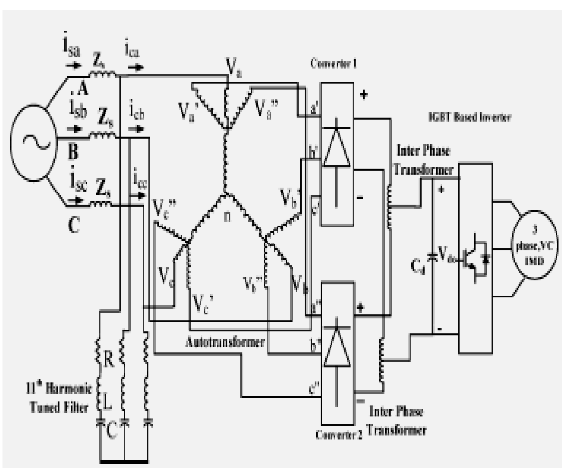

Fig. 2. Proposed 12-pulse harmonic mitigator fed VCIMD (Topology 'B')..

The phase angle between supply voltages V_a, V_b, V_c and converter 1 input voltages V_a, V_b , V_c is +15°, and that between the supply voltages *Va*, *Vb*, *Vc* and converter 2 input voltages V_a" , V_b" , V_c" is -15°, resulting in 30°, phase shift between the two converters input ac voltages, fulfilling the criterion for the 12-pulse rectification.

To achieve the 12-pulse rectification, the following conditions have to be satisfied.

1) Two sets of balanced three-phase line voltages are to be produced at 30° out of phase with respect to each other.

2) The magnitude of these line voltages should be equal.

The supply voltages are fed to the autotransformer windings connected in star. From these voltages, two sets of three-phase voltages (phase shifted through +15° and −15°) are produced.

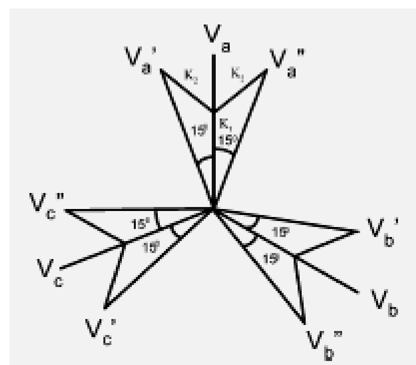

Fig. 3. Vector diagram of phasor voltages for 12-pulse-based proposed harmonic mitigator.

III. CIRCUIT CONFIGURATION OF EIGHTEEN-PULSE AC-DC CONVERTERS

An autotransformer based n-pulse ac-dc converter operates the principle of harmonic elimination. The minimum order of harmonics is nK±1, where K is a positive integer and n is the number of rectification pulses per cycle of fundamental voltage. For harmonic elimination, the required minimum phase shift is given by [3]:

Phase shift = 60/ Number of six-pulse converters.

To achieve an 18-pulse rectification, three sets of balanced 3-phase line voltages are to be produced, which are either +20° or -20° out of phase with respect to each other. Fig.3 shows the schematic diagram of an 18-pulse autotransformer based ac-dc converter with a phase shift of +20° and -20°. This topology is referred as Topology 'C'.

A. Proposed Eighteen Pulse AC-DC Converter

Here, ± 20° phase shift is used to reduce the size of magnetics and the magnitude of these line voltages should be equal to each other to result in symmetrical pulses and reduced ripple in output dc voltage. The design of the suitable autotransformer for the proposed eighteen-pulse ac-dc converter, referred as Topology 'c'. The proposed 18-pulse ac-dc converter results in elimination of 5^{th}, 7^{th}, 11^{th} and 13^{th} harmonics. Moreover, the effect of load variation on various power quality indices is also studied to demonstrate the effectiveness of proposed 18-pulse ac-dc converter.

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B. Design of the Proposed 18-Pulse AC–DC Converter

To achieve the 18-pulse rectification, the following conditions have to be satisfied.

1) Three sets of balanced three-phase voltages are to be produced, which are 20° out of phase with respect to each other.
2) The magnitude of these line voltages should be equal.

Fig. 5 shows the vector diagram of phase voltages for an 18-pulse converter. From the supply voltages, two sets of three phase voltages (phase shifted through +20° and −20°) are produced.

Fig.5 shows the winding diagram of the proposed ac-dc converter. Fig.6 shows the phasor diagram of different phase voltages of the proposed autotransformer for achieving an 18-pulse rectification. From the supply voltages, two sets of 3-phase voltages (phase shifted through +20° and -20°) are produced.

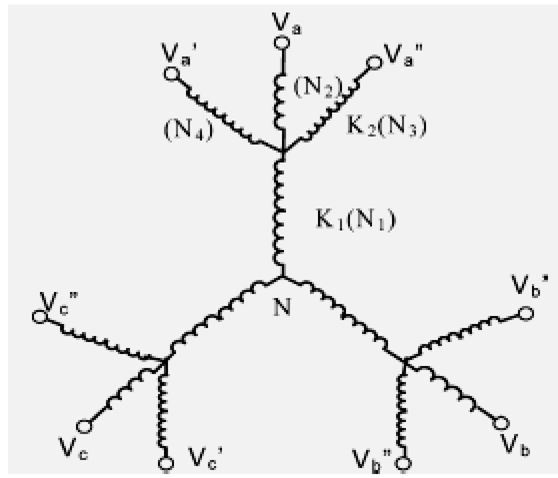


Fig. 4. Proposed autotransformer winding connection diagram.

The number of turns required for +20° and -20° phase shift are calculated as follows.

Consider phase ‘a’ voltages as:

$V_a' = K_1V_a – K_2V_b$, (1)
$V_a'' = K_1V_a – K_2V_c$. (2)
Assume the following set of voltages:

$V_a = V\angle 0°$ $V_b=V\angle -120°$ $V_c=V\angle 120°$ (3)

$V_a' = V\angle +20°$ $V_b'=V\angle -100°$ $V_c'=V\angle 140°$ (4)

Here V_a, V_b, and V_c are the phase voltages.
Similarly-

$V_a''= V\angle -20°$ $V_b''=V\angle -140°$ $V_c''=V\angle 100°$ (5)

Where, V is the rms value of phase voltage.

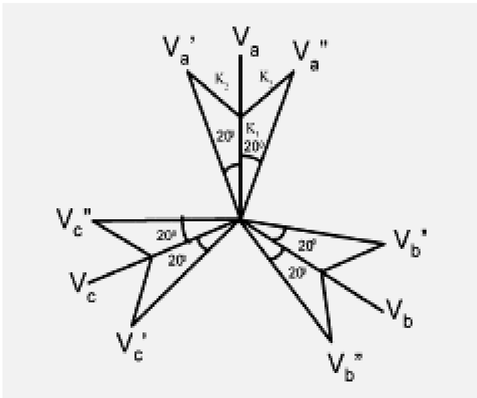


Fig. 5. Vector diagram of phasor voltages for 18-pulse-based proposed harmonic mitigator.

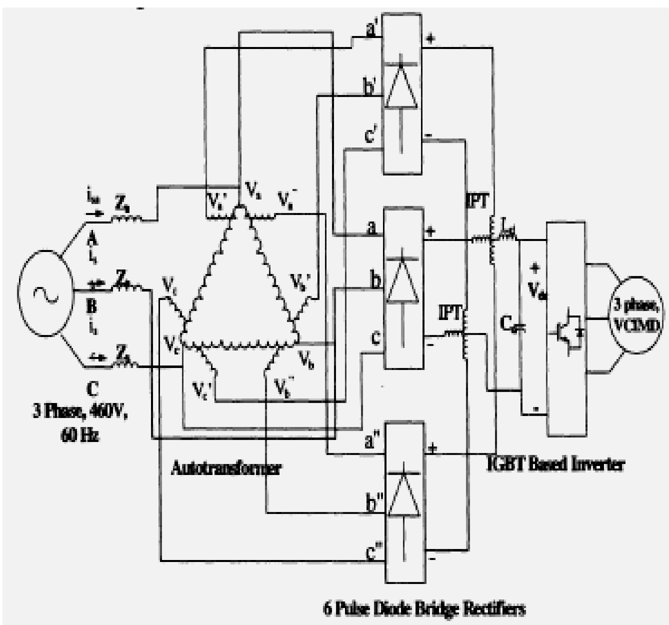


Fig. 6. Proposed 18-pulse harmonic mitigator fed VCIMD (Topology 'C').

IV. Vector Controlled Induction Motor Drive

Fig. 1 shows the schematic diagram of an indirect VCIMD. This technique uses two currents of motor phases, i.e., i_{as} and i_{bs}, and the motor speed (ω_r). The speed controller compares the reference speed (ω_{ref}) with motor speed (ω_r) and generates the reference torque T^* (after limiting it to a suitable value). The flux control signal (i_{mr}) is taken as reference flux signal. These two signals are fed to the vector controller, which calculates the torque component of current (i^*_{ds}), slip speed (ω^*_2), and the flux angle (ψ) as

$$i^*_{ds} = i_{mr} + \tau_r(\Delta i_{mr}/\Delta t) \quad (6)$$

$$i^*_{qr} = T^*/ (k\, i_{mr}) \quad (7)$$

$$\omega^*_2 = i^*_{qs}/(\tau_r i_{mr}) \quad (8)$$

$$\Psi(n) = \Psi(n-1) + (\omega^*_2 + \omega_r)\,\Delta T \quad (9)$$

where k is a constant and depends on motor parameters, i^*_{ds} and i^*_{qs} are, respectively, the flux and the torque producing current components, i_{mr} is the magnetizing current, ω^*_2 is the slip speed of the rotor, ω_r is the angular velocity of the rotor, Ψ(n) and Ψ(n−1) are the values of rotor flux angles at nth and (n− 1)th instants, and ΔT is the sampling time taken as 100 µ secs. These currents (i^*_{ds}, i^*_{qs}) in synchronously rotating frame are converted to stationary frame three-phase currents (i^*_{as}, i^*_{bs}, i^*_{cs}) as

$$i^*_{as} = -i^*_{qs}\sin\Psi + i^*_{ds}\cos\Psi \quad (10)$$

$$i^*_{bs} = [-\cos\Psi + \sqrt{3}\sin\Psi]\, i^*_{ds}(1/2) + [\sin\Psi + \sqrt{3}\cos\Psi]\, i^*_{qs}(1/2) \quad (11)$$

$$i^*_{cs} = -(i^*_{as} + i^*_{bs}). \quad (12)$$

These reference currents (i^*_{as}, i^*_{bs}, and i^*_{cs}) generated by the Vector controller and sensed currents (i_{as}, i_{bs}, and i_{cs}) are fed to the PWM current controller, which controls the gating of different switches in VSI. The VSI generates the necessary phase voltages being fed to the motor to develop the required torque for running the motor at a given speed.

V. MATLAB-BASED SIMULATION

The proposed harmonic mitigators along with the VCIMD are simulated in the Matlab environment along with Simulink and power system blockset toolboxes. Fig. 7 shows the Matlab model of the proposed harmonic mitigator based on the 18-pulse rectification. Fig. 8 shows the Matlab model of a VCIMD. The VCIMD consists of an induction motor drive controlled using indirect vector control technique. The detailed data of the induction motor are given in the Appendix.

VI. SIMULATION AND EXPERIMENTATION

The proposed harmonic mitigators feeding VCIMD are simulated in MATLAB environment along with SIMULINK and power system block set (PSB) toolboxes. Fig.7 shows the sub block of MATLAB model of a vector controlled induction motor drive. The VCIMD consists of an induction motor drive controlled using indirect vector control technique.

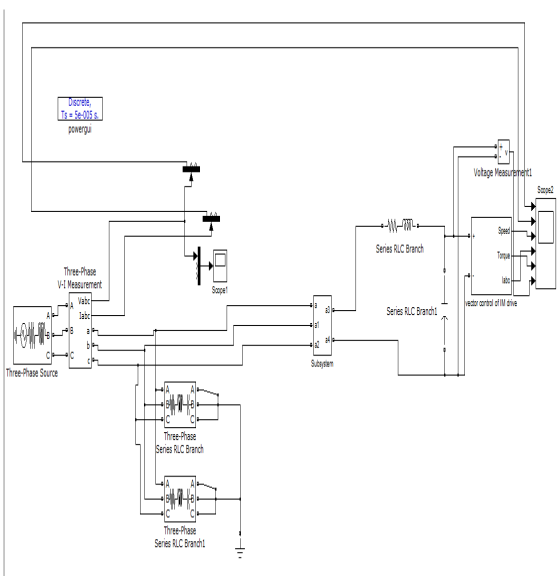


Fig. 7. Simulink diagram of sub block of Vector control of induction motor Drive

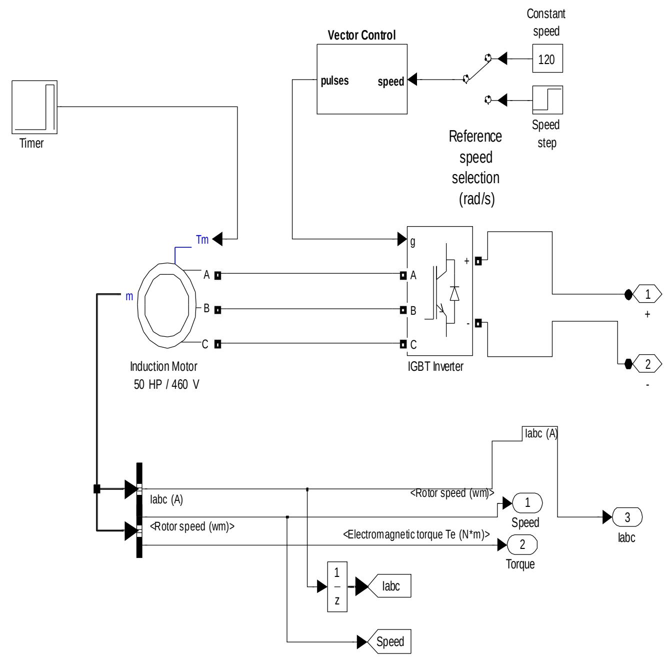


Fig. 8. Simulink diagram of sub block of Vector control of induction motor Drive

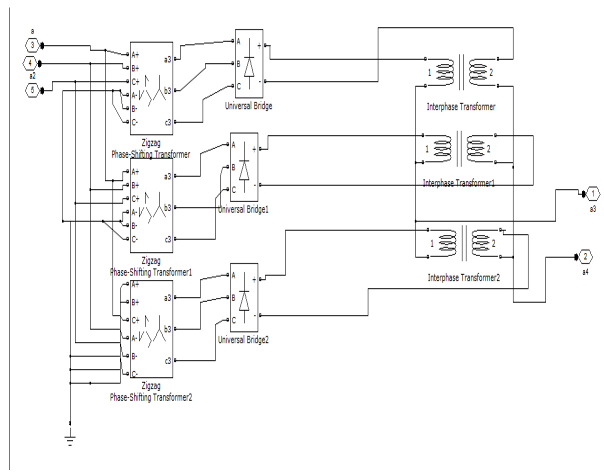


Fig. 9 Autotransformer winding connection diagram.

VII. RESULTS AND DISCUSSION

The proposed harmonic mitigator along with the VCIMD is simulated to demonstrate the performance of the proposed converter system. Fig. 10 shows supply current waveform at full load and its harmonic spectrum of a VCIMD fed by a 18-pulse diode bridge rectifier. The

THD of the ac mains current at full load is 4.8%, which deteriorates to 5.76% at light load as shown in Table I. Moreover, the power factor at full load is 0.933, which deteriorates to 0. 816 at light load (20% of full load). These results show the need for improving the power quality at ac mains using some harmonic mitigators which can easily replace the existing 18-pulse converter.

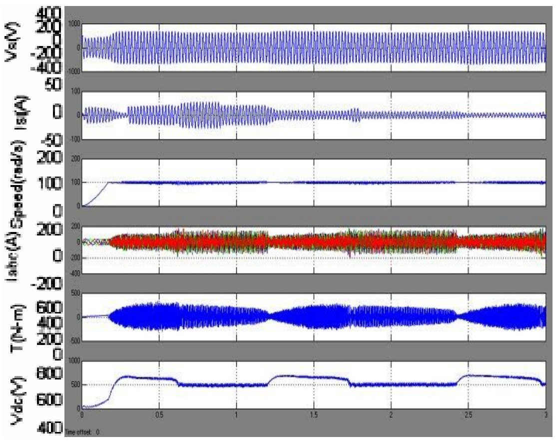
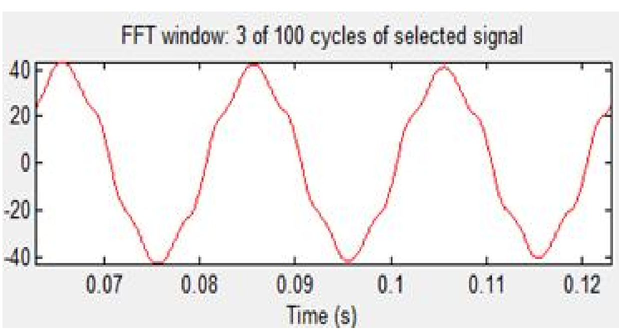


Fig.10 Dynamic response of 18-pulse diode rectifier fed VCIMD with load perturbation.



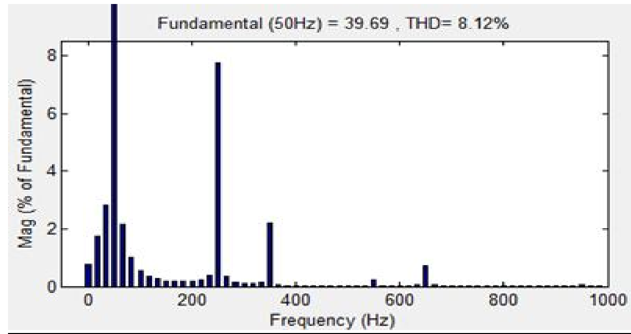
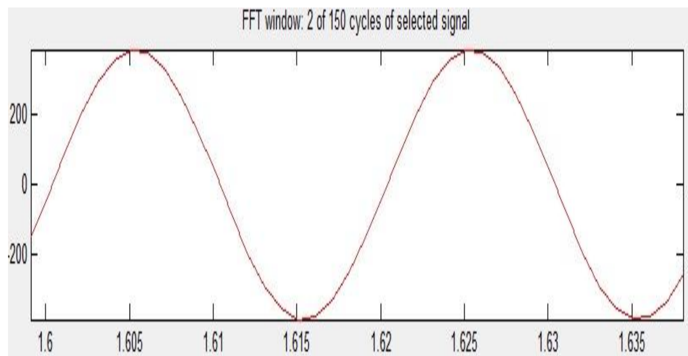


Fig. 11 AC mains current waveform along with its harmonic spectrum at full load in proposed 12-pulse ac-dc converter fed VCIMD (Topology 'B').



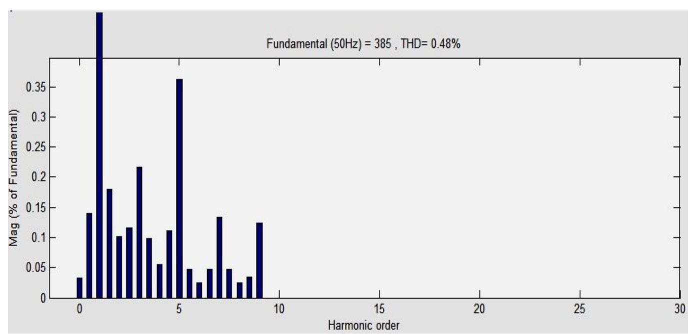


Fig. 11 AC mains current waveform along with its harmonic spectrum at full load in proposed 18-pulse ac-dc converter fed VCIMD (Topology 'D').

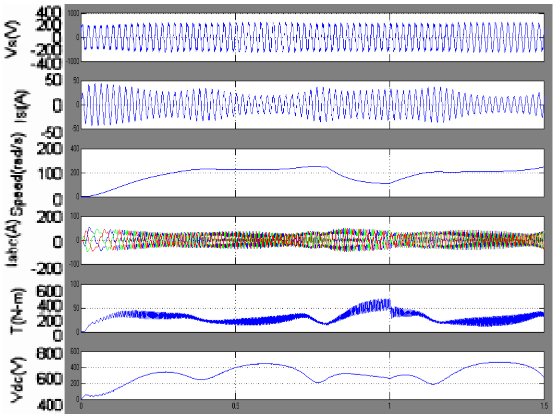


Fig.12 Dynamic response of 12-pulse diode rectifier fed VCIMD with load perturbation.

TABLE-I

Comparison power quality indices of proposed 18-pulse ac-dc converter VCIMD under varying loads.

Sl.No	Topology	THD at 20% Load	THD at full Load
1	Topology-B	8.12%	7.45%
2	Topology-C	5.42%	4.8%

VIII. CONCLUSION

The modeling, simulation, and development of 18-pulse ac–dc converter fed VCIMD has been presented for various load in two topology 'C'. It has been observed that the design of the proposed autotransformer is flexible for making it suitable for retrofit applications, where presently a six-pulse diode bridge rectifier is being used. The proposed 18-pulse ac–dc converter fed VCIMD topology-'B' has less THD as compared to topology-'C'.

IX. APPENDIX

Motor and Controller Specifications:
Three-Phase Squirrel Cage Induction Motor - 50hp (37.3kW), 3-Phase, 4 Pole, Y- connected, 460 V, 60 Hz, R_s = 43ohms, R_r = 0.228 ohms, X_{ls} = 0.3016 ohms, X_{lr} = 0.3016 ohms, X_m =13.0819 ohms, J= 1.662 kg-m2.
PI Controller: K_p = 45.0, K_i = 0.1, DC Link parameters: L_d = 0.1mH, C_d = 3200uF.
Magnetics ratings: Autotransformer Rating 8.75kVA, Interphase Transformer 1.53kVA

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