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A COMPARISON OF WITH AND WITHOUT AC-DC MULTIPULSE CONVERTER FOR VECTOR CONTROL PWM CSI IM DRIVE

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Abstract- This paper presents the comparison of with and without ac-dc multipulse converter for vector control of induction motor drives. The proposed ac-dc multipulse converter is based on the star connected zigzag autotransformer, designed for producing 15-phase shifted ac voltages for effective harmonic reduction. The proposed multipulse ac-dc converter is suitable for retrofit applications, where, presently a six-pulse IGBT bridge rectifier is being used. The multipulse ac-dc converter for vector control induction motor drive the THD is low and near unity power factor compared to the normal 6-pulse converter. The effect of load variation on various power quality indices is also presented. The proposed ac-dc converter is found suitable for applications with large load variation and where harmonic reduction is stringent.

Index terms- Multipulse converter, zigzag autotransformer, vector control induction motor drive (VCIDM), power quality improvement.

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1 INTRODUCTION:

THE rapid development of power electronics in recent years allows the use of the induction machine also in high-performance motor drives. At low- and medium-power levels the variable-speed induction motor drives are usually realized using pulse width-modulated (PWM) voltage-source inverters (PWM-VSIs). However, the switched voltages yield high du/dt voltage slopes over the stator windings, which stresses the insulations and causes bearing current problems. A possible solution for this problem is the use of a PWM current-source inverter (PWM-CSI). Both the voltages and the currents of the machine are almost sinusoidal and, therefore, the voltage stresses in the machine windings are lower.

The increased use of variable frequency induction motor drives in various industrial applications such as rolling mills, textile mills has led to the injection of current harmonics into the ac mains, resulting in power pollution at the point of common coupling (PCC). These variable frequency induction motor drives are generally used in vector control mode due to its own advantages like ease of control, energy conservation etc.

The power quality improvements in 3-phase ac-dc converters may be achieved using multipulse converters or multiphase converters. The multipulse converters are simple, robust, rugged and more efficient. For applications, where isolation is not required, autotransformer based configurations are found to be more economical due to reduced magnetic, as the magnetic transfer only a small portion of the load power. The 6-pulse ac-dc converter configuration is simple but THD of ac mains is poor. This work proposes a novel autotransformer based 30-pulse ac-dc converter for effective harmonic reduction. The design procedure of the autotransformer is given for producing 15 phase shifted voltages of equal magnitude. The autotransformer is also designed for retrofit applications, by simply varying the tap positions of different windings. A small rating interphase transformer (IPT) is required to absorb the difference in output instantaneous voltages. This ac-dc converter results in elimination up to 29th harmonic in the supply current (the two lowest order harmonics are twenty ninth and thirty first, which have very small magnitude).

A set of tabulated results giving the comparison of different power quality indices such as total harmonic distortion (THD) and power factor (PF) THD of supply voltage at PCC is presented for a VCIMD load fed from an existing 6-pulse ac-dc converter

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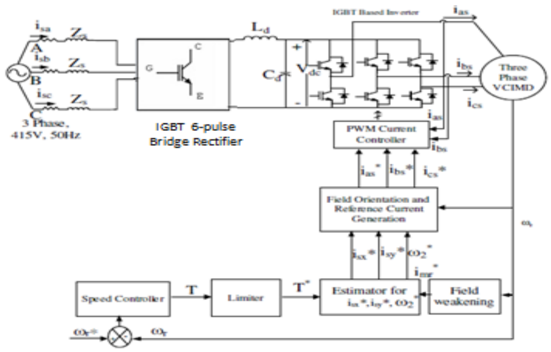

Fig1. Six pulse IGBT bridge rectifier for vector controlled induction motor

2 PROPOSED MULTIPULSE VCIMD:

The proposed thirty-pulse ac-dc converter feeding a variable frequency induction motor load is shown in Fig2.

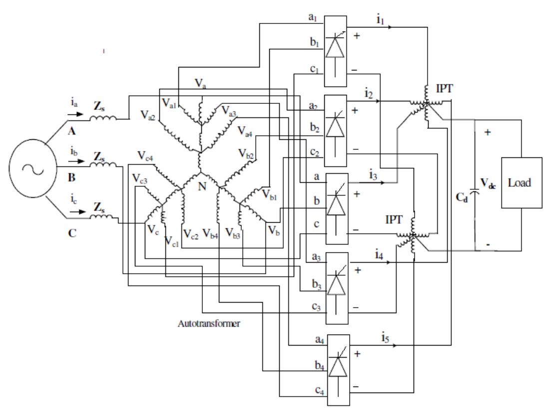

Fig2. The complete circuit consists of autotransformer, thyristors bridge rectifiers, interphase transformers and a varying load.

2.1 DESIGN OF AUTOTRANSFORMER FOR PROPOSED THIRTY-PULSE AC-DC CONVERTER:

The minimum phase shift required for proper harmonic elimination is given by:

$$\text{Phase shift} = 60^0 / \text{Number of six-pulse converters}$$

For achieving 30-pulse rectification, the phase shift required between any two nearby set of voltages is of 120. The winding connection arrangement of the proposed autotransformer is shown in Fig.3. Three-phase ac voltage is given to the autotransformer, which produces 15-phase shifted voltages of same magnitude and distributed in time through phase shift of 120, as shown in Fig.4. The numbers of turns of different windings in the autotransformer are calculated to result in 30-pulse rectifier operation.

Consider phase 'a' voltages in Fig.3 as:

$$V_{a1} = K_1V_a - K_2\, V_b \quad (1)$$

$$V_{a2} = K_3V_a - K_4V_b \quad (2)$$

$$V_{a3} = K_1V_a - K_2V_c \quad (3)$$

$$V_{a4} = K_3V_a - K_4V_c \quad (4)$$

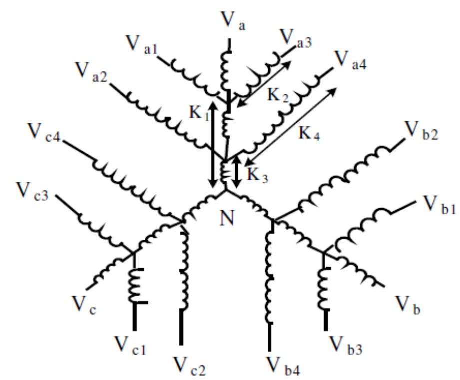

Fig3. The proposed autotransformer winding connection diagram

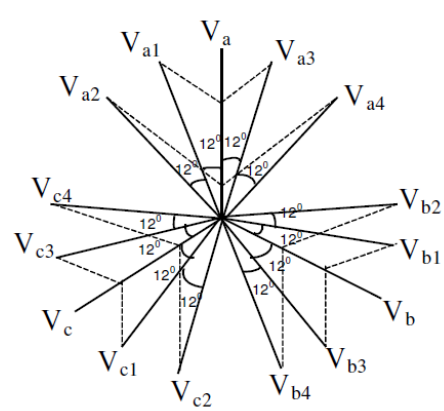

Fig4. Phasors diagram of different phase voltages in the proposed autotransformer based 30-pulse ac-dc converter

Assume the following set of voltages:

$$V_a = V\angle 0^0,\ V_b = V\angle -120^0,\ V_c = V\angle 120^0 \quad (5)$$

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$V_a = V\angle 12^0,\ V_b = V\angle -108^0,\ V_c = V\angle 132^0$ (6)

$V_a = V\angle 24^0,\ V_b = V\angle -96^0,\ V_c = V\angle 144^0$ (7)

$V_a = V\angle -12^0,\ V_b = V\angle -132^0,\ V_c = V\angle 108^0$ (8)

$V_a = V\angle -24^0,\ V_b = V\angle -144^0,\ V_c = V\angle 96^0$ (9)

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 =0.6786, K2 = 0.24, K3 = 0.6786 and K4 = 0.4696 for the desired phase shift in autotransformer.

The phase shifted voltages for phase 'a' are:

$$V_{a1} = 0.6786V_a - 0.24V_b \quad (10)$$

$$V_{a2} = 0.6786V_a - 0.4696V_b \quad (11)$$

$$V_{a3} = 0.6786V_a - 0.24V_c \quad (12)$$

$$V_{a4} = 0.6786V_a - 0.4696V_c \quad (13)$$

A phase shifted voltage (e.g. Va1) is obtained by tapping a portion (0.6786) of phase voltage Va and connecting one end of an approximately (0.24) of phase voltage (e.g. Vb) to this tap. Thus the autotransformer can be designed with these known values of winding constants i.e. K1, K2, K3 and K4. The resulting autotransformer based thirty-pulse ac-dc converter is shown in Fig2. This converter results in higher dc link voltage due to the 30-pulse Rectification. To make this converter suitable for retrofit applications, the autotransformer design is modified, as shown in Fig5. The new winding constants defined are K1′, K2′, K3′, K4′ and K5 ′. By using the above mentioned procedure, the values of these constants are calculated. These equations result in K1′ =0.815, K2′ = 0.2269, K3′ = 0.6446, K4′ = 0.4461 and K5′ = 0.1349 for the desired phase shift in autotransformer.

Thus, the autotransformer design can also be modified for achieving different voltage ratios as per the requirements. This may be achieved by simply varying the values of winding Constants, while ensuring the desired phase shift between different phase voltages. The resulting thirty-pulse ac-dc converter for retrofit applications is shown in Fig7.

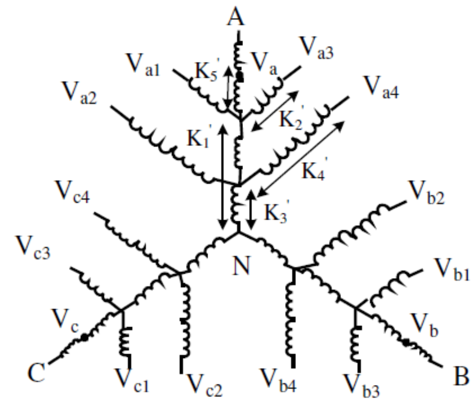

Fig 5. The Proposed autotransformer winding connection diagram

2.2 INTERPHASE TRANSFORMER:

The proposed ac-dc converter needs a small rating interphase transformer. The five sets of rectified voltages are the inputs for the interphase transformer. The interphone transformer absorbs the difference in instantaneous dc output voltages of five six-pulse converters. This results in symmetrical conduction of each diode, which helps in effective harmonic mitigation.

3 MATLAB BASED SIMULATION:

The complete system comprising of the proposed autotransformer based ac-dc converter feeding VCIMD is simulated in MATLAB environment along with Simulink and Power System Block set (PSB) toolboxes. The MATLAB model of the proposed ac-dc converter feeding VCIMD is shown in Fig.6. Fig.7 shows the MATLAB model of the sub block of the vector controlled induction motor drive. The VCIMD consists of a 10 hp; 415V induction motor drive controlled using indirect vector control technique.

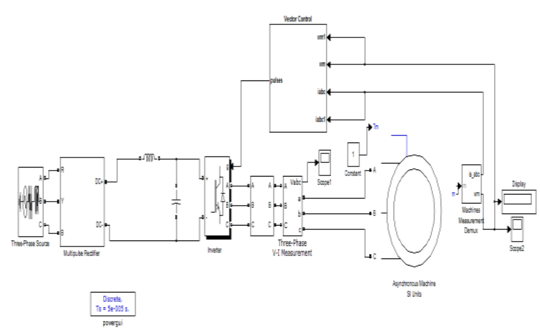

Fig6. Multipulse vector control Induction motor drive

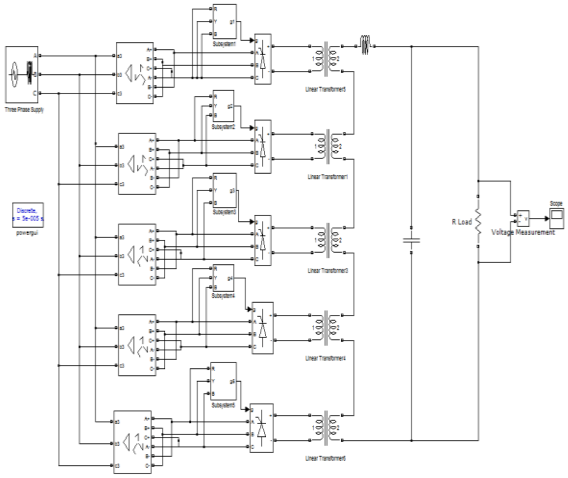

Fig7. multipulse converter using thyristors bridge rectifier circuit

4 RESULTS AND DISCUSSION:

The complete system consisting of the proposed autotransformer, interphase transformer, rectifiers and the VCIMD load has been designed, analyzed, modeled and simulated. To compare the performance of the proposed thirty pulse ac-dc converter, first the performance of a 6-pulse ac-dc converter has been computed. Fig1 shows the dynamic performance along with load perturbation on the VCIMD fed by a 6-pulse IGBT bridge rectifier. It consists of supply voltage $v_{s.}$ supply current is, rotor speed 'wr' (in electrical rad /sec), three-phase motor currents i_{sabc}, motor developed torque 'Te' (in N-m) and DC link voltage v_{dc} (V). Fig10 Shows the supply voltage waveform along with its harmonic spectrum at full load. The THD of ac mains current at full load is 30.9%, which deteriorates to 57.7% at light load as shown in Fig.1 Moreover, the power factor at full load is 0.935, which deteriorates to 0.807 as the load is reduced to 20%. These results show that there is a need for improving the power quality at ac mains.

Fig8. W_r of VCIMD 6-Pulse Rectifier

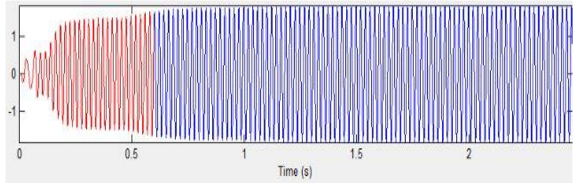

Fig9. V_{abc} response of VCIMD 6-pulse rectifier

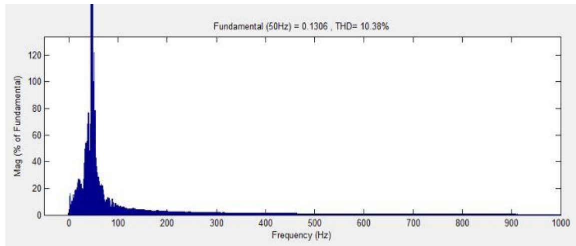

Fig10. THD of VCIMD 6-pulse rectifier

5 PERFORMANCE OF THIRTY - PULSE AC-DC CONVERTER FED VCIMD:

To improve the power quality indices, a novel autotransformer for 30-pulse ac-dc converter fed VCIMD has been designed, modeled and simulated. This configuration results in higher dc link voltage. The autotransformer is modified for retrofit applications; Fig6 shows the dynamic performance of the proposed 30-pulse ac-dc converter at starting and load perturbation. The supply voltage waveform at full load along with its harmonic spectrum is shown in Fig.13 thus demonstrating the capability of the proposed converter in varying the autotransformer output voltage with simple change in tap position.

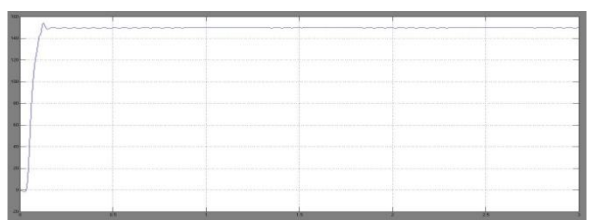

Fig11. W_r of VCIMD 30-Pulse Rectifier

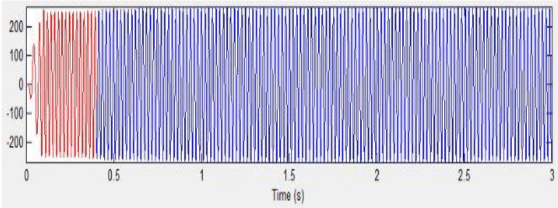

Fig12. Vabc response of VCIDM 30-pulse rectifier

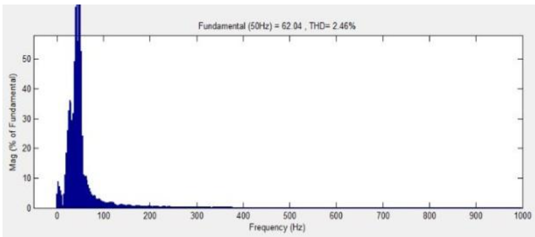

Fig13. THD of VCIDM 30-pulse rectifier

The load is varied on VCIMD shows that the proposed converter results in THD of supply current less than 5% in a wide operating range of load on the drive. Moreover, the power Factor is always above 0.99 in the wide operating range. The variation of THD of ac mains current and power factor with load is shown in Fig12 and 13 respectively, demonstrating the improvement in these power quality indices.

There is remarkable improvement in the power quality indices on dc bus in terms of low ripple factor (RF). The ripple factor of dc link voltage has improved reasonably, which means that for the same allowable dc link voltage ripple; the size of dc link capacitor can be reduced, leading to saving in capital cost.

6 CONCLUSION:

This paper has presented the design, analysis, modeling and simulation of an autotransformer based multi pulse ac-dc converter feeding vector controlled induction motor drive. It has been observed that the proposed ac-dc converter results in THD of supply current less than 5% in a wide variation of load with a nearly unity power factor operation. Moreover, it has also resulted in reduction in ac mains current reducing the losses in distribution system. The proposed multi pulse ac-dc converter may be used for retrofit applications, where presently a 6-pulse IGBT bridge rectifier is used.

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