Power Quality enhancement using Multi Pulse AC to DC Converter in Direct Torque Controlled Induction Motor Drive

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Abstract- *This paper presents a navel approach for developing method to improve power quality by enhancing number of pulses at the output of multi pulse AC to DC converter by using phase shift provided by zigzag transformer The approach is to start with normal 6 pulse AC to DC rectifier and increasing number of pulses at the output to 12, 24, 48 and then 96 pulses. The model multi pulse converter is developed in MATLAB Simulink and their effect in power quality enhancement is observed by connecting it to direct torque controlled induction motor drive. The resultof the simulation shows that there is considerable decrease in input current harmonics drawn from the supply mains resulting in power quality enhancement. In the above work it has been proved that the multi pulse converters can be a good solution for reduction of lower order harmonics in case of direct torque controlled induction motor drive.*

Keywords- DTC; Grid; THD; IMD;

I. INTRODUCTION

This paper aims at presenting a method to enhance power quality drawn from supply system by using certain connections in zigzag transformers and arranging there winding to provide certain phase shifts so that we can be able to increase the number of pulses produced at the output of Ac to Dc converter from six to twelve, twenty four, forty eight and then to finally ninety six. Converters, which are also known as rectifiers fed from three-phase ac supply in power rating above few kilowatts and have the problems of harmonics which results in poor power quality in the supply system that further causes poor power factor, ac voltage distortion and rippled in the dc outputs which causes heating and other problems inside and out of the converter. Because of these problems in ac–dc conversion, various methods are are proposed in the literature to mitigate these problems in ac–dc converters. Various filters passive, active, or hybrid are used for the said purpose, but this does not give any stable solution because of the losses and size of the component used as well as the difficulty in installation causes these methods to be unused for harmonic mitigation. [1][2]

To represent the applicability and usability in practical scenario out of various control techniques of speed control of induction motor drive direct torque control scheme is used. Direct torque control gives better dynamic performance because of the use of SVM for switching of inverter. In a DTC motor drive, the machine torque and flux linkage are controlled directly without a current control. Special features of DTC control that can be summarized as follows:

- No feedback current control
- No traditional PWM algorithm is applied
- No vector transformation as in vector control
- Feedback signal processing is somewhat similar to stator flux-oriented vector control
- Hysteresis-band control generates flux and torque ripple and switching frequency is not constant (like hysteresis-band current control)

Semiconductors played a key role in various engineering applications of electrical, electronics, instrumentation, telecommunication and control engineering. A common concern is keeping THD (Total Harmonic Distortion) below 10%. Total Harmonic Distortion gives us the information about the harmonic content in a signal w.r.t. fundamental component. Higher THD means higher distortion present on the input mains or lower power quality. The model is developed in matlab simulink and powergui blockset is used to analyse the extent of power quality enhancement as we go on increasing the number of pulses in the output of ac to dc converter from six to twelve, twenty four, forty eight and ninety six pulses. The model and resulting waveform in MATLAb simulink shows that the quality of the input current drawn enhanced considerably. The harmonics drawn from the supply mains for the currently available six pulsed AC to DC converter model was 187% which is improved to 11% by the use of 96 pulse converter. All other number of pulse converters also gives enhancement in power quality which is represented later. [3][4]

II. DIRECT TORQUE CONTROL PRINCIPAL

Induction motors are electro-mechanical devices used in most of the industrial applications for the conversion of power from electrical to mechanical form. These motors are used worldwide as the workhorse in industrial applications. Such motors are robust machines used not only for general purposes, but also in hazardous locations. In many variable speed drive applications, torque control is required, but precise, closed-loop control of speed is not necessary. The advantages of torque control in this type of application include greatly improved transient response, avoidance of nuisance over current trips, and the elimination of load-dependent controller parameters. To reach the best efficiency of induction motor drive (IMD), many new techniques of control has been developed in the last few years. Now-a-days, using modern high switching frequency power converters controlled by microcontrollers, the frequency, phase and magnitude of the input to an AC motor can be changed, hence the motor speed and torque can be controlled. Today, it is possible to deal with the axis control of machine drives with variable speed in low power applications mostly due to joint progress of the power 5 electronics and numerical electronics. The dynamic operation of the induction machine drive system has an important role on the overall performance of the system of which it is a part. In 1986 Takahashi and Noguchi proposed a new technique for the control of induction motor, quite different from field oriented control based on limit cycle control of both torque and flux using optimum PWM output voltage which gives quick torque response and is highly efficient. Here efficiency optimization in steady state operation has been considered and this proposed control circuit has the disadvantage of making some drift in extremely low frequency operation which can however be compensated easily and automatically to minimize the effect of variation of machine constant. Thomas G Habetler in 1992 proposed a direct torque control method of induction machine based on predictive, deadbeat control of the torque and flux. Here the change in torque and flux, over the switching period is calculated by estimating the synchronous speed and the voltage behind the transient reactance and the stator voltage is calculated which is required to cause the torque and flux to be equal to their respective reference values. Then Space vector PWM is used to define the inverter switching state. To be used in the transient or pulse dropping mode, an alternative approach to deadbeat control is also presented. Vector control of induction motor without encoder was proposed by James N Nash in 1997. Here an explanation of direct self-control and the field orientation concept, implemented in adaptive motor model is presented and also the reliance of the control method on fast processing techniques has been stressed. A new scheme of direct torque control of induction motor for electric vehicles was proposed in 2004 by M.vasudevan and Dr. R.Arumugan, this electric vehicle drive consists of rewound induction motors and a three-level IGBT inverter. Field Oriented Control, Direct Torque Control (DTC), and DTC using Space Vector Modulation are investigated here and also a comparison between these control schemes is presented. DTC using Space vector modulation is found to be the best scheme for this application. A detailed comparison between viable adaptive intelligent torque control strategies of induction motor was presented by M.Vasudevan, R.Arumugan and S.Paramasivam in 2005 emphasizing its advantages and disadvantages. The performance of neural network, fuzzy and genetic algorithm based torque controllers is evaluated as the various sensorless DTC techniques of IM. These adaptive intelligent techniques are applied to achieve high performance decoupled flux and torque control. In 2008 Sarat K Sahoo, Tulsiram Das, Vedam Subrahmanyam presented a simple approach to design and implementation of Direct Torque Control (DTC) of three phase squirrel cage induction motor using MATLAB/ Simulink and FPGA software. Two simple new techniques i.e. constant switching frequency and stator flux estimation are proposed to maintain this simple control structure of DTC while at the same time improving the performance of the DTC drives. A simple torque control is introduced to replace the three level hysteresis comparators to maintain a constant switching frequency. By using simple compensator based on steady state operation, the magnitude and phase error associated with stator flux estimation based on voltage model is compensated.

Among different proposals, direct torque control (DTC) is an emerging technique for controlling PWM inverter-fed induction motor (IM) drives. It allows the precise and quick control of the IM flux and torque without calling for complex control algorithms. Differently from FOC control, DTC does not tend to reproduce the electromechanical behaviour of a DC motor drive but is aimed at a complete exploitation of the flux and torque producing capabilities of an IM fed by a PWM inverter.

DTC was first introduced by Takahashi in 1984 in Japan and by Dopenbrock in 1985 in Germany and today this control scheme is considered as the world's most advanced AC Drives control technology. This is a simple control technique which does not require coordinate transformation, PI regulators, and Pulse width modulator and position encoders .This technique results in direct and independent control of motor torque and flux by selecting optimum inverter switching modes. The electromagnetic torque and stator flux are calculated from the primary motor inputs e.g. stator voltages and currents. The optimum voltage vector selection for the inverter is made so as to restrict the torque and flux errors within the hysteresis bands. The advantages of this control technique are quick torque response in transient operation and improvement in the steady state efficiency. [5]

In principle, the DTC method selects one of the inverter‘s six voltage vectors and two zero vectors as shown in Figure 2.1 in order to keep the stator flux and torque within a hysteresis band around the command or reference flux and torque magnitudes. In this figure, the switching states of the inverters are also pointed out with the corresponding voltage vectors based on the model of inverter as given in Figure 2.2 In this model, the ON state of upper limb switches are represented by1and the lower limb switches are represented by 0 and the same has been defined by Table2.1 [6]

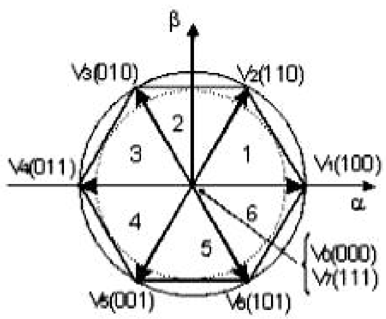

Figure 1. Direct torque control space vectors.

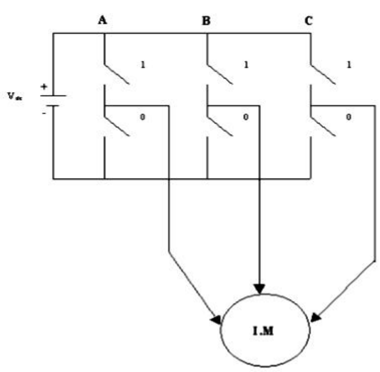

Figure 2. Model of an inverter

The core of DTC consists of hysteresis controllers of torque and flux, switching logic, and motor model as shown in Fig. 2.3 which shows the basic schematic diagram of classical direct torque control strategy of induction motor. The DTC requires the stator flux and torque estimations, which are performed by means of two different phase currents and state of the inverter. However, flux and torque estimations can also be performed using mechanical speed and two stator phase currents. The switching logic defines the suitable voltage vector based on torque and flux references. As described earlier, the flux controller is a two level comparator while torque controller is a three level comparator. Table 2.2 gives voltage vector selection table, as per which particular vector will be selected and and particular switch will be operated.

Table 1. voltage vector switching table

Voltage Vectors	Switching States		
	A	B	C
V_0	0	0	0
V_1	1	0	0
V_2	1	1	0
V_3	0	1	0
V_4	0	1	1
V_5	0	0	1
V_6	1	0	1
V_7	1	1	1

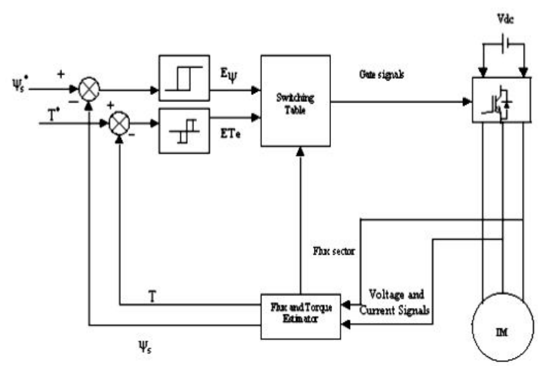

Figure 3. Block diagram of DTC of induction motor drive

The digitized output signals of the flux controller are defined as

EΨ = 1 for Ψs < Ψ*-HΨ
EΨ = -1 for Ψs < Ψ*+HΨ

and those of the torque controller as

ETe= 1 for Te<T*-HTe
ETe= 0 for Te=T*
ETe= -1 for Te<T*+HTe

Where HΨ is the flux tolerance band and HTe is the torque tolerance band of the hysteresis comparators. The digitized variables EΨ,ETe and the stator flux sector obtained from the angular position,

$\delta = \tan^{-1}(\Psi sq\Psi sd/)$the appropriate voltage vector is selected as shown in Table 2.1.

Table 2. Voltage vector selection table

		Sector					
E_ψ	E_{Te}	1	2	3	4	5	6
↑	↑	V_2	V_3	V_4	V_5	V_6	V_1
	0	V_0	V_0	V_0	V_0	V_0	V_0
	↓	V_6	V_1	V_2	V_3	V_4	V_5
↓	↑	V_3	V_4	V_5	V_6	V_1	V_2
	0	V_0	V_0	V_0	V_0	V_0	V_0
	↓	V_5	V_6	V_1	V_2	V_3	V_4

The simulation of direct torque control in MATLAB/ Simulink for controlling speed of an induction motor drive gives harmonic current drawn from the supply mains to be as high as 187% i.e the DTC control work efficiently as for as the control of speed and torque pulsation is concern but it also suffers large amount of harmonics drawn from the supply mains. In this work we are going to make a multipulse converter and make a table for improvement in harmonics drawn from the supply mains as we go on increasing pulses at the output of AC to DC converter. The table will be prepared when 6 pulse, 12 pulse, 24 pulse 48 pulse and 96 pulse converter feeding DTC based induction motor drive and harmonics drawn from ac mains will be shown.

III. HIGHER PULSE CONVERTERS

There are various harmonics mitigation techniques available as, passive techniques, active techniques, and hybrid harmonic reduction techniques using a combination of active and passive methods. out of all these available methods multi pulse converter is chosen for the study because of the numerous advantage of multi pulse converter that due to phase shifting process through transformers to convert from original three-phase ac supply to multiphase ac supply which further results in higher number of pulses in dc output for reducing in ripple and a high number of steps in ac mains current to make it close to sinusoidal with reduced and acceptable THD. The concept of zigzag, polygon, T connection, tapped winding, plurality of winding of isolated multilinking transformers and autotransformers is used to achieve the desired phase shift to cancel, eliminate, and to reduce harmonics in input ac mains feeding ac–dc converters. Three phases, 6-pulse static power converters, such as those found in VSD, generate low frequency current harmonics. Predominantly, these are odd lower order harmonics i.e. 5th, 7th, 11th, and 13th with other higher orders harmonics but with lower amplitudes. With an ordinary 6-pulse converter circuit, harmonics of the order $6k \pm 1$, where$k$ = 1, 2, 3, 4, and so forth, will be present in the supply current waveform drawn. In high-power applications, AC-DC converters based on the concept of multi pulse, namely, 12, 18, 24, 48 pulses, are used to reduce the harmonics in AC supply currents. They are referred to as a multi pulse converters. They use either a diode bridge or thyristor bridge and a special arrangement of phase shifting magnetic circuit zigzag transformers and inductors to produce the required supply current waveforms [19] high levels of voltage distortion at the supply‘s PCC because of the presence of an LC resonance circuit[7,8].

IV. MODELLING AND SIMULATION

A 12 pulse diode rectifier consists of two 6 pulse diode rectifiers in series configuration which gives twelve peaks of output voltage.

Circuit consists of a three phase a.c supply connected to zig zag transformers. Consecutive transformers increase their phase shift by a value of 30˚ [9]. It suppresses triplet harmonic currents i.e. third, ninth, fifteenth etc. [10] to supply 3 phase power as an autotransformer. It supplies phase shifted 3-phase power [11]. This voltage is fed to a 6 pulse diode rectifiers connected in series configuration with each other. By connecting two 12-pulse circuits with a 〖15〗^ophase shift produces a 24-pulse system. Fig 4.2 shows one such system in which the two twelve -pulse circuits are connected in parallel to produce the required twenty four pulse system. The eleventh and thirteenth harmonics now removed from the supply current waveform leaving the 23rd as the first to appear. Only harmonics of the order $24k\pm1$, where k=1, 2, 3, 4, and so forth, will be present in a 24-pulse system [12], [13]. The circuit consists of 3 phase ac supply connected in series with 4 Zig Zag transformers each of them in star-wye configuration. Each transformer increases its phase shift value by 15˚.

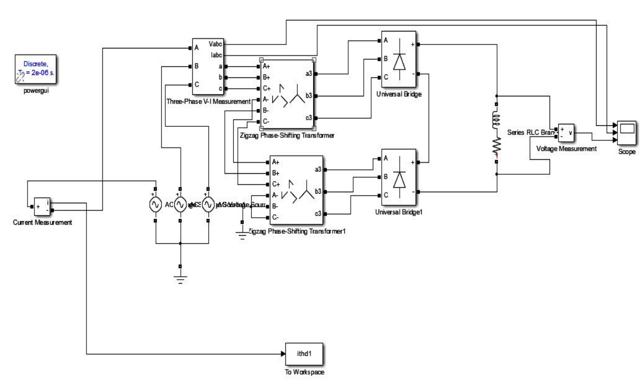

Figure 4. 12 pulse AC to DC converter

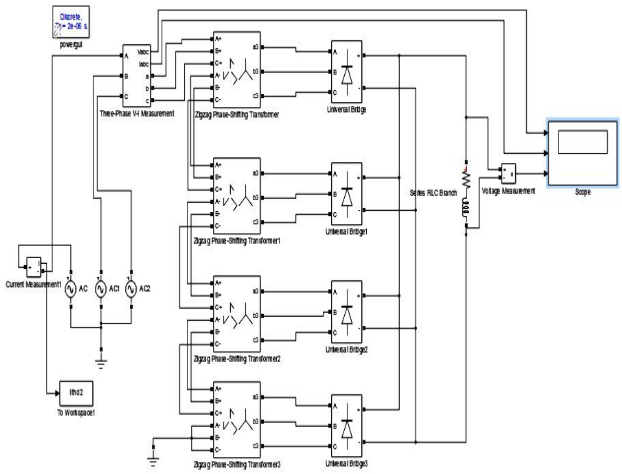

Figure 5. 24 pulse AC to DC converter

With the similar concept of zigzag transformers and phase difference obtained by them is used with parallel connection of bridge 24, 48 and 96 pulse AC to DC converters are designed and tested to DTC driven induction motor drive for reduction in harmonics drawn from the supply mains in MATLAB SIMULINK as shown by THD analysis in powergui fig 4.3, 4.4. 4.5 and 4.6.

THD ANALYSIS FOR DIRECT TORQUE CONTROL

As we have studied in literature review about thd of direct torque control demo was obtained as 187.81%.

As proposed for improvement in total harmonic distortion in the input side of the direct torque control following subsystem has been introduces in series to i/p 3 phase power supply in the following direct torque control demo available in MATLAB 2012b.

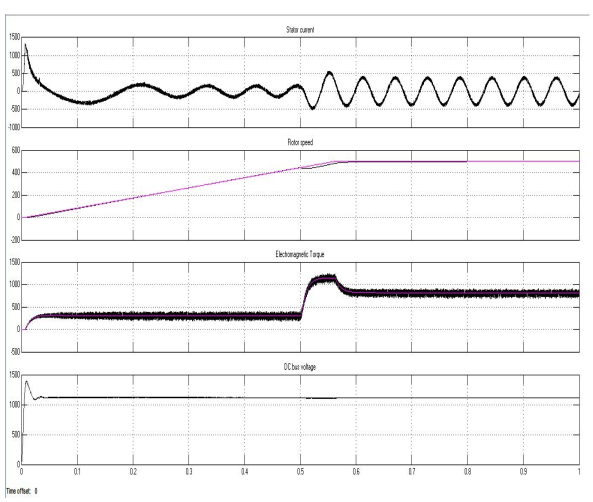

Figure 6. waveforms of DTC using 12 pulse converter

The detailed THD analysis has been calculated through matlab Simulink version 2012b and the following are the results obtained

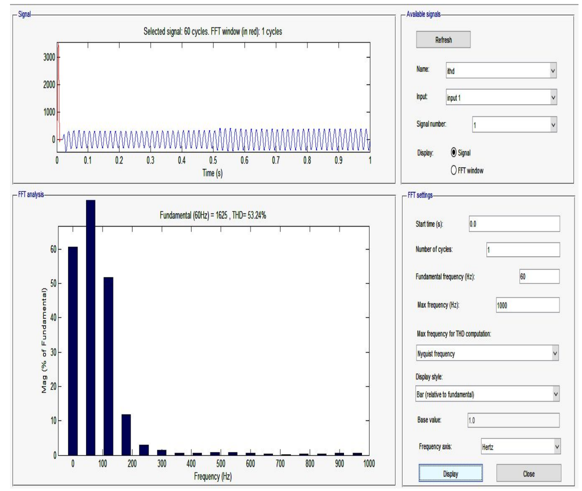

Figure 7. THD calculation of DTC using 12 pulse converter

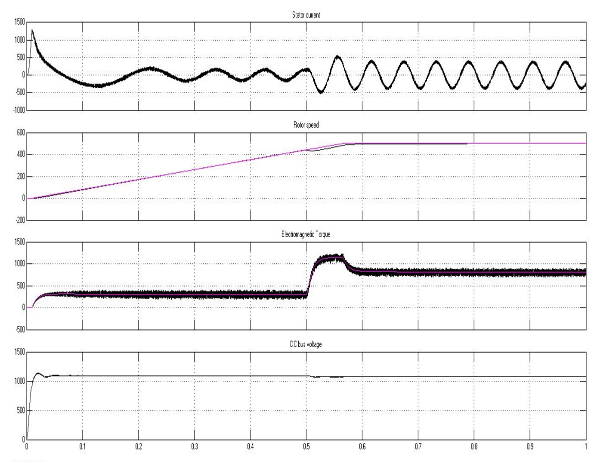

Figure 8. waveforms of DTC using 48 pulse converter

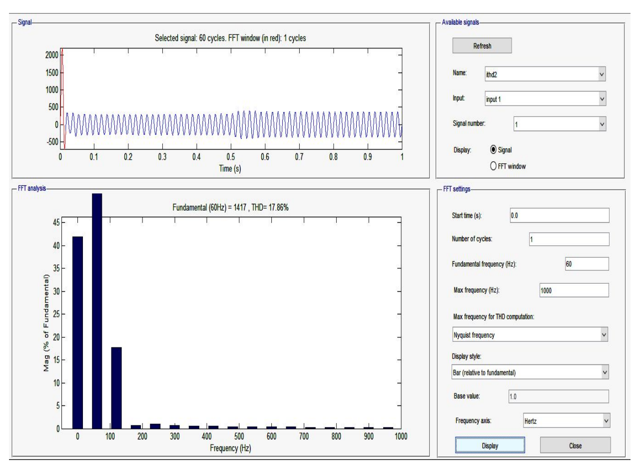

Figure 9. THD calculation of DTC using 48 pulse converters

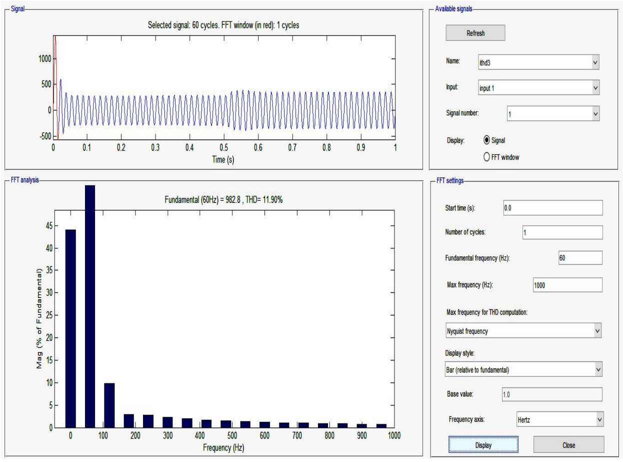

Figure 10. THD calculation of DTC using 96 pulse converters

V. CONCLUSION

Harmonic mitigation techniques can be further studied to reduce the input supply voltage harmonics. The presence of this harmonics may be reduced by using higher pulse converters at the input side as per the following table. As per the table input harmonics drawn from the supply system while driving direct torque controlled induction motor is considerably reduced from 187% to 11%.

Table 1.

METHOD USED	THD (in %)
DIRECT TORQUE CONTROL	187.71%
12 PULSE MPC FED DTC	53.24%
24 PULSE MPC FED DTC	41.26%
48 PULSE MPC FED DTC	17.86%
96 PULSE MPC FED DTC	11.9%

The main characteristics of the pulse converter depend on the phase shift given in the transformer block. One of the major objectives to increase the number of pulses in ac–dc converters is to improve the harmonic drawn from the supply mains which eventually results in increased losses. Poor power factor and lower efficiency. There are a number of options for power quality improvement, out of those methods multi pulse converter are quite effective in improving THD due to lower components count compared to other means of power quality improvement.

REFERENCES

[1] Bose, B. K., Modern Power Electronics and AC Drives, Prentice-Hall, N.J., 2002.

[2] P. C. Sen, “Electric motor drives and control-past, present and future,” IEEE Trans. Ind. Electron., vol. 37, no. 6, pp. 562–575, Dec. 1990.

[3] E. F. El-Saadany and M. M. A. Salama, “Reduction of the net harmonic current produced by single-phase non-linear loads due to attenuation and diversity effects,” International Journal of Electrical Power and EnergySystems,vol.20, no.4,pp. 259– 268,1998.

[4] T.Keyand J.S.Lai, “Analysis of harmonic mitigation methods for building wiring systems,” IEEE Transactions on Power Systems, vol.13, no.3,pp.890–897,1998

[5] M.H.Rashid and A.I.Maswood,“A novel method of harmonic assessment generated by three-phase AC-DC converters under unbalanced supply conditions,” IEEE Transactions on Industry Applications,vol.24,no.4,pp.590–597,1988.

[6] Giusuppe Buja,Domenico Cassedei And Givorrani Scara ―Direct Torque Control Of Induction Motor Drives‖.

[7] E.Owen, M.F. Mc Granghan, and J.R.Vivirito, Distribution system harmonics: controls for large power converters, IEEE Transactions on Power Apparatus and Systems, vol. 101, no. 3, pp.644–652,1982

[8] J. C. Das, Power System Analysis, Short-Circuit Load Flow and harmonics, Marcel Dekker, NewYork, NY, USA, 2002.

[9] Venkatesh P1, Dr. M. N. Dinesh2, Harmonic Analysis of 6-Pulse and 12-Pulse Converter Models

[10] Khera, P.P. (October 1990). "Application of zigzag transformers for reducing harmonics in the neutral conductor of low voltage distribution system" (PDF). IEEE Trans. on Industry Applications. doi:10.1109/IAS.1990.152320.

[11] Lawhead, Larry; Hamilton, Randy; Horak, John (May 2006). ―Three phase transformer winding configurations and differential relay compensation (PDF). 60th Annual Georgia Tech Protective Relay Conference. pp. 8–10. Retrieved 27 December 2015.

[12] F. Javier Chivite-Zabalza, Student Member, IEEE, Andrew J. Forsyth, Member, IEEE, and David R. Trainer -―A Simple, Passive 24-Pulse AC–DC Converter With

Inherent Load Balancing

[13] T.H.Chenand M.Y.Huang,― Network modelling of 24-pulse rectifier transformers for rigorous simulation of rail transit power systems, Electric Power Systems Research, vol. 50, no. 1, pp.23–33,1999.