Analysis, Design, and Comparison of VSI Fed Scalar & Vector Control 3-Φ Ac Drives

Garima Solanki
Electrical & Electronics Engineering Department,
JIT, Borawan, Khargone(M.P.)

Chandan Gurjar
Electrical & Electronics Engineering Department,
JIT, Borawan, Khargone(M.P.)

Mahesh Lokhande
Electrical & Electronics Engineering Department,
JIT, Borawan, Khargone(M.P.)

Abstract: The main objective of this paper is execution of scalar & vector control of three phase induction motor drives. The scalar control is very simple technique for controlling the speed of induction motor compared to the vector control which is more complex. Vector control is completely mathematical model on control of torque and speed of a three-phase space vector controlled induction motor drive. In this paper, an execution of speed control of an induction motor (IM) using space vector modulation control (SVPWM) and (SPWM) scalar control technique has been developed and simulated. The comparative study of SVPWM and conventional v/f control of IM is done this work. The VCIM drive involves decoupling of the stator current component which produces torque and flux of induction motor. It is seen that it provides smooth speed control and compared to v/f control. Finally comprise the result of scalar and vector control technique. The complete proposed system is simulated in MATLAB/Simulink.

Keywords: Induction Motor, SVPWM, VSI, v/f Scalar & Vector Control.

I. INTRODUCTION

Motion control is required in large number of industrial and domestic applications like transportation systems, rolling mills, paper machines, textile mills, fans, pumps, robots, washing machines etc. System employed for motion control are called drives and may employ any of the prime movers such as, diesel or petrol engines, gas or steam turbines, steam engines, hydraulic motors and electric motors for supplying mechanical energy for motion control.
These have also proved to be more reliable than DC motors. Apart from these advantages, they have some unfavorable features like their time varying and non-linear dynamics. Speed control is one of the various application imposed constraints for the choice of a motor. Variable speed application can be dominated by dc drives. The speed control of DC motors can be carried out in a simple way, since the torque and flux are decoupled but they have the disadvantage of higher rotor inertia and maintenance problems associated with commentators and brushes.
In this paper comparative cram between the conventional scalar control and vector control is done. For the scalar control closed loop v/f control and space vector control (SVC) are selected.

II. INDUCTION MOTOR CONTROL TECHNIQUES

The speed control of an induction motor requires more elaborate techniques than speed control of DC machines. First, we will analyze the basic relationship for the speed-torque characteristics of an induction motor:

$$T_e = 3\left(\frac{P}{2}\right)\frac{R_r}{S\omega_e}\frac{V_s^2}{\left(R_s + R_r / S\right)^2 + \omega_e^2\left(L_{ls} + L_{lr}\right)^2} \quad (1)$$

By examining this equation, one can conclude that the speed [or slip s] can be controlled if at least one of the following parameters is altered: Armature or rotor resistance, Armature or rotor inductance, Magnitude of terminal voltage, Frequency of terminal voltage
Each of the techniques by itself is not sufficient. However when more than one are combined, the control of the induction motor becomes more effective. Although it is not evident by examining equation 1, there are other useful and effective techniques for speed control. Among them are:

1. Rotor voltage injection

2. Slip energy recovery

3. Scalar control (Voltage/frequency)

4. Vector Control

In this paper explain scalar and vector control techniques based three phase IM drive.

A) Scalar control

Scalar control as the name indicates, is due to magnitude variation of the control variables only and disregards the coupling effects in the machine. A variable-frequency drive (VFD**)** is a system for controlling the rotational speed of an alternating current (AC) electric motor by controlling the frequency of the electrical power supplied to the motor. A variable frequency drive is a specific type of adjustable-speed drive. Variable-frequency drives are also known as adjustable-frequency drives (AFD), variable-speed drives (VSD), AC drives, micro drives or inverter drives. Since the voltage is varied along with frequency, these are sometimes also called VVVF (variable voltage variable frequency) drives. The most common type of packaged V/F drive is the constant-voltage type, using pulse width modulation to control both the frequency and effective voltage applied to the motor load.

B) Space Vector Control

Space vector modulation (SVM) for three-leg VSI is based on the representation of the three phase quantities as vectors in a two-dimensional (α-β) plane. Fig. 1(a) we see that the line voltages *Vab*, *Vbc*, and *Vca* are given by

$$Vab = Vg$$
$$Vbc = 0$$
$$Vca = -Vg \qquad (2)$$

This can be represented in the (α-β), plane as shown in Fig. 1(b), where voltages Vab, Vbc, and Vca are three line voltage vectors displaced 120˚ in space.

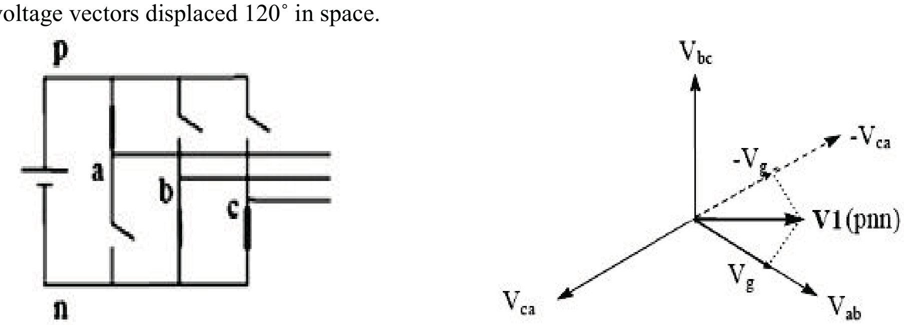


Fig.1a, Topology 1-V1 (pnn) of a VSI b) α-β, plan

Proceeding on similar lines the six non-zero voltage vectors (V1 - V6) can be shown to assume the positions shown in Fig.2.

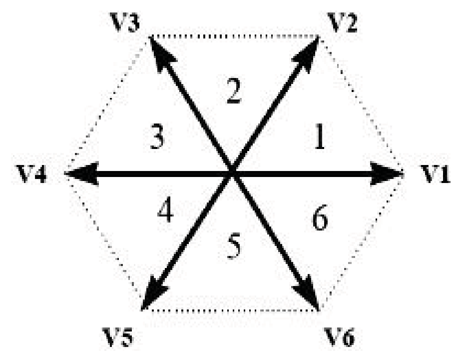


Fig. 2, Non-zero voltage vectors in the plane

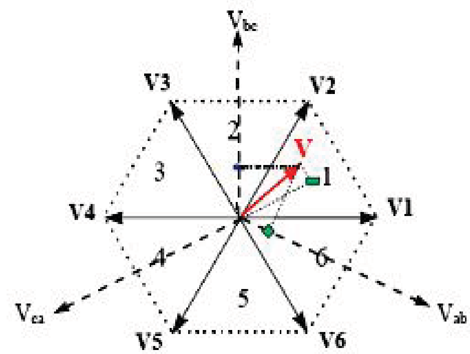


Fig. 3, Output voltage vector in the plane.

The desired three phase voltages at the output of the inverter could be represented by an equivalent vector V rotating in the counter clock wise direction as shown in Fig. 3. The magnitude of this vector is related to the magnitude of the output voltage and the time this vector takes to complete one revolution is the same as the fundamental time period of the output voltage.

III. MATLAB/SIMULINK MODEL AND RESULTS

The work demonstrates the speed control of Vector Controlled Induction motor and the v / f (scalar) control and the proposed design is tested by MATLAB/simulink. Computer modelling and simulation is widely used to study the behavior of various complex systems. With proper simulation techniques, a significant amount of experimental cost could be saved in the prototype development.

A) v/f SPWM based close loop VSI fed IM drive model

Simulation is done on a three phase induction motor fed by a SPWM inverter developed in Matlab/Simulink environment. The figure 4 shows the Simulink diagram of the developed model. The three phase induction motor drive is fed by a three phase PWM VSI inverter. The modulation technique used for the generation of three phase balanced output from the inverter is the sinusoidal pulse width modulation technique.

The tested motor has the following characteristics: rated power 3 HP, voltage 420 V, current 11 A, speed 1480 r/min, torque 11.9 Nm, and the moment of inertia 0.038 kgm^2, Kp=30 and Ki=120. In this model speed taken in 1300 rpm to 1500 rpm step.

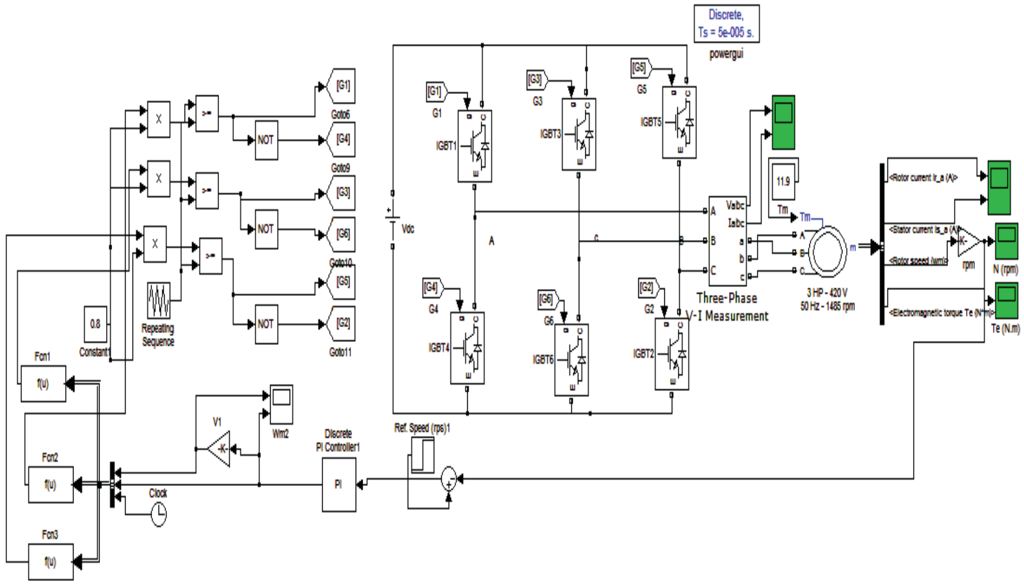


Fig. 4, SPWM based close loop VSI fed IM drive model

a) Simulation Results

Results are obtained by simulating the circuit. Here we analyze the inverter and motor performance for under modulation range i.e. for the value of m < 1. Amplitude Modulation index is defined as the ratio of control signal amplitude and carrier signal amplitude i.e.

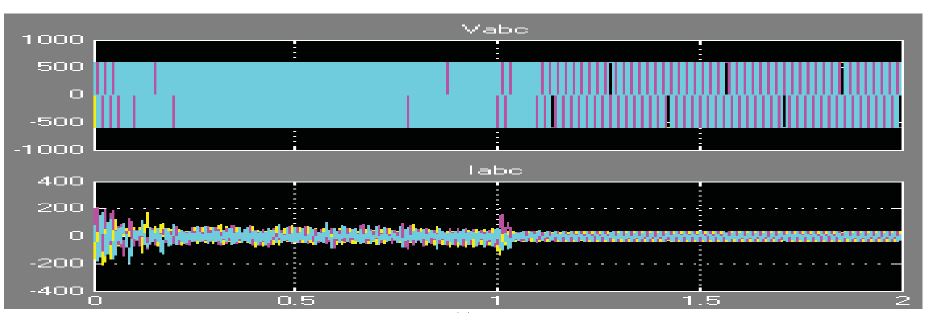
$$m_a = A/Ac \qquad (3)$$

The number of pulses per half cycle depends upon the value of the frequency modulation index mf defined by the relation

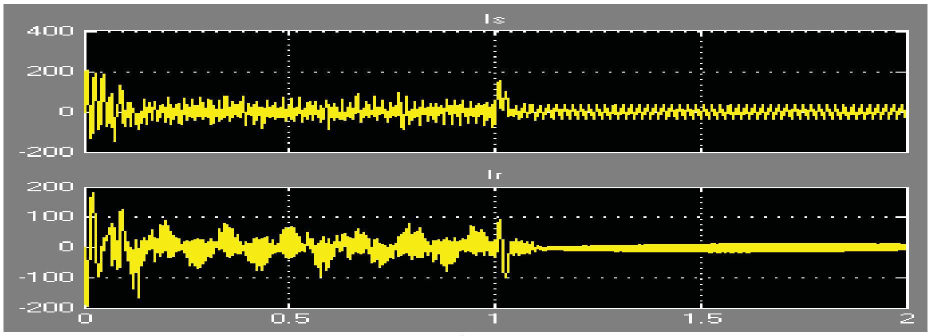
$$m_f = fc\ /(f), \qquad (4)$$

Where, fc= frequency of the carrier signal
And f= frequency of the modulating signal

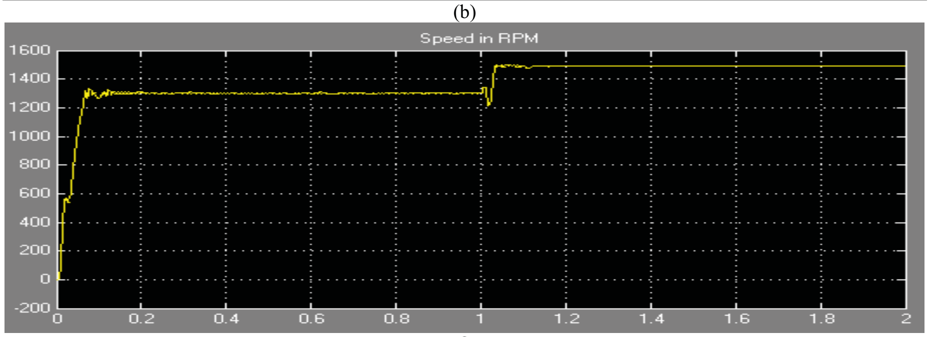
Figure 5a shows the waveform of inverter line voltage Vabc and current Iabc. Fig.5b, shows IM stator current and rotor current wave form. Fig.5c, shows rotor speed in rpm. Fig.5d, shows electromagnetic torque in NM.



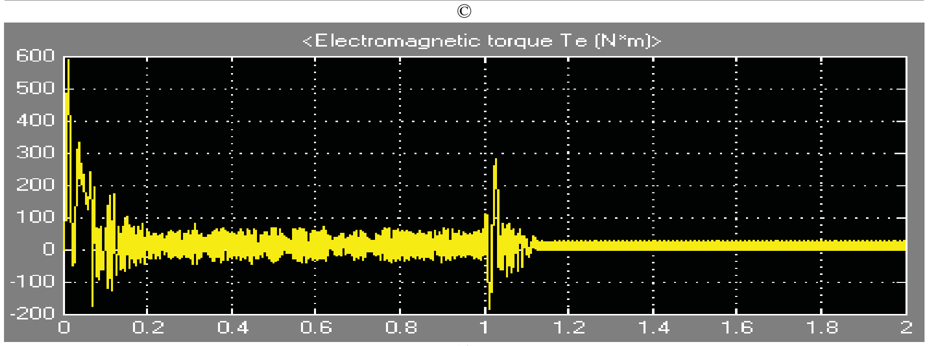
(a)



(b)



©



(d)

Fig.5.a) Line voltage and current (Vabc & Iabc) b) Stator rotor & Current waveform c) rotor speed d) Electromagnetic torque waveform (ma= 0.8, mf=15)

B) SVPWM Based VSI Fed Close Loop IM Drive Model

The closed loop vector controller takes only the speed from the machine while all other parameters are estimated. The implementation of the closed loop space vector control is as shown in Figure 6. The control objective is to regulate the actual quantity with the reference command. The rotor speed and reference speed compare and which can be regulated to synthesize the modulation signals for the inverter. Since the speed is dc quantity to regulate these quantity normal PI, PD or PID controller can be used, but usually a PI controller achieves the best performance. In this model reference speed is given in steps to 1300 rpm to 1500 rpm. This speed is maintained the drive model. The PI controller used integral gain Ki =120 and propagation gain Kp=0.6.

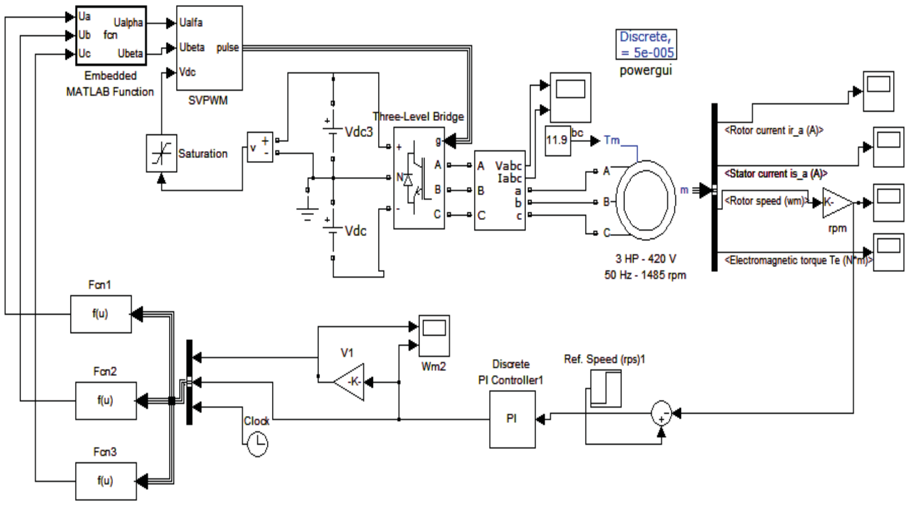
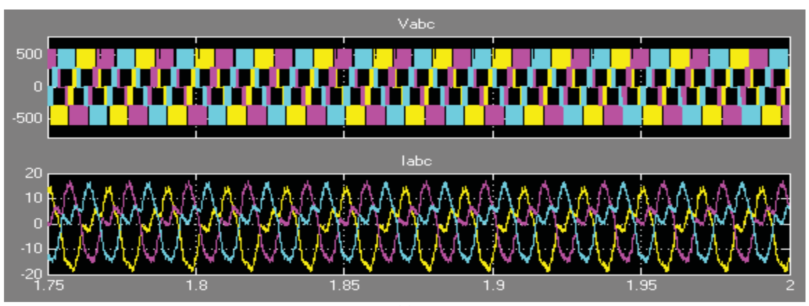


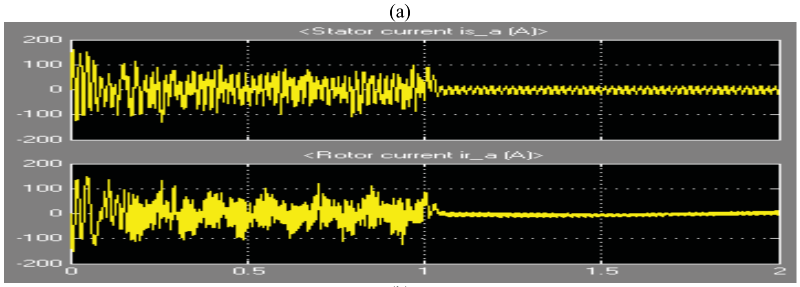
Fig.6, SVPWM based close loop VSI fed IM drive model

a) Simulation Results

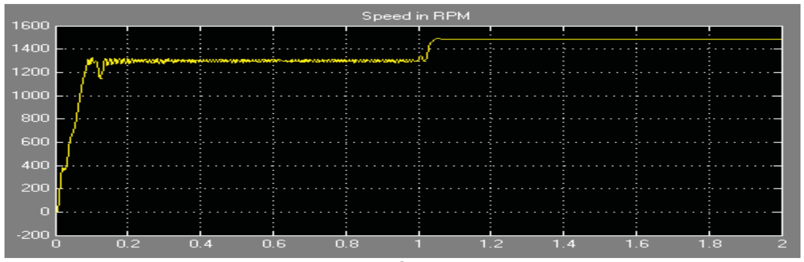
The performance results are shown in reference speed steps 1300 rpm to 1500 rpm at t=1 sec with rated torque 11.9 N-m. Fig. 7a, shows inverter terminal voltage (Vabc) and current (Iabc). Fig. 7b indicates stator current and rotor current in reference speed steps. Similarly Fig. 7c&d shows that the rotor speed & torque indicates slight increment of speed step 1300rpm to 1500 rpm at 1 sec time.



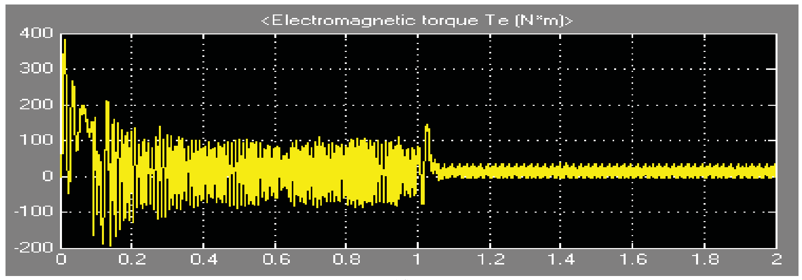
(a)



(b)



©



(d)

Fig. 7 a) Inverter line voltage (Vabc & Iabc) b) Stator current & Rotor current c) speed d) torque

IV. CONCLUSION

This paper presents a comparative performance study of v/f IM drive with scalar and SVPWM based for speed control.

Scalar control is cheap and well implementable method because of these advantages and simplicity, many applications in the industry operate with this control technique. On the other hand it is not satisfactory for the control of drives with fast dynamic behavior, since it gives slow response to transients. It is a low performance control, but it is a stable control technique. The SVPWM method operates with fast responses. So it satisfies the requirements of dynamic drives method to handle transients. The only disadvantage is its complexity.

Both the SVPWM and V/f control of induction motor uses PI controller, which is an excellent controller for linear systems. It reduces the steady state error and provides a smooth tracking with the command signal. But if the system is inclined by fears, which usually composed of impulsive variations in the machine parameters external load disturbances and modeled and non-linear dynamics, it is very hard or impossible to design the control structure based conventional PI controllers. To provide better control in the presence of such uncertainties. PI controller can be replaced by other robust control techniques, such as optimal control, Variable structure control, Adaptive, Fuzzy and neural control.

REFERENCES

[1] M.H. Rashid, Power Electronics Circuits, Drives and Application 3rd Edition 2007 Pearson Prentice Hall.
[2] Bimal K. Bose, Modern Power Electronics and AC Drives, 3rd impression, India: 2007. Pearson Education, Inc.
[3] S.K. Pillai, A First Course on Electrical Drives 2nd Edition 2004, New Age International Publication.
[4] Gopal K. Dubey, Fundamentals of Electrical Drives, 2nd edition, 2007, Narosa publishing house, New Delhi, India.
[5] Bimal K. Bose, "High Performance Control and Estimation in AC Drives", IEEE IECON Conf. Rec., pp. 377-385, 1997.
[6] Bhim Singh *an*d Sanjay Gairola "A 40-Pulse AC–DC Converter Fed Vector- Controlled Induction Motor Drive", IEEE TRANSACTIONS ON ENERGY CONVERSION, VOL. 23, NO. 2, JUNE 2008.
[7] P.C. Krause, O.Wasynezuk, S.D. Sudhoff, "Analysis of Electric Machinery and Drive System", IEEE press, Newyork.
[8] C´esar Cataldo Scharlau, Lu´ıs Fernando Alves Pereira "Performance of a Five-Phase Induction Machine With Optimized Air Gap Field Under Open Loop *V/f* Control", IEEE TRANSACTIONS ON ENERGY CONVERSION, VOL. 23, NO. 4, DECEMBER 2008, p.g.-1046-1056.
[9] Xiaorong Xie, Qiang Song, Gangui Yan, Wenhua Liu"*MATLAB-based Simulation of Three-level PWM Inverter-fed Motor Speed Control System*" IEEE 0- 7803-7768-0/03.
[10] J. Holtz, "Pulse width modulation- a survey", IEEE Trans. On Industrial Electronics, Vol. 39, No. 5, pp. 410-420, Oct.1992.
[11] M. Nasir Uddin and Hao Wen," Development of a Self-Tuned Neuro-Fuzzy Controller for Induction Motor Drives", IEEE TRANSACTIONS ON INDUSTRY APPLICATIONS, VOL. 43, NO. 4, JULY/AUGUST 2007, p.g.-1108-1116.

[12] Joachim Schraud, Ewald F. Fuchs, “Experimental Verification of Critical-Speed Increase of Single-Phase Induction Machines via Winding Reconfiguration With Solid-State Switches”, IEEE TRANSACTIONS ON ENERGY CONVERSION, VOL. 23, NO. 2, JUNE 2008, p.g.-460-465.
[13] M. Depenbrock, “Pulse width control of a three-phase inverter with non sinusoidal phase voltage of a three-phase PWM inverter”, Proc. IEEE Int. semiconductor Power Conversion Conf., Orlando, Florida, USA, pp. 399-403, 1977.
[14] Gonzalo Abad*, Member, IEEE*, Miguel A´ ngel Rodr´ıguez, “Two-Level VSC-Based Predictive Direct Power Control of the Doubly Fed Induction Machine with Reduced Power Ripple at Low Constant Switching Frequency”, IEEE TRANSACTIONS ON ENERGY CONVERSION, VOL. 23, NO. 2, JUNE 2008, p.g.-570-580.
[15] Radu Bojoi and Alberto Tenconi, “Vector Control of Dual-Three-Phase Induction-Motor Drives Using Two Current Sensors”, IEEE TRANSACTIONS ON INDUSTRY APPLICATIONS, VOL. 42, NO. 5, SEPTEMBER/OCTOBER 2006, p.g.-1284-1292.