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VECTOR CONTROL OF INDUCTION MOTOR USING XILINX SYSTEM GENERATOR

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Abstract

This paper0has realized the vector0control of an induction0motor using Xilinx0System0Generator toolbox to investigate0the possibility of embedding0vector control into field0programmable0gate array (FPGA). The vector control0of an0induction motor is simulated in MATLAB/SIMULINK environment with System Generator blocksets. This tool allows generating automatically the VHDL file which can be implemented0directly in FGPA hardware. This solves all the difficulties0encountered in previous researchers which require a great knowledge of the programming language VHDL. The0aim is to get the desired0speed at output and fast0torque response.

Keywords: *- Xilinx System Generator, FPGA, Field-Oriented Control, Induction Motor*

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1. INTRODUCTION

AC Induction motor has simple construction, cheap, good robustness and maintained easily. Due to this AC induction motor is commonly used in the modern0ac drive system. But, AC induction motor cannot realize the high performance speed governing [1]. So by using the development0of power electronic0technology and AC0induction motor control theory, can achieve a high speed governing.

Here in this study, a vector controller is modeled by a Xilinx System0Generator in Matlab/Simulink environment The advantage of using System0Generator over0traditional methods are first, the implemented0algorithm is assured to function0exactly as in the0simulation and second, there is no need to create two0different models that is one for the0simulation and one for the0implementation [3].

Xuejie Wang. et al. [1] proposed, based0on the analysis of0asynchronous motor dynamic mathematical0model and the0principle of vector0control, the motor control0system was constructed though vector0control method. C.P. Ooi. et al. [4] developed a0flexible, high0computation speed and cost0effective field programmable0gate array (FPGA)-based speed0controller for an0induction motor with field-oriented0control was presented. Ozkan AKIN. et al. [5] investigated the0feasibility of0embedding the0field oriented control (FOC) 0of an induction0machine into field programmable0gate arrays (FPGA). Jean-Gabriel. et al. [6] presented to show the0usefulness of using0XSG to prototype0complex control0algorithms such as the vector0control, a well known control0strategy for AC0drives, particularly0those based on induction0motors.

From the research, it is observed that, many papers are published on vector0control of induction0motor using Matlab/Simulink. To implement this control algorithm in hardware we need very-high-speed hardware description language (VHDL) 0codes to generate the control0signals for the related0controller. Normally, Matlab/Simulink package doesn't provide0an interface for the VHDL0needed for the0controller and also Matlab HDL codes alone is insufficient for synthesizing, simulating and verifying the HDL codes. However, the Xilinx0System0Generator (XSG) achieves these goals and also provides an interface for the VHDL0needed for the controller to be0embedded in the FPGA chip.

The Objectives of the proposed work are:

- To exhibit the usefulness of using XSG to prototype complex control0algorithms in the vector control of0Induction motor, a well known control0strategy for0AC drives.
- The vector control0considered as a special field of0digital signal processing0exhibiting a complex modularity is designed0using0XSG.
- To simulate and implement a digital controller for three phase induction motor drives.

Section 2 presents the implementation of Vector control in XSG. Sections 3 discuss the simulation results while Section 4 sketches few conclusions.

2. PRINCIPLE OF VECTOR CONTROL

The Field0Oriented0Control (FOC) is also called vector control which is a control method used in variable0frequency drive. In this method three-phase stator currents are identified as two0orthogonal quantities that are visualized as a vector in an AC motor. One component defines the magnetic0flux of the motor, the other as torque. Using vector control principle, AC motors can be0controlled as a separately0excited DC0motor. By using vector-control method high dynamic0performance can be achieved. The scalar0control strategy used in IM is having limitations in terms of performance i.e. it generates oscillations on the produced torque. Hence to achieve better dynamic performance, a more superior control scheme is used for induction motor [2].

Fig-1 explains the fundamentals of0vector control. In this method, the machine model is represented in synchronously0rotating reference frame. For simplicity, inverter is omitted0from the figure. Assuming0that the vector0control has unit current gain; the machine0model is as0shown in the Fig-1. Unit current gain is achieved by generating currents i_a, i_b and i_c from the controller which are dictated by command0currents i_a^*, i_b^* and i_c^*. Using three-phase to two-phase transformation the terminal phase currents of machine i_a, i_b and i_c are converted to i_{ds}^s and i_{qs}^s. Before applying i_{ds}^s and i_{qs}^s it to $d^e - q^e$ machine model, they are converted into stationary rotating reference frame using unit vector components $\cos\theta_e$ and $\sin\theta_e$. In this technique the controller performs two inverse transformations to achieve control currents i_{ds}^* and i_{qs}^* corresponding i_{ds} and i_{qs} respectively. The unit vector provides direction to i_{ds} with Ψ_r and i_{qs} perpendicular to it.

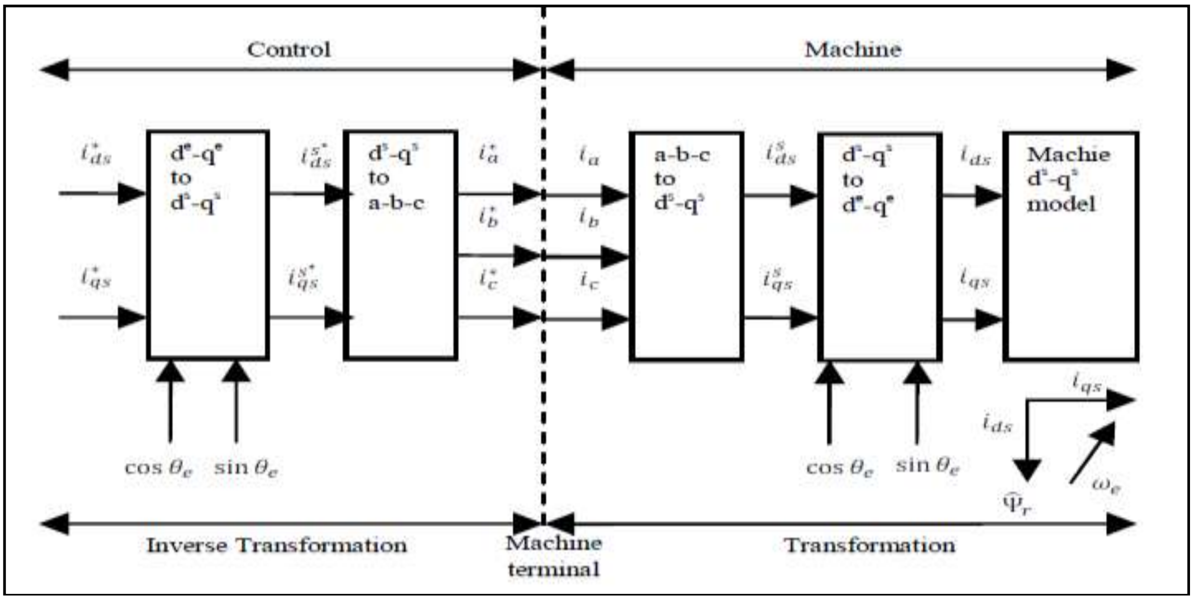

Fig 1: Vector-control implementation principle with $d^e - q^e$ reference model.

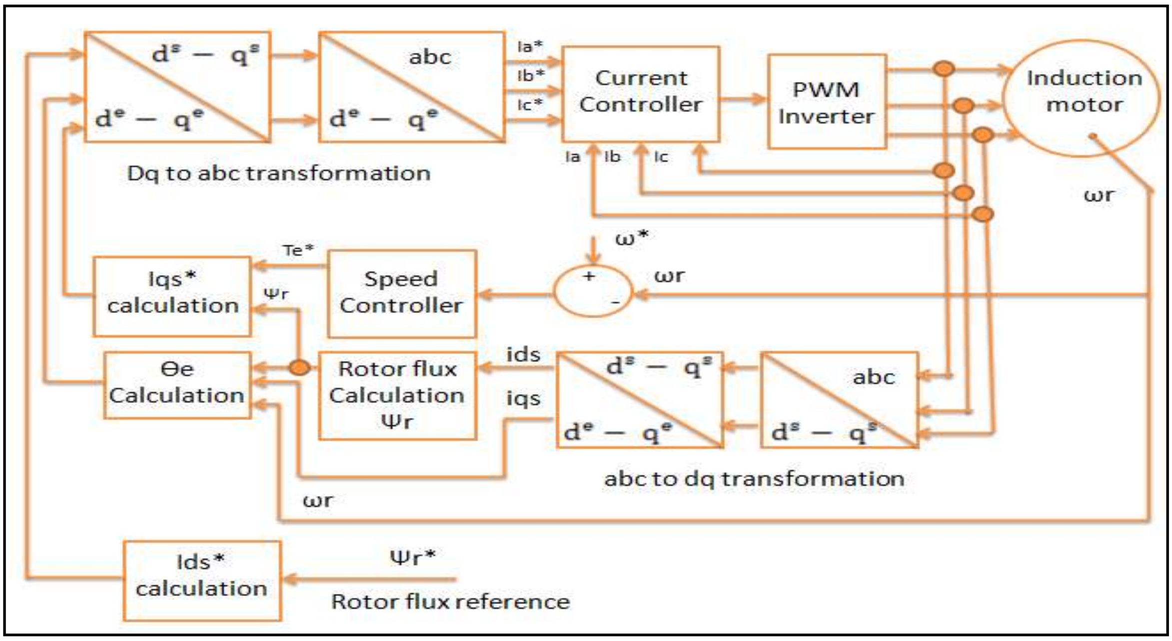

Fig 2: Closed loop vector control of IM drives system.

In Fig-2, the 3-phase induction motor is fed from a PWM inverter. The 3-phase currents i_a, i_b and i_c are sensed and converted into equivalent two-phase quantities i_d^s-i_q^s using Clark's transformation. The transformations obtained are with respect*0*to stationary reference frame. Further i_d^s and i_q^s are converted into i_d^e and i_q^e with respect to the synchronously*0*rotating reference frame using Park's transformation. The measured values of id_s and iq_s are used for the calculation of rotor flux Ψr and rotor angle Θe. A current reference iq_s* is calculated using reference torque Te* and the rotor flux Ψr. The torque reference Te* required for the calculation of iqs* is current reference ids* is*0*calculated from the reference rotor flux Ψr*. The generated reference currents ids* and iqs* are converted into 3-phase quantities ia*, ib* and ic* using Inverse Park's transformation and Inverse Clark's transformation. These currents are further processed in the current regulator producing required signals for switching of PWM inverter.

From the Fig-2, the 3-phase induction motor is fed from a PWM inverter. The 3-phase currents ia, ib & ic are sensed and converted into I_α and I_β components by Clarke transformation with equation (1) and (4).

$$I_\alpha = I_a \tag{3}$$

$$I_\beta = (1/\sqrt{3})\, Ia + (2\sqrt{3})\, Ib \tag{4}$$

These are then converted to synchronously rotating frame, Id and Iq by the unit vectors, $\sin\theta$ and $\cos\theta$ with Park transformation, using equation (5) and (6).

$$I_d = I\alpha \cos\theta + I\beta \sin\theta \tag{5}$$

$$Iq = -I\alpha \sin\theta + I\beta \cos\theta \tag{6}$$

The unit vectors, the computation of $\sin\theta$ and $\cos\theta$ is very crucial in order to obtain correct0alignment of I_d with the flux vector, Ψ_r and I_q perpendicular to it. The unit0vectors are generated by the current0model based on I_α, I_β and ω_r by implementing equation (7) to (11).

$$\sin\theta = \frac{\Psi_{qr}}{\Psi_r} \tag{7}$$

$$\cos\theta = \frac{\Psi_{dr}}{\Psi_r} \tag{8}$$

Where, $\Psi_r = \sqrt{{\Psi_{qr}}^2 + {\Psi_{dr}}^2}$ (9)

Where Θ is the rotor flux position, L_m is magnetizing inductance; T_r is the rotor circuit time constant and ω_r is the feedback speed.

The command value of Isd* reference is obtained from the Id reference module with equation (10).

$$Ids* = \frac{\text{Phir}*}{\text{Lm}} \tag{10}$$

The Isq reference is obtained from the PI velocity controller module by implementing equation (11).

$$Iqs* = \left(\frac{2}{3}\right)*\left(\frac{P}{4}\right)*\left(\frac{Lr}{Lm}\right)*\left(\frac{Te*}{Phir}\right) \tag{11}$$

Where, Phir = $\frac{Lm*Id}{(1+Tr)}$ (12)

Lr = rotor inductance
Rr = rotor resistance
P = no of pole inside the inductance motor

The torque reference, Te* is obtained by comparing the desired speed with the motor's feedback speed via PI controller. The generated reference currents ids* and iqs* are converted into 3-phase quantities ia*, ib* and ic* using Inverse Park's transformation and Inverse Clark's transformation. These currents are further processed in the current regulator producing required signals for switching of PWM inverter.

3. IMPLEMENTATION OF VECTOR CONTROL IN XSG

Matlab0Simulink software0package provides a0powerful high level modeling0environment for people who are involved in system0modeling and0simulations. XSG Tool developed for Matlab/Simulink package is widely used for algorithm0development and verification purposes in0Digital Signal0Processors (DSP) and Field0Programmable Gate Arrays0 (FPGAs). System0Generator Tool allows an abstraction0level algorithm development0while keeping the traditional0Simulink blocksets, but at the same0time automatically0translating designs into hardware implementations0that are faithful, synthesizable, and efficient [5].

3.1 Speed Controller

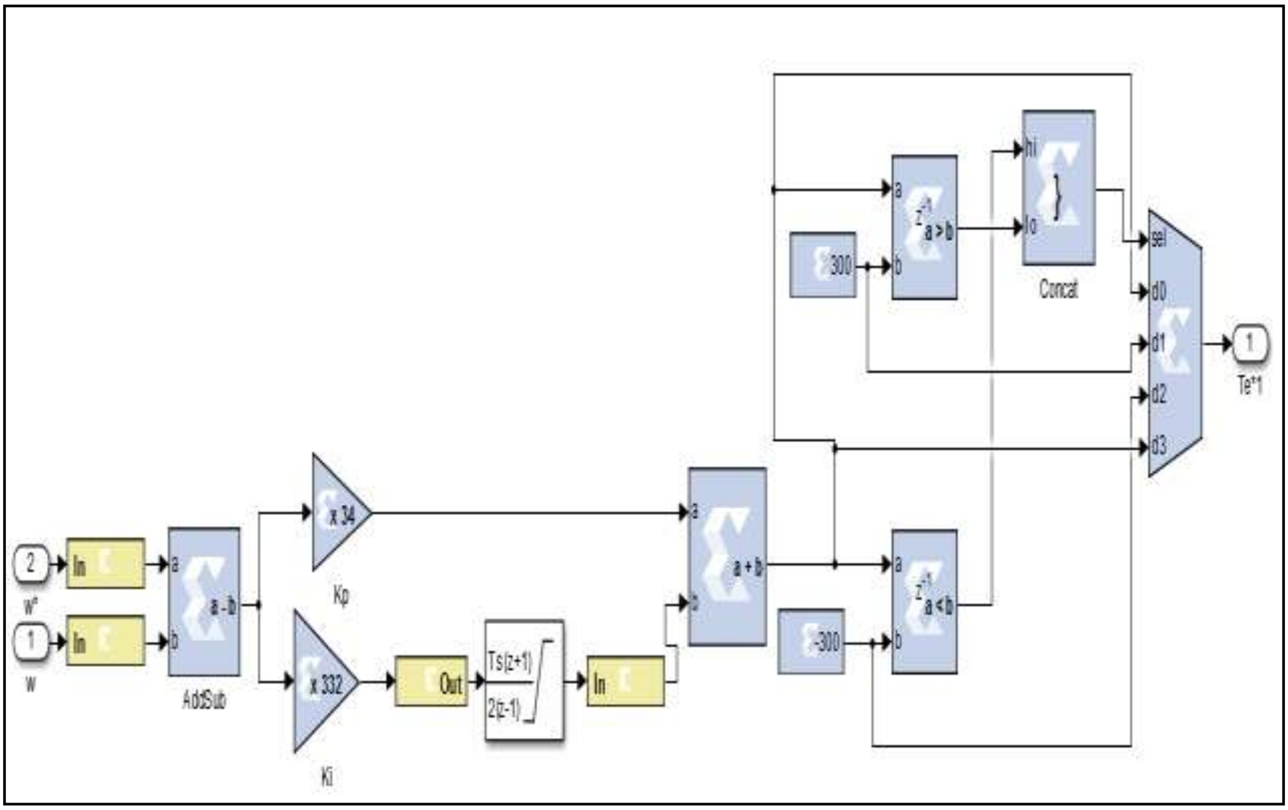

Fig 3: Speed Controller Block.

The output of the speed error block calculates the difference between the reference speed and the measured speed. The speed error block is applied as input to both the proportional block and integral block. After the error data is processed in each block, the outputs of each block are added to form the PI controller. This output is applied as input to the torque limiter block. When the output of the PI controller exceeds the limit values of the torque, the limiter block limits it and generates the appropriate torque reference. The torque reference limiter block provides the generation of torque component current command for the controlled induction motor.

3.2 Hysteresis Current Controller

Current Controller can realize using hysteresis tracking control of the induction motor three-phase current. The structure of which is shown in Fig. 3. The input is three-phase reference and measured current value and the output is six PWM control signal. While No 1, No 3, No 5 control signal are complementary to No 2, No 4, and No 6 control signal. This module can be constructed by the relay and logical operator module.

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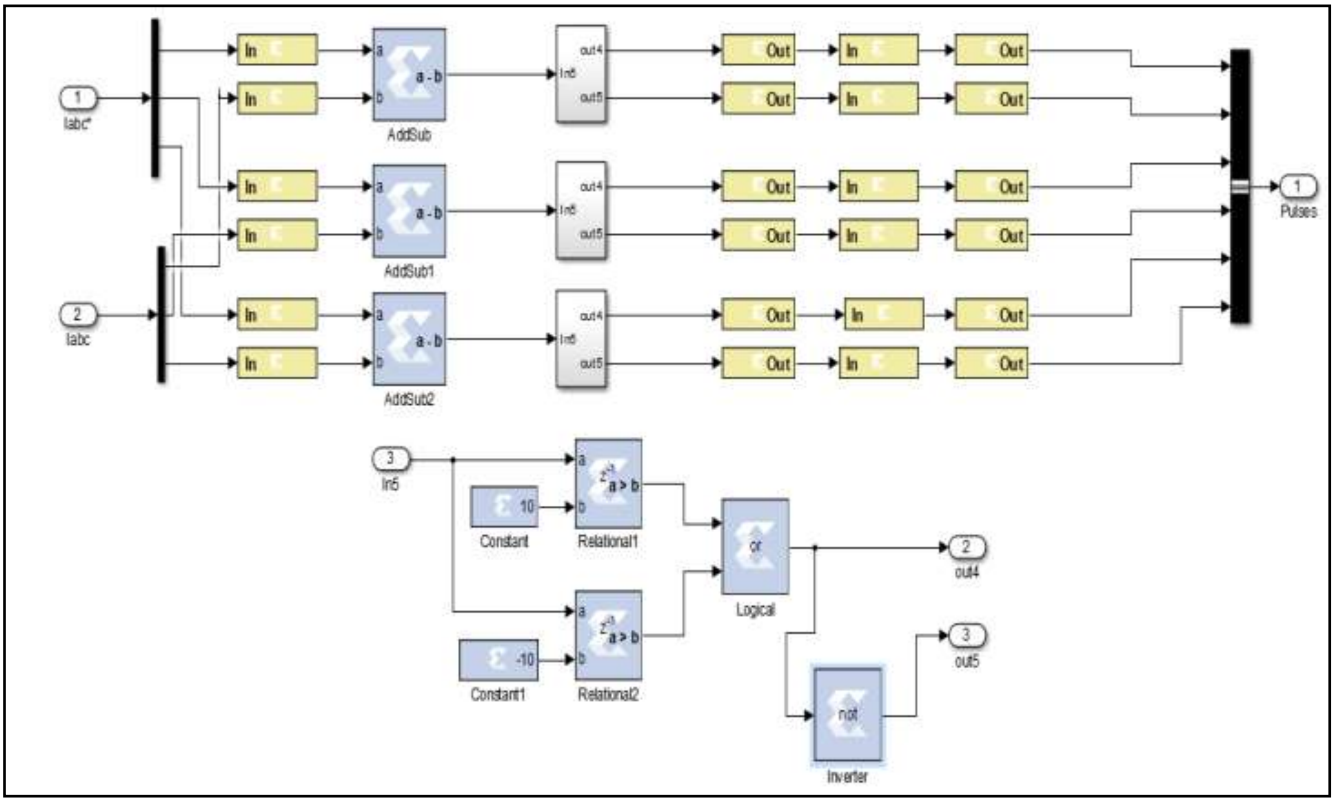

Fig 4: Current Controller Block.

4. RESULTS AND DISCUSSIONS

In order to validate the vector control0algorithm in an XSG, an example of one particular test is depicted. Simulation0of the vector control of induction0motor drive system using0Matlab/Simulink as shown in Fig-5.

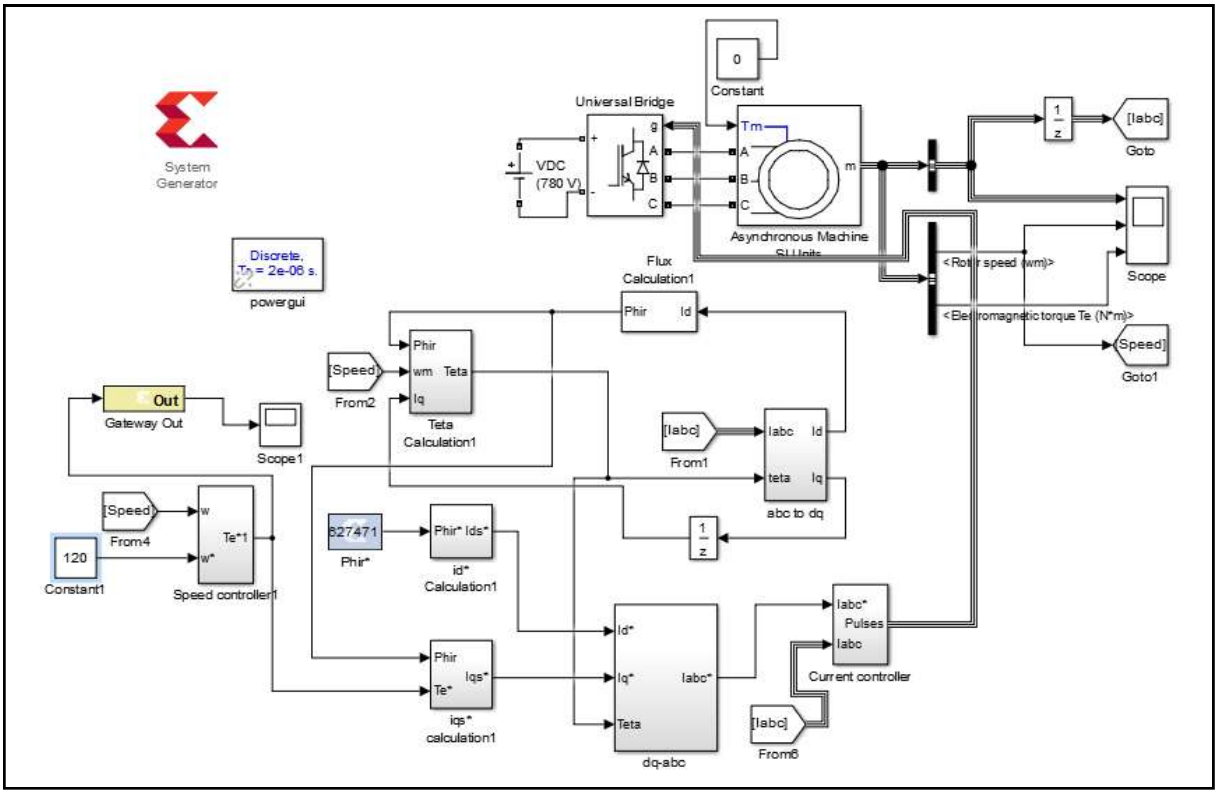

Fig 5: Simulink block diagram of Vector control of IM drive0system using XSG.

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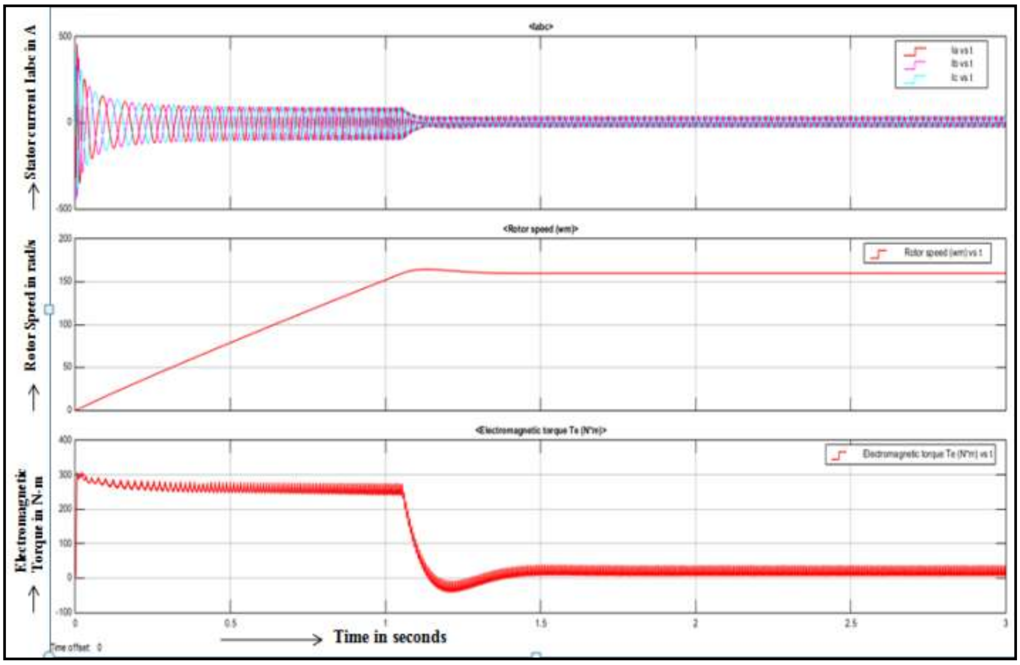

Fig 6: Performance of vector control IM drive system when given reference speed is 160rad/sec at no load.

Fig-6, shows the performance characteristic of a 50hp, 460V, 60Hz IM, operating with a PI speed controller. The given reference0speed is 160 rad/sec at no load. It is observed that motor pick up the speed 165 rad/sec at starting0and also it draw high starting current 450 Amps. The phase current0peak is relatively large during the accelerating process, which is 2-3 times*0*larger than the rated0current. When flux0linkage reaches steady-state value, motor output the maximum0torque and0accelerate. Motor current reach a value of 50 Amps at t=1.1 sec and motor torque settle a value of 50 Nm after t=1.1 sec at the starting mode the high value error is amplified across the PI0controller provoking high variations in the motor torque.

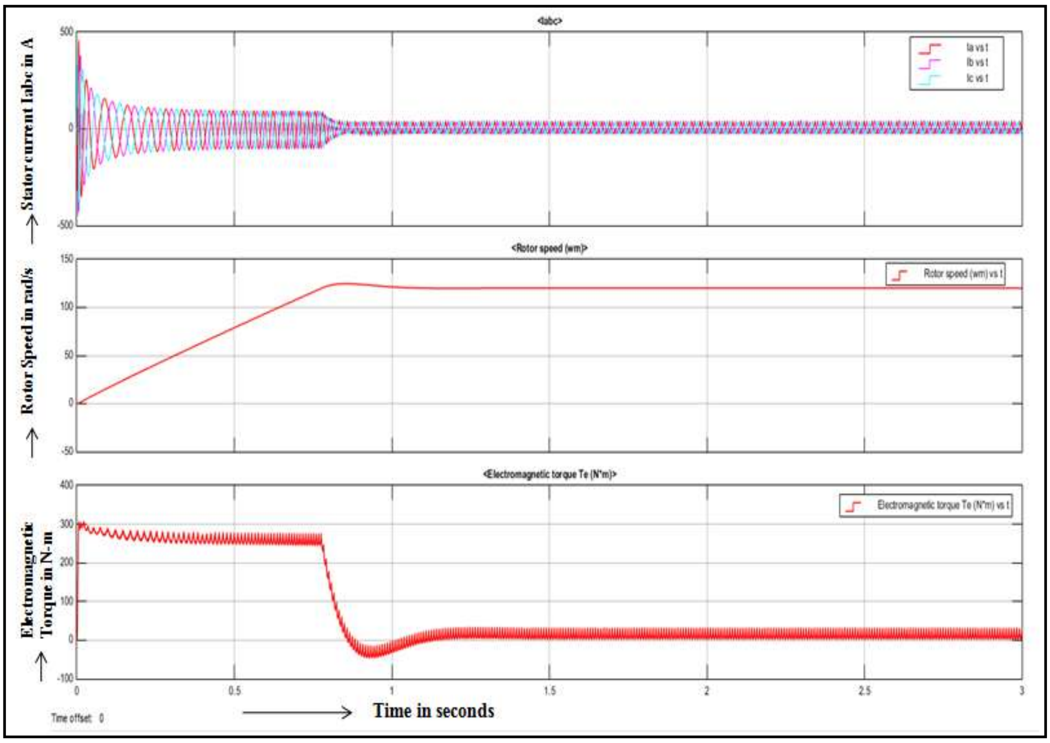

Fig 7: Performance of vector control IM drive system when given reference speed is 120rad/sec at no load.

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The simulation is carried out for a reference speed of 120rad/sec and no-load and the results have been verified. The controller yields optimum speed control for various speed values under no-load conditions. Digital Simulations have been performed under load conditions for a load0torque of 25 Nm and 50 Nm and a reference speed of 120 rad/sec. the simulation results shown in Fig-8 for a load torque of 25Nm and Fig. 8 of 50Nm indicate the speed response provided by the controller.

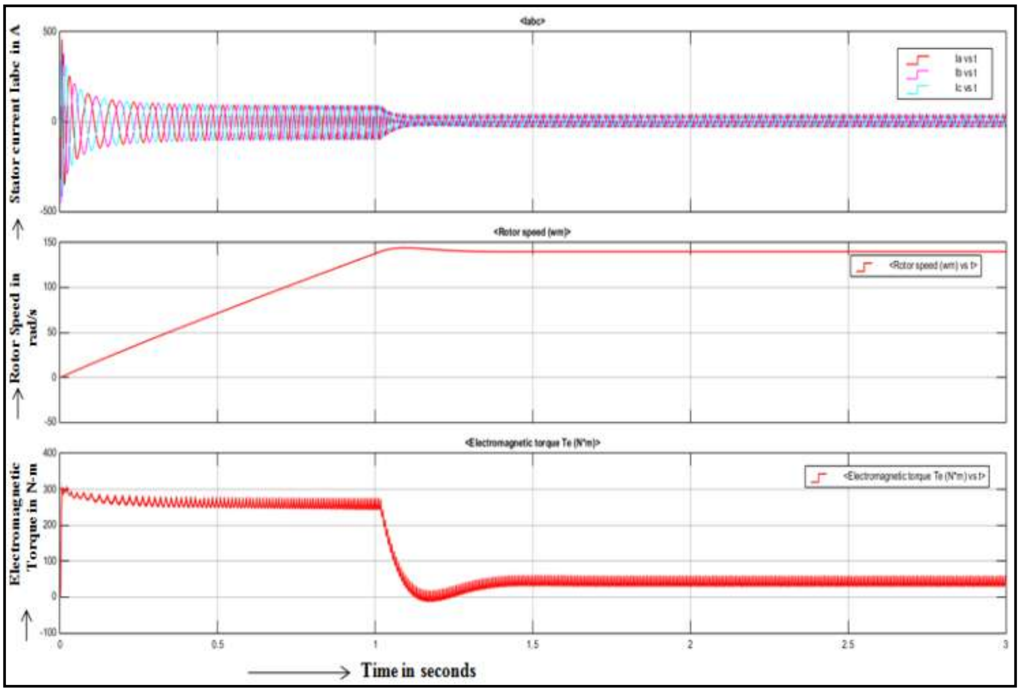

Fig 8: Performance of vector control IM drive system when given reference speed is 120rad/sec at load 25N-m.

Simulation analysis is carried for variable reference speeds at variable torque. The controller yields a stable response under varying load and provides constant speed control. The matching in speed is verified for both variable reference sped and constant reference speed. Also, the rise time taken for the0actual speed to match the reference0speed is less in case of vector0control.

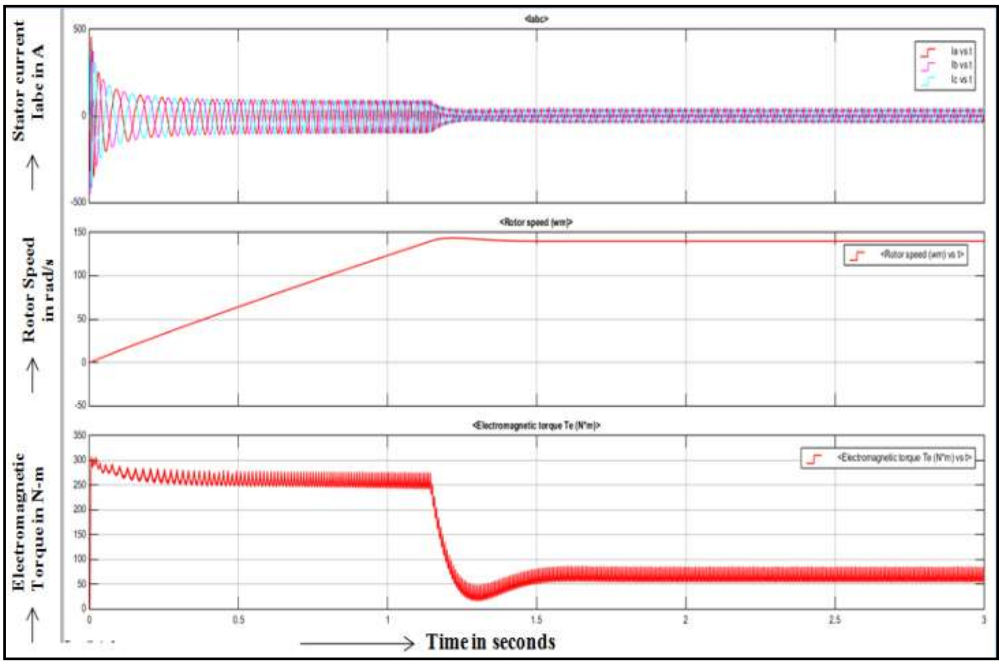

Fig 9: Performance of vector control IM drive system when given reference speed is 120rad/sec at load 50N-m.

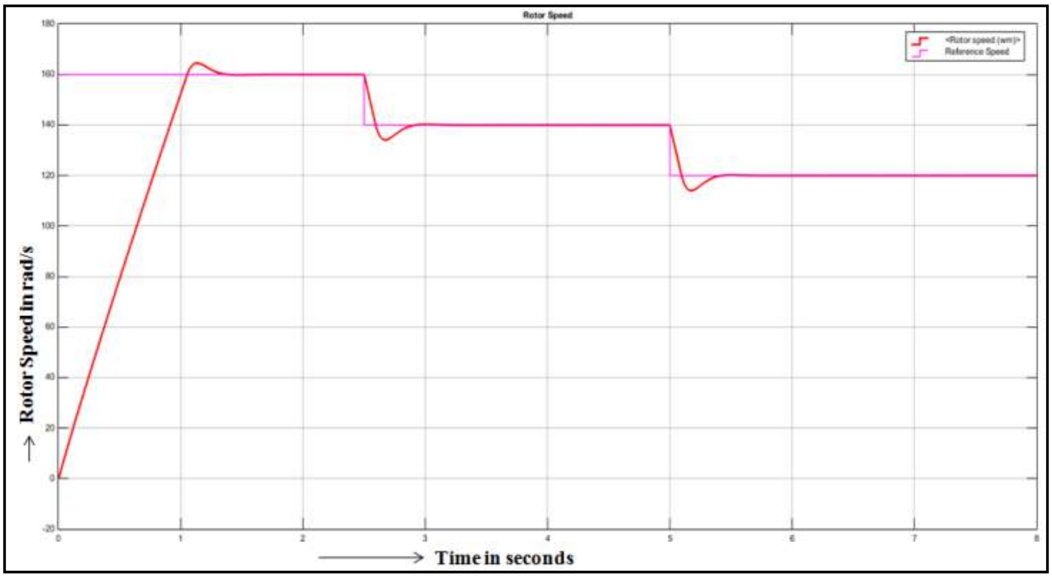

Fig 10: Rotor speed at variable reference speed condition.

It can be seen from the graphical outputs that the vector0control scheme provides better control when compared with other control scheme. The efficiency of vector0control is more pronounced at the loaded conditions than the conventional speed control schemes.

5. CONCLUSION

Based on the adequate analysis of vector principle and induction motor0mathematical model, simulation0model in MATLAB/SIMULINK environment has been0constructed. The simulation0results show that the speed of the0machine is controlled for the required speed and the torque0response is obtained fast by estimating, measuring, calculating0the position and magnitude0of the motor flux in the machine.

In this0study, vector controller is0preferred for the design0of the controller. The digital0blocks provided by Xilinx0System0Generator (XSG) in0MATLAB/SIMULINK environment0are used for the0completion of the0controller. By foreseeing and reducing the errors even in the design stage, an optimized0controller can be designed thus reducing the cost for developing experimental0prototype.

The huge available0number of Xilinx0System0Generator blocks and committed libraries for implementing0complex control0algorithm makes it a highly suitable0environment for designing0and simulating the0control0systems in modern FPGA's with the benefit of being0close to0real hardware.

The work presented here focuses on the simulation of vector control using Xilinx system generator. The performance can be analyzed through proper hardware configuration using FPGA. Further, this work can be expanded to obtain high performance sensorless control of induction motor.

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