FSS Based Control of Induction Motor Drive

Rajinder, Mini Sreejeth , Madhusudan Singh

Abstract: The poly phase induction motor has become the motor of preference today for many applications. In this paper the performance analysis of constant Volts-Hertz (V/f) and Indirect Field Oriented Control (IFOC) methods have been presented. The constant volts-hertz control method is used to keep the V/f ratio constant and the indirect field oriented control method is used to produce high performance by decoupling torque and flux producing components of stator current. Modeling and simulation for both constant V/f and vector control (IFOC) have been developed by using MATLAB/ Simulink and Full Spectrum Simulator (FSS) to generate the dynamics of induction motor for evaluation. Full spectrum simulator has allowed us to do both offline and real time simulation with hardware in loop facility. These constant V/f and IFOC models have been simulated offline and validated with real time simulation under different speed and load condition. Results obtained from both MATLAB and FSS offline simulator are in agreement with the FSS online simulator.

Index Terms: Induction motor, MATLAB/Simulink, simulation, speed control, vector control.

I. INTRODUCTION

There are various control methods available for the efficient control of induction motor (IM). The development in semiconductors, power electronics, digital signal processing and the microprocessors has lead to introduction of induction motors in advanced performance control applications. In industry major portion of the generated power is consumed by electric motors. So in order to reduce the nation losses in terms of energy and environment, motors to be optimized to improve the energy efficiency [1].

Induction motor speed control methods like variation in frequency, rotor resistance, stator voltage, slip recovery, constant V/f, pole changing etc., are based on the magnitude of the control variables. Among these methods, the constant V/f method is most commonly used. In this method, torque and flux remains unchanged during speed variation by keeping V/f ratio constant. The V/f control method is cheap, easy to implement, has wide range of speed control, good steady state and transient performance, low requirement of starting current and wider operating region. However, it has somewhat poorer dynamic performance in comparison to vector control. Thus in applications where higher value of accuracy is required, the constant V/f control method is not used [2].

For an IM the stator current can be projected along the rotor flux linkage by knowing the position of the synchronously rotating rotor flux at any instant, and then the IM can be controlled in the same way as that of a separately excited dc motor. Scalar and vector speed control methods are widely used in industry. Various methods have been projected in literature for the control of induction motor, among which vector control has become the most effective scheme for high performance applications and to overcome the restrictions of scalar control schemes. In vector control scheme the flux and the torque current components can be controlled independently [3], [4].

The control techniques based on decoupling are direct torque control (DTC) and field oriented control (FOC), which are used for controlling speed and torque. Field oriented control is the most accepted vector control scheme which has higher efficiency, lower energy consumption and lower operating cost. In [5] decoupling in torque and rotor flux is achieved by using the magnetizing current components. In [6] decoupling in torque and rotor flux is achieved by using the artificial neural networks (ANNs) for induction motors using FOC principle. In [7] the performance between direct torque control and field oriented control are compared for IM drive. In [8] the motor loss is obtained to optimize the IM drives from system-level based minimization method and is found lower than the component-based methods like motor loss model, dc-link power minimization and torque maximization etc. In [9] speed sensor less control of IM drive is achieved by using modal reference adaptive system. To obtain variable frequency and voltage from an inverter [10] suggested that space vector pulse width modulation has better dc bus utilization and easier digital realization as compared to the other pulse width modulations.

In this paper V/f speed control and an indirect field oriented vector control of three phase squirrel cage induction motor using space vector modulation are analyzed by using MATLAB/Simulation model and full spectrum simulator mini-001 at different speed and load torque.

II. FULL SPECTRUM SIMULATOR (FSS) MINI

Simulation is very important tool for engineers to design and understand the complicated systems. Different types of offline simulator with standard software packages are available in market such as MATLAB etc. But, these software suffers from various disadvantages. There is no relationship between simulation and the physical time in case of an off-line simulator whereas, in real-time simulation, the simulation and the physical time domain are same and allows analysis of a physical system in real-time.

FSS is very important and flexible simulation tool for analyzing power electronics and power systems related development activities. Hence, FSS is becoming popular in teaching as well as in research and development activities for analyzing the components and systems in a solver for circuit equations with user

Revised Manuscript Received on April 17, 2019.

Rajinder, Department of Electrical Engg., Delhi Technological University (DTU), Delhi, India.

Mini Sreejeth, Department of Electrical Engg., Delhi Technological University (DTU), Delhi, India.

Madhusudan Singh, Department of Electrical Engg., Delhi Technological University (DTU), Delhi, India..

defined elements (SEQUEL) environment.

The simulator based on SEQUEL can be used for the simulation of circuits and is a general purpose, public domain package. It has been developed for an easy incorporation of new library elements. FSS is useful for offline and real-time simulation in the areas of testing, control system and development for different power system and power electronic applications.

FSS can perform real-time and off-line simulation at a reasonable cost and is easily configurable for conventional applications. Block diagram of interfacing FSS with controller is shown in Fig 1. FSS has three cards each having three processors so that nine processes can be done simultaneously. For developing the system there are various components available in element library of FSS, which can be utilized for simulation. Furthermore, the user can create their own components to develop the various applications for addition in element library. The experimental set up for FSS Mini real time simulation is shown in Fig 2.

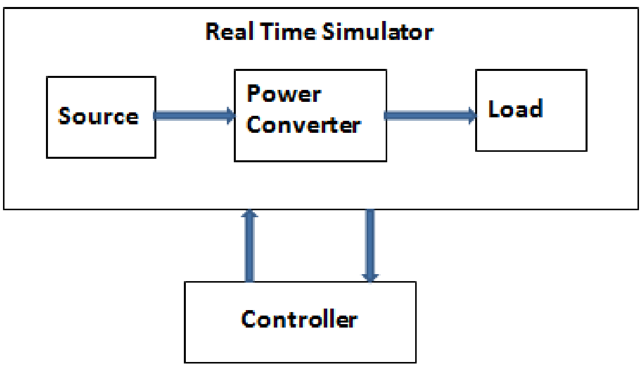


Fig. 1. Block diagram of interfacing controller with FSS

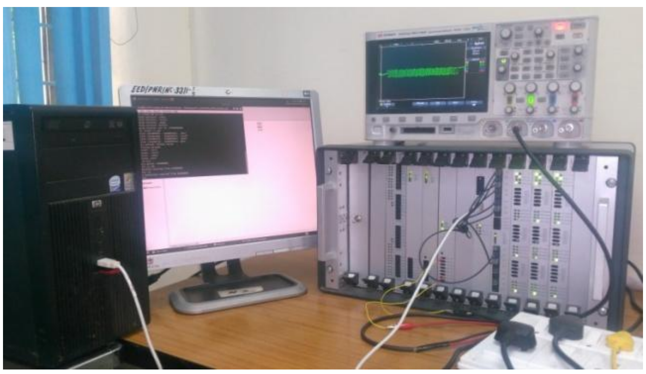


Fig. 2. Real time simulator set up

III. Induction Motor Model

The torque and voltage equations that explain the dynamic analysis of an IM is time varying and due to continuously changing of the coupling coefficient between rotor and stator windings, the dynamic control of an IM is complex. The complexity of the IM can be reduced by changing the three phase stator and rotor variables to a set of two phase winding called d-q transformation [11]. In synchronously reference frame the *d-q* axis equivalent circuit of the IM is shown in Fig.3

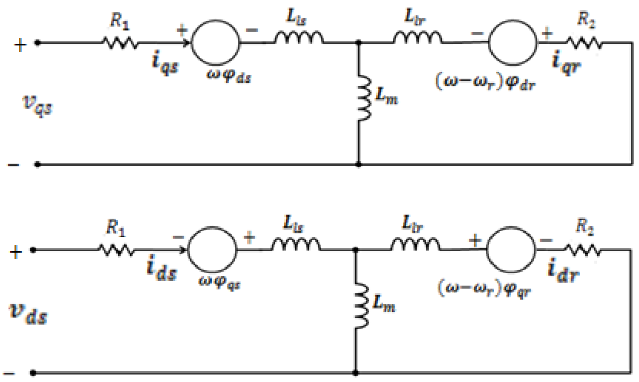


Fig. 3. d-q equivalent circuit

From *d-q* equivalent circuit, the voltage equations can be represented as:

$$v_{qs} = R_1 i_{qs} + \frac{\partial\varphi_{qs}}{\partial t} + \omega\varphi_{ds} \quad (1)$$

$$v_{ds} = R_1 i_{ds} + \frac{\partial\varphi_{ds}}{\partial t} - \omega\varphi_{qs} \quad (2)$$

$$v_{qr} = R_2 i_{qr} + \frac{\partial\varphi_{qr}}{\partial t} + (\omega-\omega_r)\varphi_{dr} = 0 \quad (3)$$

$$v_{dr} = R_2 i_{dr} + \frac{\partial\varphi_{dr}}{\partial t} - (\omega-\omega_r)\varphi_{qr} = 0 \quad (4)$$

The motor torque equation in terms of flux linkage and stator current components can be written as:

$$T_e = \frac{3P}{4}\frac{L_m}{L_r}(\varphi_{dr} i_{qs} - \varphi_{qr} i_{ds}) \quad (5)$$

Where $v_{ds}, v_{qs}, v_{dr}, v_{qr}$ are the stator and rotor voltages in *d-q* axis, $\varphi_{ds}, \varphi_{qs}, \varphi_{dr}, \varphi_{qr}$ are the stator and rotor flux linkages in *d-q* axis, $i_{ds}, i_{qs}, i_{dr}, i_{qr}$ are the stator and rotor currents in *d-q* axis, ω and ω_r are the angular speed of reference frame and rotor, R_1, R_2 are the stator and rotor resistances, L_m, L_r, L_s are the mutual, rotor and stator inductances.

The flux linkages equations can be represented as:

$$\varphi_{qs} = L_s i_{qs} + L_m i_{qr} \quad (6)$$

$$\varphi_{ds} = L_s i_{ds} + L_m i_{dr} \quad (7)$$

$$\varphi_{qr} = L_r i_{qr} + L_m i_{qs} \quad (8)$$

$$\varphi_{dr} = L_r i_{dr} + L_m i_{ds} \quad (9)$$

Further it can be shown that:

$$\varphi_{qs} = L_s\sigma i_{qs} + \frac{L_m}{L_r}\varphi_{qr} \quad (10)$$

$$\varphi_{ds} = L_s\sigma i_{ds} + \frac{L_m}{L_r}\varphi_{dr} \quad (11)$$

where $\sigma = 1 - L_m^2/L_s L_r$ is the leakage coefficient

Putting these values from (10) and (11) into (1) and (2) yields:

$$v_{qs} = (R_1 + \frac{\partial}{\partial t}L_s\sigma)i_{qs} + \omega(L_s\sigma i_{ds} + \frac{L_m}{L_r}\varphi_{dr}) \quad (12)$$

$$v_{ds} = (R_1 + \frac{\partial}{\partial t}L_s\sigma)i_{ds} - \omega L_s\sigma i_{qs} + \frac{L_m}{L_r}\frac{\partial}{\partial t}\varphi_{dr} \quad (13)$$

When d axis locked on the rotor flux vector then:

$$\varphi_{qr} = 0 \text{ and } \varphi_{dr} = \varphi_r$$

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

Putting these values in (3) and (5), yields:

$$(\omega - \omega_r) = \omega_{sl} = \frac{L_m}{L_r}\frac{R_2}{\varphi_{dr}} i_{qs} \quad (14)$$

$$T_e = \frac{3P}{4}\frac{L_m}{L_r}\varphi_{dr} i_{qs} \quad (15)$$

where $i_{qr} = -\frac{L_m}{L_r} i_{qs}$ and

ω_{sl} = slip frequency

For the steady state condition ($\varphi_{dr} = L_m i_{ds}$), the above expressions can be written as:

$$\omega_{sl} = \frac{R_2}{L_r}\frac{i_{qs}}{i_{ds}} \quad (16)$$

$$T_e = \frac{3P}{4}\frac{L_m{}^2}{L_r} i_{ds} i_{qs} \quad (17)$$

Hence rotor flux and torque of the IM can be controlled by d and q components of stator current.

IV. Speed Control of Induction Motor

Motor speed can be changed by changing frequency of input signal, by changing number of poles and by changing slip. Changing the number of poles is normally not feasible once the motor design is completed and cost of motor also increases with increase in poles. Thus, generally frequency of motor is altered to increase or decrease the speed of motor and on the basis of this scalar and vector speed control techniques have been developed. Variable frequency drive (VFD) receives fixed voltage, fixed frequency sine wave input from power sources and it converts it into variable frequency, variable voltage, which is then used to control the speed of IM. Output of scalar or vector speed control method is given to VFD to generate sine wave supply of required frequency and voltage. A three phase 2.2Kw, 430V induction motor is used to carry out MATLAB simulation.

A. Constant Volts-Hertz (V/f) Method

In constant V/f ratio method, motor develops constant torque, except at low speed or frequency and only the magnitude of control variables is controlled. There are open loop and closed loop scalar speed control methods available. The open loop volts/Hz control method of induction motor is very attractive due to its simplicity. Traditionally, induction motors were used for constant speed applications only. But with the use of various speed control method available in literature it becomes possible to use induction motor for variable speed applications.

Matlab simulink model is developed to analyze the open loop constant Volt/Hz method and to study the speed-torque characteristic. The power circuit consists of three phase power supply, rectifier, LC filter and PWM voltage fed inverter. The phase voltage V_s^* is generated from speed command by gain factor G which is calculated from rated voltage and frequency of motor so that the air gap flux remains constant. The boost voltage (V_o) is added for getting the rated motor flux and corresponding torque. The speed command is integrated to get angle θ and corresponding desired sinusoidal phase voltages (V_a^*, V_b^*, V_c^*) are generated as shown in the Fig 4. These signals are fed to voltage source inverter which uses this signal to drive the three phase induction motor.

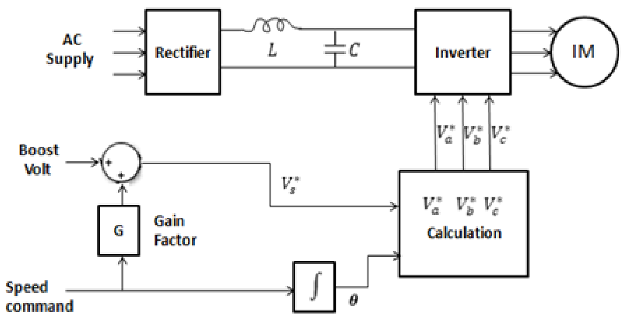


Fig. 4. MATLAB Simulink model for constant V/f

B. Indirect Field Oriented Control (IFOC)

In IFOC vector control method of induction motor the unit vector is generated in feed forward manner and the dynamics of motor is improved for practical applications, where the flux and torque currents are mutually decoupled so that the motor behaves similar to a separately excited dc motor.

Matlab/Simulink model is used in this paper for simulation of three phase IM drive system. It consists of inverter, three-phase IM and PI controllers. For analyzing the system performance, all of these components were modeled. The torque command current (i_{qs}^*) component is generated from the speed controller loop, whereas the current command (i_{ds}^*) is generated from the flux command. For executing the vector control approach, IM line currents are controlled with the help of current controller so as to track the reference voltage commands. The unit vector is generated by integrating the summation of the motor speed and slip frequency. The complete diagram of the drive system is shown in Fig 5.

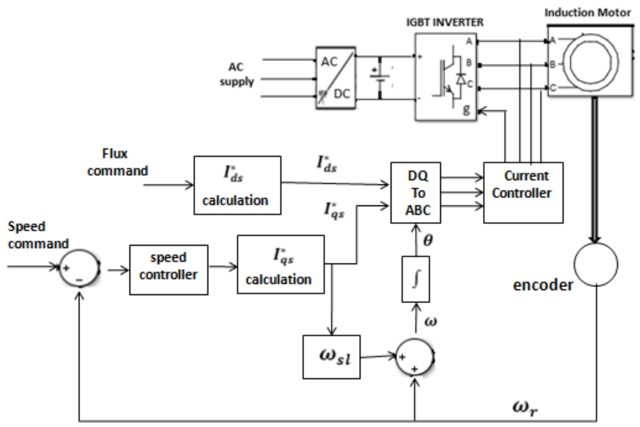


Fig. 5. MATLAB Simulink model for IFOC

V. Results and Discussion

The simulation of constant V/f speed control and indirect vector control of three phase IM drive is carried out by using both MATLAB/Simulink model and full spectrum simulator for various operating conditions of sudden change in load torque and speed. FSS offline simulation of 50 micro second step sizes was used with simulation start time of zero second and simulation end time of 3 seconds (i.e. 0 to 60000 micro seconds).

A Constant Volts-Hertz (V/f) Method

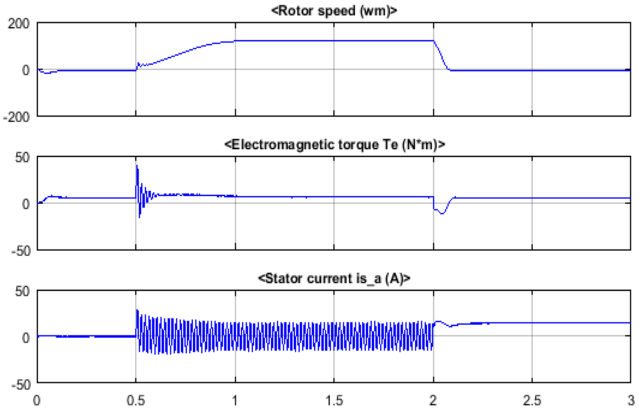
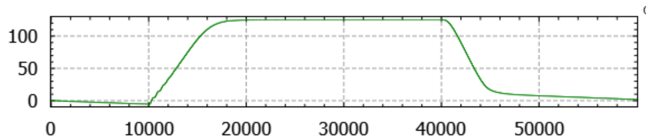
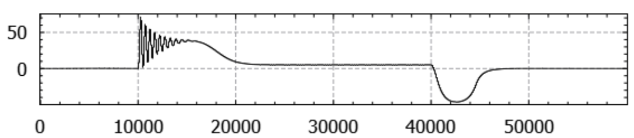


Fig. 6. Matlab simulation for speed, torque and current

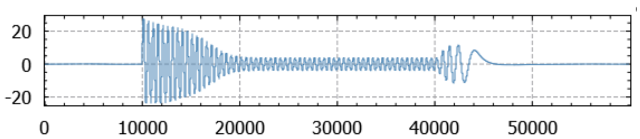
Simulation of constant V/f IM drive system is analyzed for a sudden change in speed and load torque by using MATLAB and FSS simulink. Fig 6 shows dynamic performance of constant V/f using MATLAB simulink while Fig 7 and Fig 8 show dynamic performance by using FSS for offline and real time simulation respectively. Initially the motor is at rest and started with sudden speed command of 125 rad/sec at t = 0.5 sec and then again changed to zero rad/sec at t = 2 sec with a load torque of 5 Nm. Initially motor draws high starting current to develop the required starting torque as shown in the simulated result. But, when motor starts tracking of the commanded speed, motor current starts decreasing with the increase of frequency. Similarly, the torque developed by the motor tracks the commanded value by keeping the proportionate value of the stator current. Small ripples in the developed torque and motor current are observed in simulation due to switching effect of the current controller.



(a) Speed

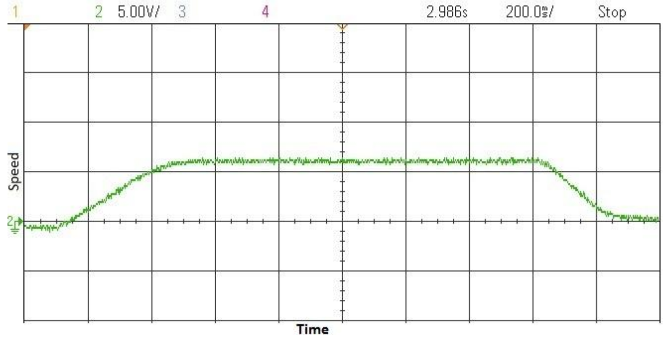


(b) Torque

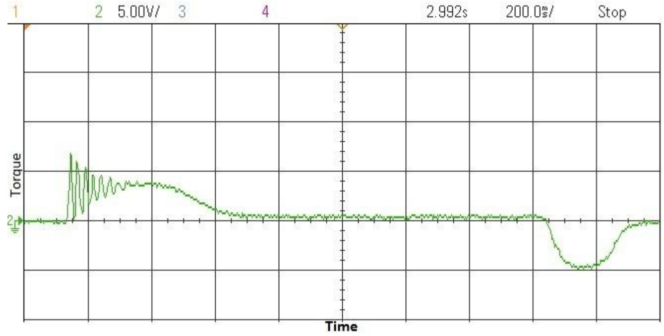


(c) Current

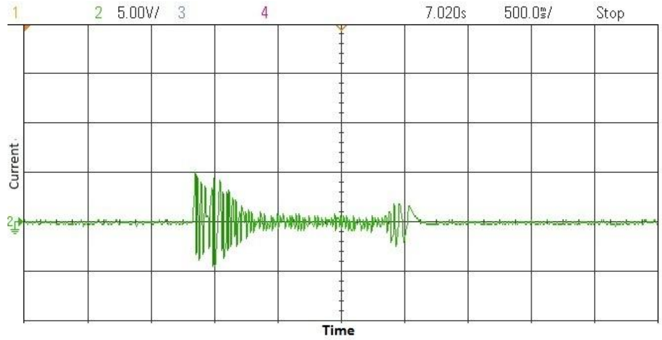
Fig. 7. FSS offline simulation for (a) speed, (b) torque and (c) current



(a) Speed



(b) Torque



(c) Current

Fig. 8. FSS real time simulation for (a) speed, (b) torque, (c) current

B. Indirect Field Oriented Control (IFOC)

Simulation of IFOC IM drive system is analyzed for a sudden change in speed and torque by using MATLAB and FSS simulink. Fig 9 represents dynamic performance of indirect FOC using MATLAB simulink while Fig 10 and Fig 11 show dynamic performance by using FSS for offline and real time simulation respectively. Initially the motor is at rest and started with sudden speed command of 100 rad/sec at t = 0.5 sec and then again changed to zero rad/sec at t = 2 sec with a load torque of 5 Nm. Initially motor draws high starting current to develop the required starting torque as shown in the simulated result and explained earlier. Small ripples in the developed torque and motor current are observed in simulation due to switching effect of the current controller.

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

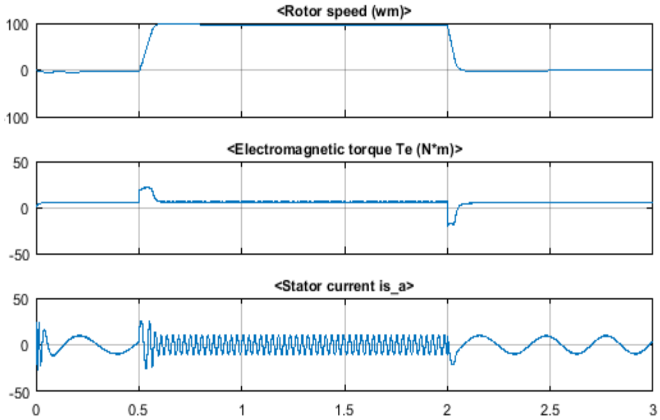
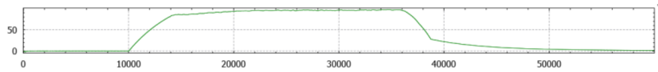
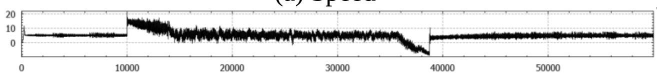


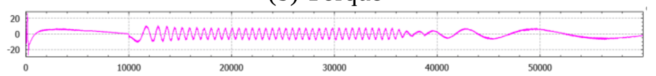
Fig. 9. Matlab Simulation for speed, torque and current



(a) Speed

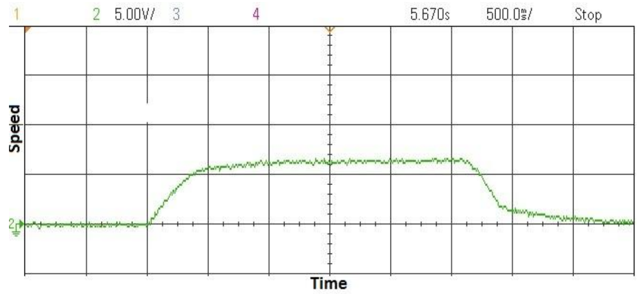


(b) Torque

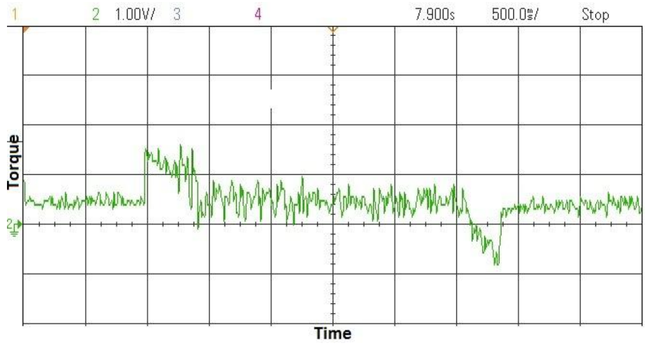


(c) Current

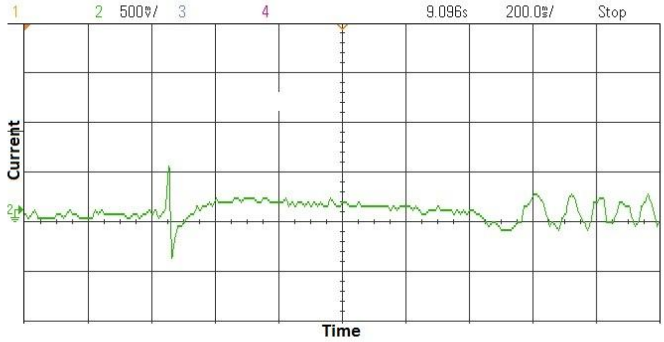
Fig. 10. FSS offline Simulation for (a) speed, (b) torque and (c) current



(a) Speed



(b) Torque



(c) Current

Fig. 11. FSS real time simulation for (a) speed, (b) torque, (c) current

VI. CONCLUSION

Offline and online simulation of constant V/f and indirect field oriented controller methods are carried out in MATLAB and FSS under different speed and load conditions. It is observed that developing system in MATLAB is much easy as compared to developing system in FSS due to the graphical approach. But in FSS user can develop system as per the requirement. It allows great flexibility in creating and modifying circuit element, which is very important in developing new system. Also, it is observed that the results obtained using FSS are superior then the result obtained using MATLAB. Practical application of the constant V/f method at low frequency is challenging, because of the stator resistance influence and the required rotor slip to generate torque. But, IFOC control method shows good results in transient conditions. Moreover, the apparent comparison of these both MATLAB and FSS offline simulator are in agreement with the FSS online simulator.

ACKNOWLEDGMENT

The authors like to express thanks Centre for Development of Advanced Computing (CDAC) and DTU for providing the training and hardware facility during the progress of this work, which is carried out in the Project and Research laboratory, Electrical Engg. Department, DTU, Delhi, India.

REFERENCES

1. R Krishnan, "Electric motor drives: modeling, analysis and control," edition 2013, Pearson Prentice Hall,.
2. K.Anitha, G. Santosh, L. Suneel, K. Spandana, E. Raviteja, "Simulation and Speed Control of 3-Phase IM Drives," Issue No. 4, Vol. 6, , DOI 10.4010/2016.1028 , IJESC, 2016.
3. Pabitra K. Behera, Manoj K. Behera, Amit K. Sahoo, "Comparative Analysis of scalar & vector control of IM through Modeling & Simulation," Int. J. of Innovative Research In Electrical, Elex., Inst. and Control Engg., Vol. 2, Issue 4, 2014, ISSN (Print) 2321 – 5526
4. G. Kohlrusz, D. Fodor, "Comparison of scalar and vector control strategies of induction motors," Hungarian J. of Ind. Chemistry, 2011, pp. 265-270.
5. Rutuja S Hiware, Jagdish G Chaudhari, "Indirect Field Oriented Control for IM," ICETET, 2011, IEEE, 4th Int. Conf., pp. 191-194, DOI: 10.1109/ICETET2011.56
6. A. Ba-Razzouk, A. Cheriti & G. Olivier, "Field-oriented control of induction motors using neural-network decouplers," IEEE Trans. on Power Elect., Volume 12, Issue 4, 1997, pp. 752 –763, DOI:10,1109/63/602571.

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

7. Garg Rachna, Mahajan Priya, & Gupta Nikita., "A comparative study between FOC and DTC of AC traction motor," Recent Adv. and Innovations in Engg. (ICRAIE), May 2014, DOI:10.1109/ICRAIE.2014.6909201.
8. Sridharan Srikanthan, & Krein Philip T., "Mini. of system-level losses in VSI based induction motor drives: offline strategies," IEEE Trans. on Ind. Applications. Volume 53, Issue 2, March-April 2017 , pp 1096 – 1105, DOI:10.1109/TIA. 2016.2631513.
9. Kumar Rakesh, Das Suanta and Chattopadhyay Ajit Kumar, "Comparative assessment of two different mras schemes for speed sensorless control of induction motor drives," IET Elect. Power Appl., Vol. 10,Iss. 2, 2016, pp. 141-154.
10. Raichurkar Priya Subhash, & Jamadar Asif Liyakat, "V/F speed control of 3 ph. induction motor using space vector modulation," Int. J. of Engg. Research & Technology (IJERT), Vol. 4, ISSN: 2278-0181, Issue 05, 2015.
11. Rahaman Naveed, & Govindraju H.V., "Modelling & simulation of a 3 phase electric traction induction motor using matlab simulink," Int. J. of Elect., Elex and Comp. Systems (IJEECS), ISSN : 2347-2820, Vol. -2, Issue-5, 2014, pp. 18-25.

AUTHORS PROFILE

Rajinder received his B.E. and M.E. degrees from Deen Bandhu Chhotu Ram Uni. of Science and Tech., Murthal and Delhi Technological University (DTU), Delhi -110042, India respectively. He joined Guru Nanak Dev Institute of Technology (GNDIT), Rohini, Delhi- 110089, India as a lecturer in 1998. Presently he is a lecturer (selection grade) in the Electrical Engg. Department, GNDIT and a Research Scholar in DTU, Delhi. His research interests are in the field of electrical machines, drives and control system. Mobile No.-09868735288, e-mail- rajinder871@gmail.com

Dr. Mini Sreejeth received her B. E., M. E. and Ph.D degrees from Mahatma Gandhi Uni., Calicut Uni. and Uni. of Delhi respectively. She joined DTU in 2007 as a senior lecturer. Presently she is an associate professor in the Electrical Engg. Department, DTU. Her research interests are in the field of control and operation of distributed drives. She is a life member of the ISTE, New Delhi, India and Member of IEEE, (USA). Mobile No.- 09868272722, e-mail- minisreejeth@dce.ac.in

Professor Madhusudan Singh received his B.Sc., M.E. and Ph.D. degrees from Faculty of Tech. Dayalbagh Edu. Inst. Agra, Uni. of Allahabad, Allahabad and Uni. of Delhi, Delhi, India, respectively. Presently he is a Professor and head in the Dept. of Electrical Engg. in DTU. His research interests are in the field of modelling and analysis of elect. machines, power elex. and drives He is a member of the Institution of Engineers, India and IETE, New Delhi, India. He is also a member of the Institution of Engineering Technology and IEEE (USA). Mobile No.- 09968404221, e-mail- madhusudan@dce.ac.in