IJIREEICE

ISSN (Online) 2321-2004
ISSN (Print) 2321-5526

International Journal of Innovative Research in
Electrical, Electronics, Instrumentation and Control Engineering

Vol. 6, Issue 12, December 2018

Design and Performance Analysis of Vector Control AC Drive System using Different Conventional Controllers

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Abstract: This research work present design and performance analysis of vector control ac drive system using different conventional controllers. In this research work design two three phase AC drives e.g. induction motor and permanent magnet synchronous motor based drives. A controller is a device which when introduced in feedback of the system, controls the steady state and transient response as per the requirement. The conventional P, PI, PD, and PID controller performances are compared. Among these controller PID controller has minimised ripple contents of speed and torque and also improved dynamic performance under transient and steady-state operating conditions.

Keywords: Conventional controller, IM drives, PMSM drives, Vector control method, VSI

I. INTRODUCTION

Induction motors have been widely used in the industrial drive system as a means of converting electric power to mechanical power. With the development of the vector control technology, the induction machine drive systems offer high performance as well as independent control on torque and flux linkages, which is similar to that of the DC machine. Furthermore, it is possible to drive the induction machines above their rated speed through flux weakening, which also finds a lot of industrial applications. Permanent magnet synchronous motors (PMSM) are widely used in low and mid power applications such as computer peripheral equipments, robotics, adjustable speed drives and electric vehicles. The growth in the market of PM motor drives has demanded the need of simulation tools capable of handling motor drive simulations. Simulations have helped the process of developing new systems including motor drives, by reducing cost and time. Simulation tools have the capabilities of performing dynamic simulations of motor drives in a visual environment so as to facilitate the development of new systems. In this work, the simulation of a vector controlled PMSM motor & IM drive system is developed using Simulink. The simulation circuit will include all realistic components of the drive system. This enables the calculation of currents and voltages in different parts of the inverter and motor under transient and steady conditions. The different speed and load torque can be calculated using conventional controller.

II. DRIVE SYSTEM

The motor drive consists of four main components, motor, voltage source inverter (VSI), control unit and the speed sensor. The components are connected as shown in fig. 1.

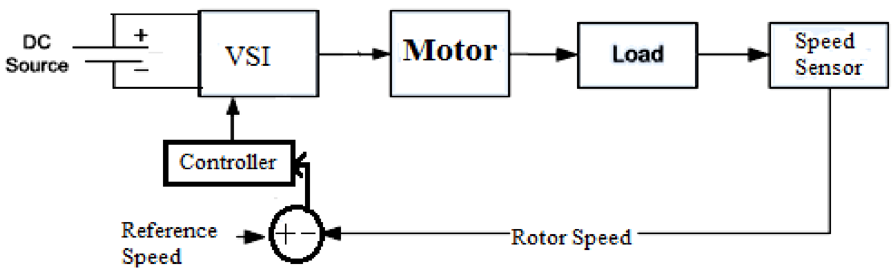

Fig-1 Drive System

VSI: inverter is a device that converts fixed DC supply to variable AC voltage & frequency according the requirement. The stator windings of the motor are fed by an inverter that generates a variable frequency variable voltage.

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Motor: The synchronous motor and IM are the most widely used types of AC motor. The difference between the two types is that the synchronous motor rotates in exact synchronism with the line frequency. The synchronous motor does not rely on current induction to produce the rotor's magnetic field. By contrast, the induction motor requires slip, the rotor must rotate slightly slower than the AC current alternations, to induce current in the rotor winding.

Vector Control: Vector control refers not only to the magnitude but also to the phase of variables. Matrix and vectors are used to represent the control quantities. This method takes into account not only successive steady-states but real mathematical equations that describe the motor itself, so that obtained results have a better dynamic for torque variations in a wider speed range. Vector control offers a solution to circumvent the need to solve high order equations with a large number of variables and nonlinearities and achieve an efficient control with dynamic. Vector control is applicable to both induction and synchronous motor drive. Vector control and corresponding feedback signal processing, particularly for modern sensor less vector control are complex and the use of powerful microcomputer or DSP is mandatory. It appears that eventually, vector control will oust scalar control, and will be accepted as the industry standard control for ac drives. The performance of an induction motor is strongly dependant on its control files which have been used in the preparation of this template.

III. SPEED CONTROLLERS

The design of the speed controller is important from the point of view of imparting desired transient and steady-state characteristics to the speed-controlled AC drive system. The purpose of a motor speed controller is to take a signal representing the demanded speed, and to drive a motor at that speed. Speed controller calculates the difference between the reference speed and the actual speed producing an error, which is fed to the controller. The following types of controllers are available:

- Proportional controller (P type)
- Proportional-Integral controller (PI type)
- Proportional-Derivative controller (PD type)
- Proportional-Integral-Derivative controller (PID type)

A controller is a device which when introduced in feedback of the system, controls the steady state and transient response as per the requirement. Such device converts input to the controllers to some other form of error than proportional to error due to which steady-state and transient response gets improved.

IV. IM VECTOR CONTROL

In this section, the concept of vector control has been presented and the induction motor drive is simulated using vector control. For evaluation of implemented drive, different torque and speed responses of drive are presented. Starting response of for the source current, generated torque and rotor speed of the vector controlled IM drive is presented.

A. Simulation model

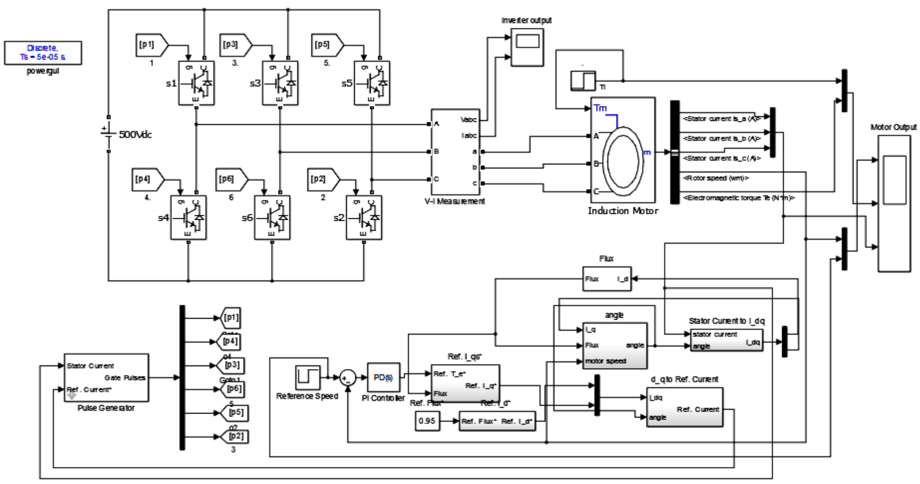

Fig.-2: Vector control of IM drive

IJIREEICE
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The dynamic performance of the motor is obtained for the set of different speed and also torque to the motor. The parameters of the motor, used for simulation are: Squirrel-cage IM, 3-Phase, 420V, 3hp, 50 Hz, ω=150rad/sec, P = 4, Rs = 1.405Ω, Lls=0.005839h, Rotor resistance Rr'=1.395 ohm, inductance Llr'= 0.005839h, Inertia J= 0.0131 kg.m^2. The vector control based simulation model shown in fig below:

B. Performances of IM drive at different Speed Controllers

In this section, performances of IM drive system using P, PI, PD and PID at different speed. The controller has been verified at no-load, variable load and various speed conditions. Hysteresis band current controller has been used for all operation of IM drives. The research work is focused on minimization of the ripple at transient and steady state conditions. Fig.3 shows VSI output voltage and motor current at various speeds (100, 150 and 100rad/sec after 0.5 sec) at full load (14.5 NM). Every different speed motor current and voltage are also change and settle after few seconds.

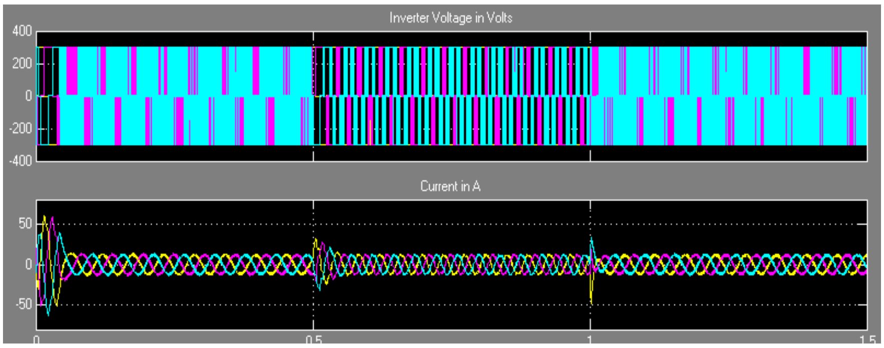

Fig.3: Inverter output voltage and motor current at various speed

C. Performance of conventional P controller under different speed at full- load torque

Fig. 4 shows the performance of P controller for different reference speed at full load-torque. At full-load speed is not reaches the reference speed. After 0.5 sec. speed is increases 100rad/sec to 150 rad/sec, ripple contents of the rotor speed are obtained 2.3 rpm. The starting overshoot of load torque is high and settles after 0.1 sec. in every variation of speed load torque overshoot is obtained and settles after few seconds.

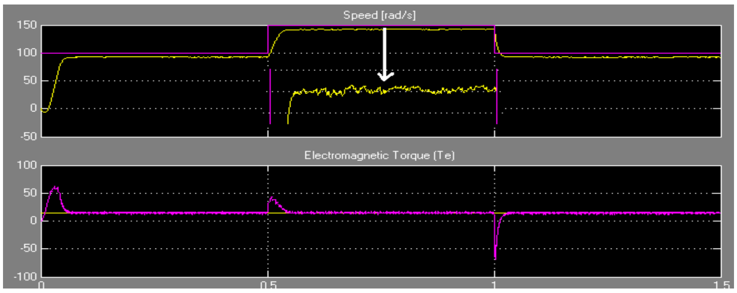

Fig. 4 Rotor speed responses using P controller during full-load.

D. Performance of conventional PI controller under different speed at full- load torque

Fig. 5 shows the performance of PI controller for different reference speed at full load-torque. At full-load speed is reaches the reference speed but taken more settling time. After 0.5 sec. speed is increases 100rad/sec to 150 rad/sec, ripple content is totally remove and obtained smooth rotor speed. The settling time of the rotor speed is 0.1 sec, after motor speed is increase settling time is reduces in PI controller. The starting overshoot of load torque is high and settles after 0.1 sec. in every variation of speed load torque overshoot is obtained and settles after few seconds.

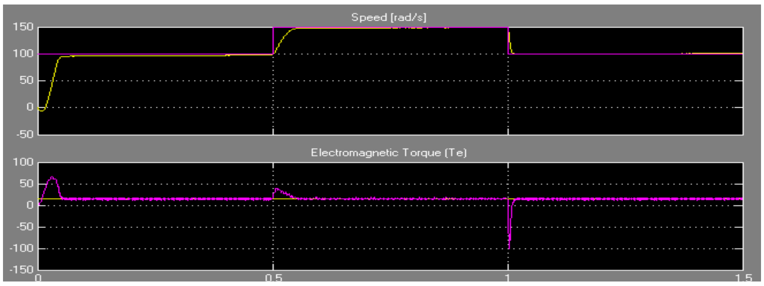

Fig. 5 Rotor speed responses using PI controller during full-load.

IJIREEICE

ISSN (Online) 2321-2004
ISSN (Print) 2321-5526

International Journal of Innovative Research in
Electrical, Electronics, Instrumentation and Control Engineering

Vol. 6, Issue 12, December 2018

E. Performance of conventional PD controller under different speed at full- load torque

Fig. 6 shows the performance of PD controller for different reference speed at full load-torque. At full-load speed is not reaches the reference speed. After 0.5 sec. speed is increases 100rad/sec to 150 rad/sec, ripple content is totally remove and obtained smooth rotor speed. The settling time of the rotor speed is 0.1 sec, after motor speed is increase settling time is reduces in PD controller. The starting overshoot of load torque is high and settles after 0.1 sec. in every variation of speed load torque overshoot is obtained and settles after few seconds.

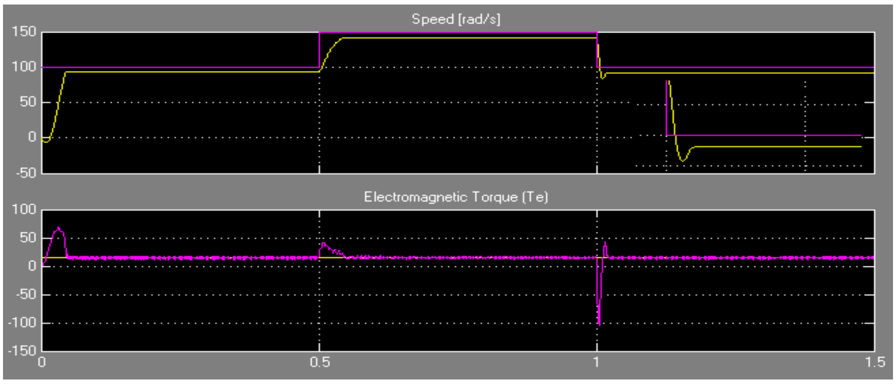

Fig. 6 Rotor speed responses using PD controller during full-load.

F. Performance of conventional PID controller under different speed at full- load torque

Fig. 7 shows the performance of PID controller for different reference speed at full load-torque. At full-load speed is reaches the reference speed. After 0.5 sec. speed is increases 100rad/sec to 150 rad/sec, ripple content is totally remove and obtained smooth rotor speed. The settling time of the rotor speed is 0.1 sec, after motor speed is increase settling time is reduces in PID controller. The starting overshoot of load torque is high and settles after 0.1 sec. in every variation of speed load torque overshoot is obtained and settles after few seconds.

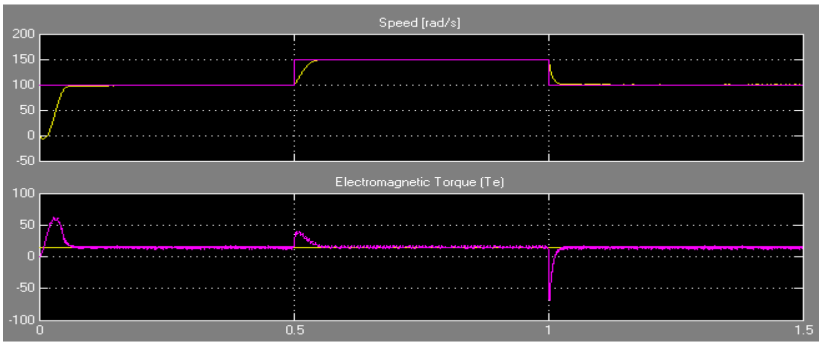

Fig. 7 Rotor speed responses using PID controller during full-load.

G. Performance of conventional controller under different full- load torque at constant speed

Fig. 8 shows the performance of different load-torque from 0 NM to 14.5 NM to 5 NM at a time interval of 0.5 sec is apply with 100 rad/sec reference speed. In starting load-torque overshoot is high and settles after 0.15 sec. Conventional PID controller rotor speed is down 2 rad/sec at full load torque.

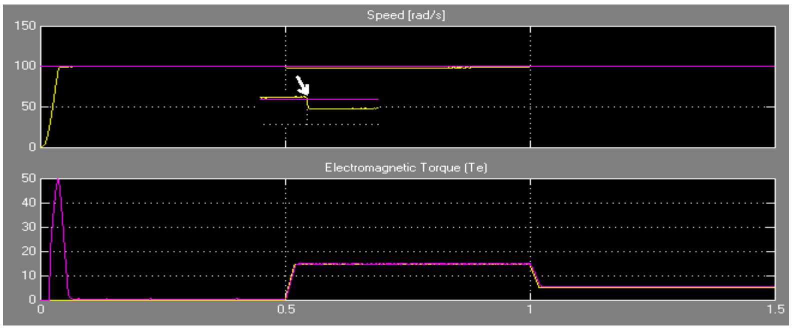

Fig. 8 Motor different load-torque at constant speed

IJIREEICE

ISSN (Online) 2321-2004
ISSN (Print) 2321-5526

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Electrical, Electronics, Instrumentation and Control Engineering

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V. PMSM DRIVES

In this section, vector control PMSM drive is simulated using vector control. The main aim of this research work is to analyze and compare the performances of conventional P, PI, PD and PID as different reference speed and load torque. Vector control PMSM drive system using hysteresis band current controller and conventional controller based performance; we choose the PMSM drive system.

A. Simulation model

The dynamic performance of the motor is obtained for the set of different speed and also torque to the motor. The simulation model is shown in fig. 2, only change IM to PMSM. MATLAB/Simulink models were developed for 3hp PMSM and the other system parameters values are: Salient pole PMSM, 3-Phase, 420V, 3hp, 50 Hz, ω=150rad/sec, P = 4, Rs = 0.86Ω, Inductances Ld =Lq =5.24mh, Flux linkage=0.18. Inertia J= 0.8e-3 kg.m^2.

B. Performances of PMSM drive at different Speed Controllers

In this section shows performances of PMSM drive system using conventional P, PI, PD and PID at different speed. The controller has been verified at no-load, variable load and various speed conditions. Hysteresis band current controller has been used for all operation of PMSM drives. The main focused of this research work to minimization of the ripple at transient and steady state conditions.

Fig. 9 shows VSI output voltage and motor current at various speeds (100, 150 and 100rad/sec after 0.5 sec) at full load (14.5 NM). Every change of reference speed motor current and voltage are also change and uniform after few seconds. PMSM drives starting more transient are obtained as compare to IM drives. In different reference speed motor current are more stable as compare to IM drive.

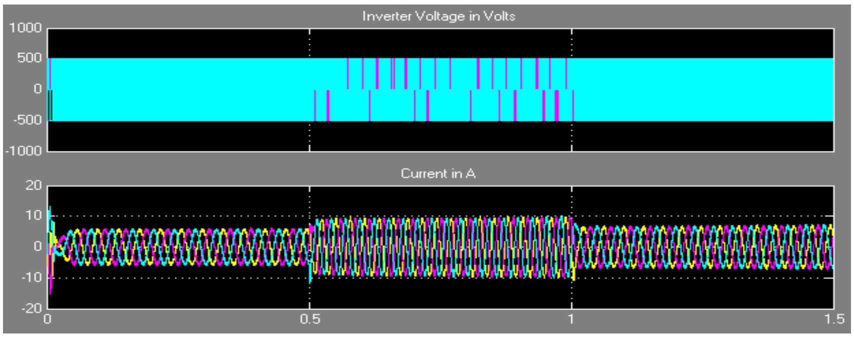

Fig. 9: PMSM Inverter output voltage and motor current at various speed

C. Performance of conventional P controller under different speed at full- load torque

Fig. 10 shows the performance of P controller for different reference speed at full load-torque. At full-load speed is not reaches the reference speed. After 0.5 sec. speed is increases 100rad/sec to 150 rad/sec, ripple contents of the rotor speed are obtained. The starting overshoot of load torque is high and settles after 0.15 sec. In every variation of reference speed, load torque overshoot is obtained and settles after few seconds.

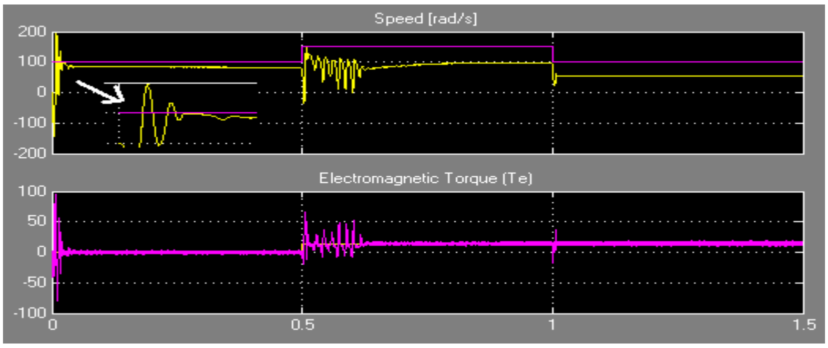

Fig. 10 PMSM Rotor speed responses using P controller during full-load.

D. Performance of conventional PI controller under different speed at full- load torque

Fig. 11 shows the performance of PI controller for different reference speed at full load-torque. At full-load overshoot is high in starting and settle after few seconds. After 0.5 sec. speed is increases 100rad/sec to 150 rad/sec, ripple content is presence. The starting overshoot of load torque is high and settles after 0.1 sec. in every variation of speed load

ISSN (Online) 2321-2004
ISSN (Print) 2321-5526

IJIREEICE

International Journal of Innovative Research in
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Vol. 6, Issue 12, December 2018

torque overshoot is obtained and settles after few seconds. In various speed starting load torque overshoot is minimum as compare to IM drive.

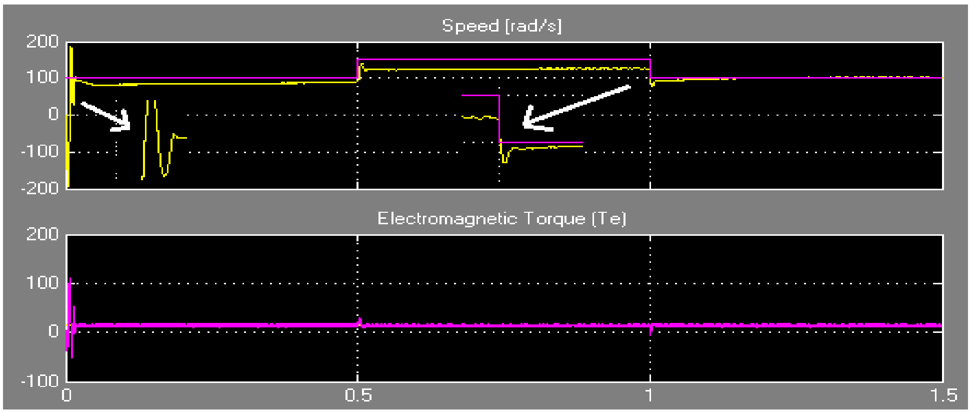

Fig. 11 PMSM Rotor speed responses using PI controller during full-load.

E. Performance of conventional PD controller under different speed at full- load torque

Fig. 12 shows the performance of PD controller for different reference speed at full load-torque. At full-load speed is not reaches the reference speed. The settling time of the rotor speed is 0.15 sec, after motor speed is increase settling time is reduces in PD controller. In different reference speed motor speed is nearest to zero then increases and settles. The starting overshoot of load torque is high and settles after 0.1 sec. in every variation of reference speed load torque overshoot is obtained and settles after few seconds.

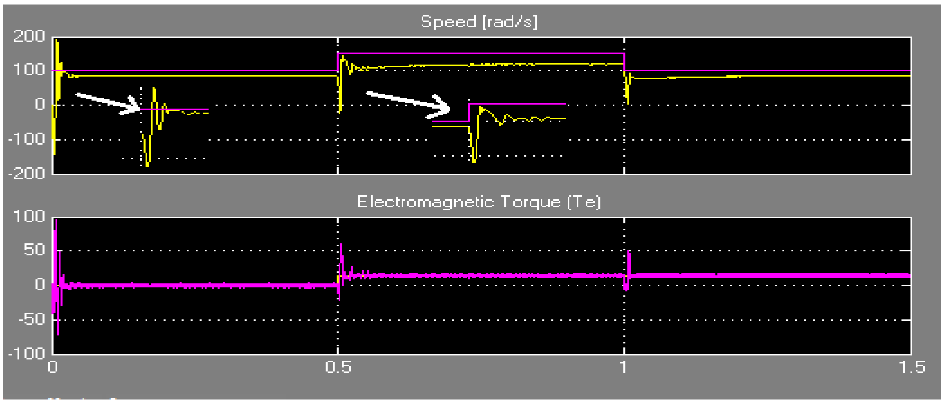

Fig. 12 PMSM Rotor speed responses using PD controller during full-load.

F. Performance of conventional PID controller under different speed at full- load torque

Fig. 13 shows the performance of PID controller for different reference speed at full load-torque. At full-load speed is reaches the reference speed. After 0.5 sec. speed is increases 100rad/sec to 150 rad/sec, ripple content is totally remove and obtained smooth rotor speed. The settling time of the rotor speed is 0.1 sec, after motor speed is increase settling time is reduces in PID controller. The starting overshoot of load torque is high and settles after 0.1 sec. in every variation of speed load torque overshoot is obtained and settles after few seconds.

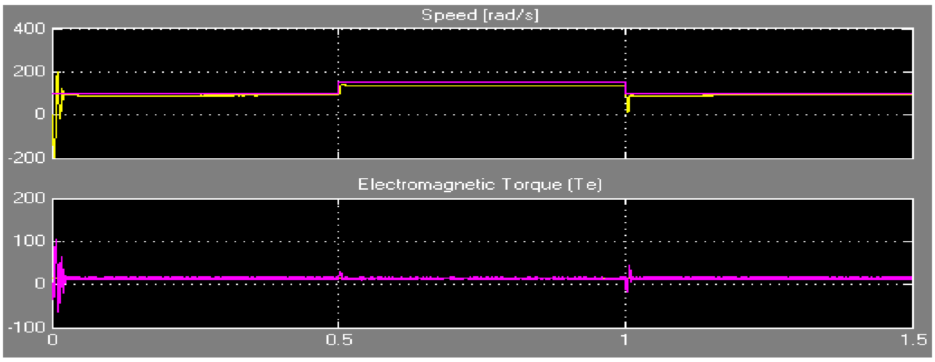

Fig. 13 PMSM Rotor speed responses using PID controller during full-load.

G. Performance of conventional controller under different full- load torque at constant speed

Fig. 14 shows the performance of different load-torque from 0 NM to 14.5 NM to 5 NM at a time interval of 0.5 sec is apply with 100 rad/sec reference speed. In starting load-torque overshoot is presence and settles after 0.15 sec. After 0.5 sec motor run at full load, overshoot present and settle after few seconds. In every changing time speed overshoot or down shoot present and settle after few seconds.

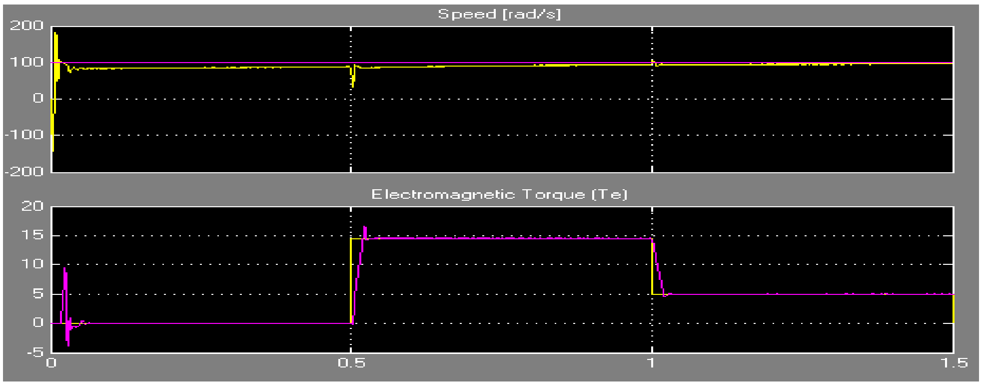

Fig. 14 PMSM performance with different load-torque at constant speed

VI. COMPARISON OF IM AND PMSM DRIVE

- In the case of IM drive the speed response is faster and more robust than the PMSM drive. The IM drive scheme has a better speed and torque response.
- PMSM drive load torque smoothly and starting torque overshoots less than based drives. PMSM drive has more speed overshoot as compared to IM drive. Steady-state error is also reduced as compared to PMSM drives.
- The IM drive can be operated as a conventional drive in the event of converter failure.
- IM drives have low maintenance, and low wear and tear.
- Harmonics are high at frequencies at near to supplies frequency and wave form is distorted.
- PMSM motors are must operate with a drive; IM can be used without drives.
- PMSM drive systems are most efficient as compared to IM drive system.
- PMSM drives are more expensive than IM drives.

VII. COMPARISON OF CONVENTIONAL CONTROLLER P, PI, PD AND PID

The comparisons of conventional controller are shown in Fig. 3 to 14. The most important points are evaluated:

- Rise time is high in P, PD controller and low in the case of PI and PID.
- In PID and PI settling time and overshoot are lesser as compared to other conventional controller.
- In full-load torque case P, PD, PI conventional controller transient response is higher than as compared to PID.
- In full load motor speeds are decrees in case of P, PD controller and smaller change in case of PI and PID.
- During steady-state and transient conditions, PID controller minimize torque ripple as compared to P, PD and PI controllers.

CONCLUSION

This research work is mainly emphasized on the study of performance of vector control IM and PMSM drive system using conventional controllers. The vector control is to achieve high dynamic performance in AC motor drive system e.g. to make the drive system respond in a fast manner to change in the reference speed or torque. It is clear from simulation results; in steady-state and transient conditions conventional controller reduces the speed and torque ripple. In the case of IM drive the speed response is faster and more robust than the PMSM drive. The IM drive scheme has a better speed and torque response. While comparing both drives with the conventional P, PI, PD, and PID controller and achieved superior performance. PID controller has minimised ripple contents of speed and torque and also improved dynamic performance under transient and steady-state operating conditions. We conclude that from the above simulation results PID speed controller is providing smooth and improved performances as compared to other controllers.

DOI 10.17148/IJIREEICE.2018.6121

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