Vol 5 Issue 2 Nov 2015

ISSN No : 2249-894X

Monthly Multidisciplinary Research Journal

Review Of Research Journal

Welcome to Review Of Research

RNI MAHMUL/2011/38595 **ISSN No.2249-894X**

Review Of Research Journal is a multidisciplinary research journal, published monthly in English, Hindi & Marathi Language. All research papers submitted to the journal will be double - blind peer reviewed referred by members of the editorial Board readers will include investigator in universities, research institutes government and industry with research interest in the general subjects.

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Review Of Research
ISSN 2249-894X

Impact Factor : 3.1402(UIF)
Volume - 5 | Issue - 2 | Nov - 2015

A DYNAMIC MODELING PERMANENT MAGNET SYNCHRONOUS MOTOR DRIVE SYSTEM

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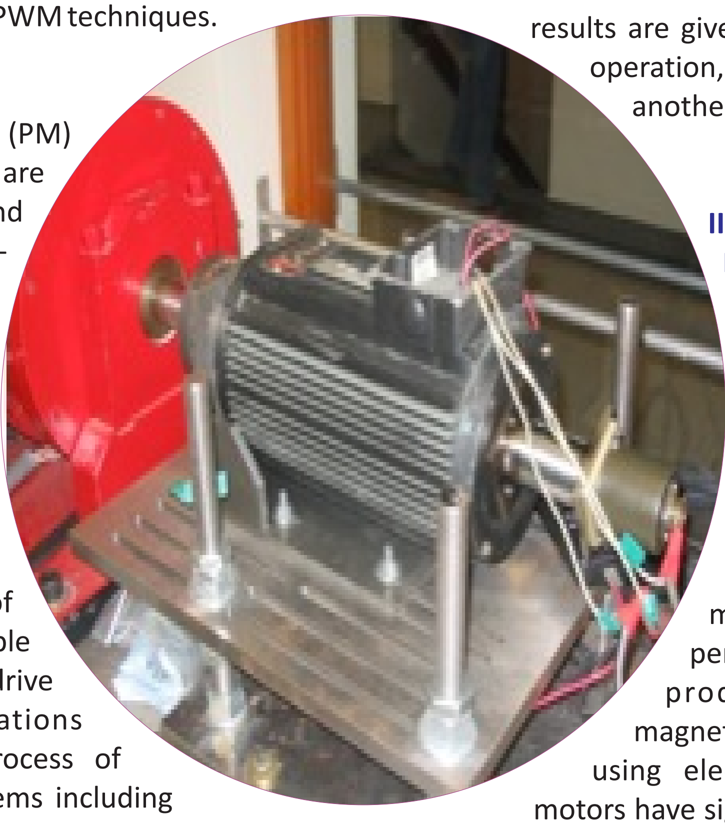
ABSTRACT:
Field oriented control is used for the operation of the drive. The simulation includes all realistic components of the system. This enables the calculation of currents and voltages in different parts of the inverter and motor under transient and steady conditions.

KEY WORDS: pmsm; pmsm drive system; FOC; hysteresis controller; PWM techniques.



I.INTRODUCTION:

Permanent magnet (PM) synchronous motors are widely used in low and mid power applications such as computer peripheral equipment, 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. A closed loop control system with a PI controller in the speed loop has been designed to operate in constant torque and flux weakening regions. Implementation has been done in Simulink. A comparative study of hysteresis and PWM control schemes associated with current controllers has been made in terms of harmonic spectrum and total harmonic distortion. Simulation results are given for two speeds of operation, one below rated and another above rated speed.

II. PERMANENT MAGNET SYNCHRONOUS MOTOR DRIVE SYSTEM

A. Permanent Magnet Synchronous Motor

A permanent magnet synchronous motor (PMSM) is a motor that uses permanent magnets to produce the air gap magnetic field rather than using electromagnets. These motors have significant advantages, attracting the interest of researchers and industry for use in many applications

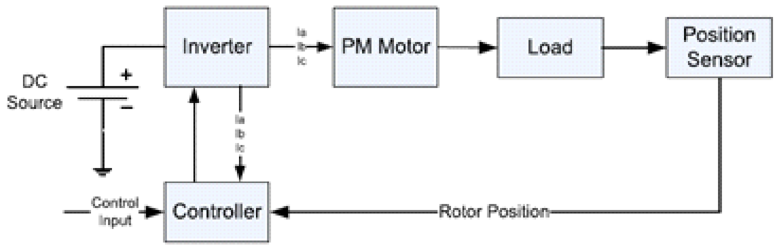


Fig-1. PMSM drive system

B.Classification of Permanent Magnet Motors

1.Direction of field flux

PM motors are broadly classified by the direction of the field flux. The first field flux classification is radial field motor meaning that the flux is along the radius of the motor. The second is axial field motor meaning that the flux is perpendicular to the radius of the motor. Radial field flux is most commonly used in motors and axial field flux have become a topic of interest for study and used in a few applications.

2.Flux density distribution

PM motors are classified on the basis of the flux density distribution and the shape of current excitation. They are PMSM and PM brushless motors (BLDC). The PMSM has a sinusoidal-shaped back EMF and is designed to develop sinusoidal back EMF waveforms

III.MODELING OF PM DRIVE SYSTEM

Detailed modeling of PM motor drive system is required for proper simulation of the system. The d-q model has been developed on rotor reference frame. At any time t, the rotating rotor d-axis makes and angle θr with the fixed stator phase axis and rotating stator mmf makes an angle a with the rotor d-axis. Stator mmf rotates at the same speed as that of the rotor.

$$V_q = R_S\, i_q + \omega_r \lambda_d + \rho\lambda_q$$
$$V_d = R_S\, i_d - \omega_r \lambda_q + \rho\lambda_d$$

Fulx Linkage are given by

$$\lambda_q = L_q i_q$$
$$\lambda_d = L_q i_d + \lambda_f$$

Arranging equations in matrix form

$$\begin{pmatrix} Vq \\ Vd \end{pmatrix} = \begin{pmatrix} R_s + \rho L_q & \omega_r L_d \\ -\omega_r L_d & R_s + \rho L_d \end{pmatrix} \begin{pmatrix} Iq \\ Id \end{pmatrix} + \begin{pmatrix} \omega_r \lambda_f \\ \rho\lambda_f \end{pmatrix}$$

The developed torque motor is being given by

$$T_e = \frac{3}{2}\left(\frac{P}{2}\right)(\lambda_d i_q - \lambda_q i_d)$$

A.Equivalent Circuit of Permanent Magnet Synchronous Motor

Equivalent circuits of the motors are used for study and simulation of motors. From the d-q modeling of the motor using the stator voltage equations the equivalent circuit of the motor can be derived.

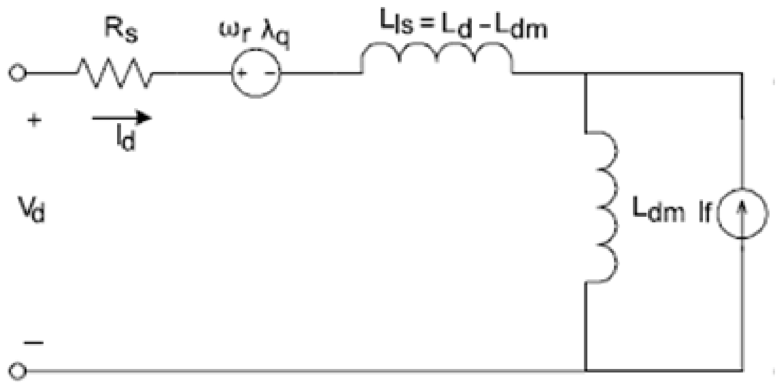


Fig-2. PMSM electric circuit d-axis

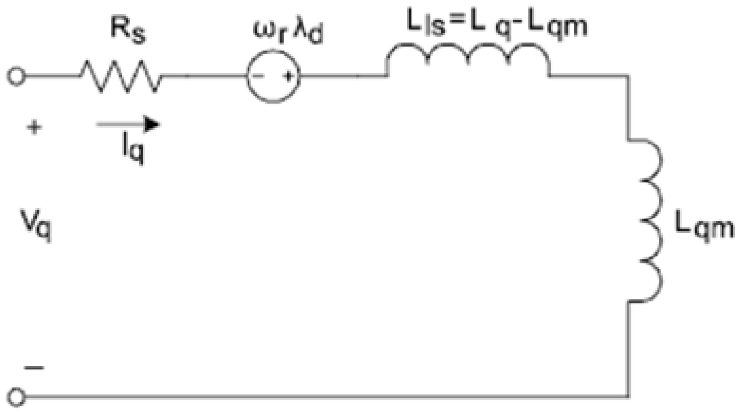


Fig-3. PMSM electric circuit q-axis

Field oriented control was invented in the beginning of 1970s and it demonstrates that an induction motor or synchronous motor could be controlled like a separately excited dc motor by the orientation of the stator mmf or current vector in relation to the rotor flux to achieve a desired objective. In order for the motor to behave like DC motor, the control needs knowledge of the position of the instantaneous rotor flux or rotor position of permanent magnet motor. This needs a resolver or an absolute optical encoder. Knowing the position, the three phase currents can be calculated. Its calculation using the current matrix depends on the control desired. Some control options are constant torque and flux weakening. These options are based in the physical limitation of the motor and the inverter. The limit is established by the rated speed of the motor, at which speed the constant torque operation finishes and the flux weakening starts as shown in figure.4.

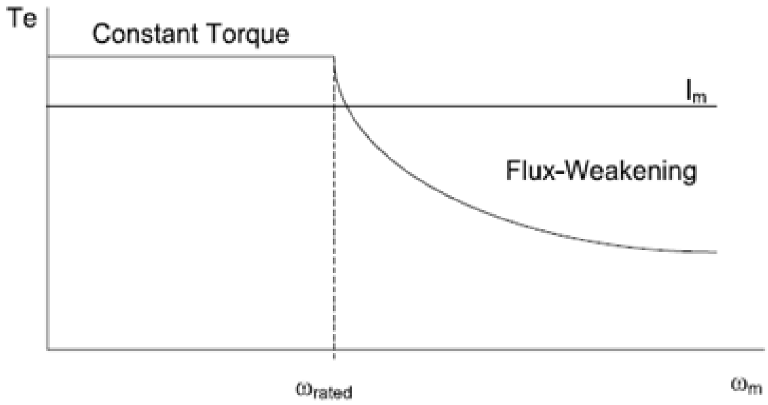


Fig-4. Steady state Torque Vs Speed

1. Constant torque operation

Constant torque control strategy is derived from field oriented control, where the maximum possible torque is desired at all times like the dc motor. This is performed by making the torque producing current iq equal to the supply current Im.

2.Flux Weakning

Flux weakening is the process of reducing the flux in the d axis direction of the motor which results in an increased speed range. The motor drive is operated with rated flux linkages up to a speed where the ratio between the induced emf and stator frequency (V/f) is maintained constant. After the base frequency, the V/f ratio is reduced due to the limit of the inverter dc voltage source which is fixed. The weakening of the field flux is required for operation above the base frequency.

B.Speed control of PM motor

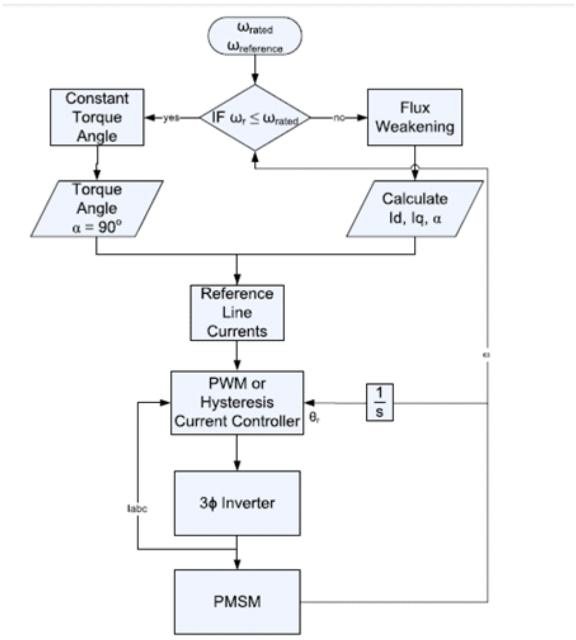


Fig-5. System flow diagram

Speed controller calculates the difference between the reference speed and the actual speed producing an error, which is fed to the PI controller. PI controllers are used widely for motion control systems. They consist of a proportional gain that produces an output proportional to the input error and an integration to make the steady state error zero for a step change in the input. Block diagram of the PI controller is shown in figure 6.

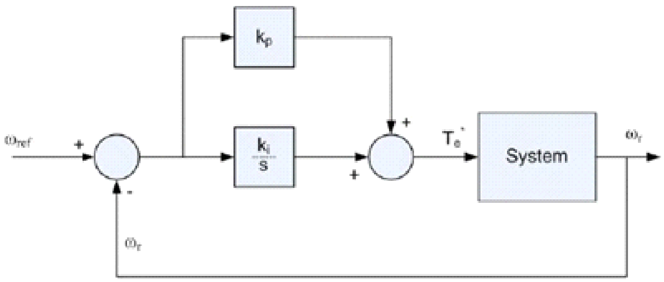


Fig-6. PI controller

Speed control of motors mainly consist of two loops the inner loop for current and the outer loop for speed. The order of the loops is due to their response, how fast they can be changed. This requires a current loop at least 10 times faster than the speed loop. Since the PMSM is operated using field oriented control, it can be modeled like a dc motor. The design begins with the innermost current loop by drawing the block diagram. But in PMSM drive system the motor has current controllers which make the current loop. The current control is performed by the comparison of the reference currents with the actual motor currents.

IV.DRIVE SYSTEM SIMULATION IN SIMULINK

The PM motor drive simulation was built in several steps like abc phase transformation to dqo variables, calculation torque and speed, and control circuit. The abc phase transformation to dqo variables is built using Parks transformation and for the dqo to abc the reverse transformation is used. For simulation purpose the voltages are the inputs and the current are output. Parks transformation used for converting Vabc to Vdqo is shown in figure 7.

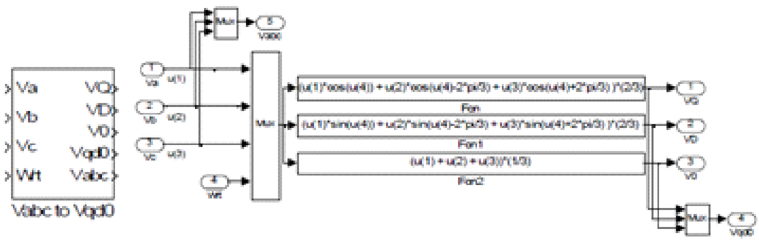


Fig-7.Vabc to Vdqo Block

The d and q axis motor circuits built using Simulink elements are shown in figure 8. And 9.

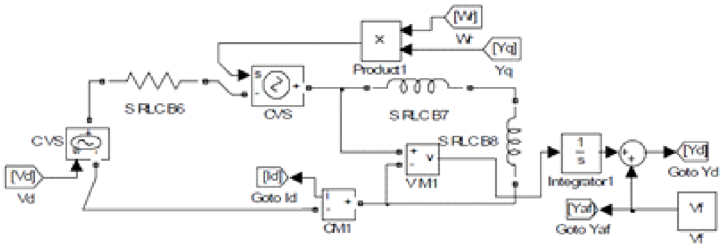


Fig-8. d axis circuit

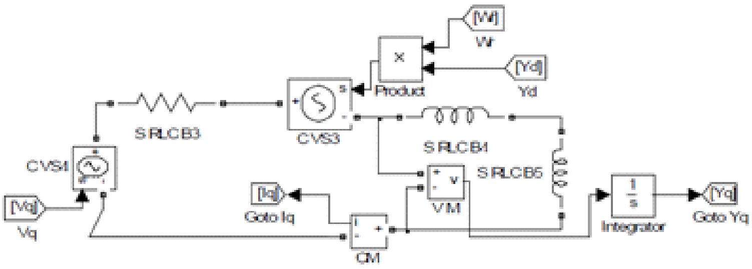


Fig-9. q axis circuit

V. RESULTS

The system built in Simulink for a PMSM drive system has been tested with the two current control methods, Hysteresis and PWM, at the constant torque and flux-weakening regions of operation. The motor parameters used for simulation are given in table 1. These parameters were taken from reference.

The motor is operated with constant torque up to its rated speed and beyond that rated speed flux-weakening mode is adopted. Simulation results are given at electrical speeds of 200 radians per second (31 Hz) and 600 radians per second (95 Hz). The above speeds represent below and above rated speed of the motor.

Table-1 Interior Permanent Magnet Motor Parameters

Symbol	Name	Value
V_{LL}	Rated Voltage	220 V
Pout	magnetic flux	900w
P	Number of Poles	4
ω_m	Rated Speed	1700 rpm
Rs	Stator Resistance	4.3 Ω
λ_{af}	PM Flux Linkage	0.272 Wbturns
Ld	q-axis Inductance	27 mH
Ld	d-axis Inductance	67 mH
Is	Rated Current	3 A
Ismax	Maximung Current	2Israted
J	Motor Inertia	0.000179 kg m^2

The simulation was carried out using two current control techniques to study the performance of the motor drive. The techniques are Hysteresis current control and PWM current control. The plots of current, torque and speed are given for both cases.

A.Simulation for Operation at 200 rad/s

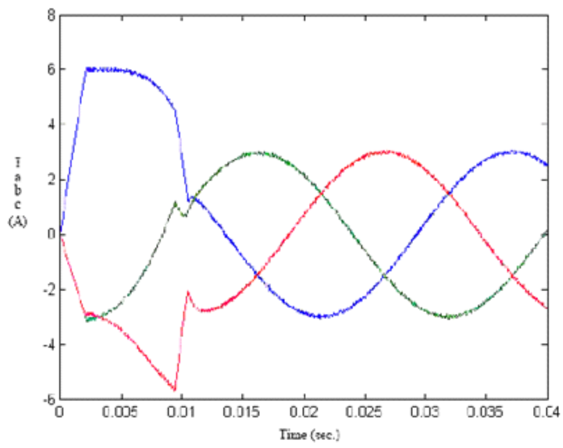


Fig- 10 Iabc Currents with Hysteresis Control at 200 rad/s

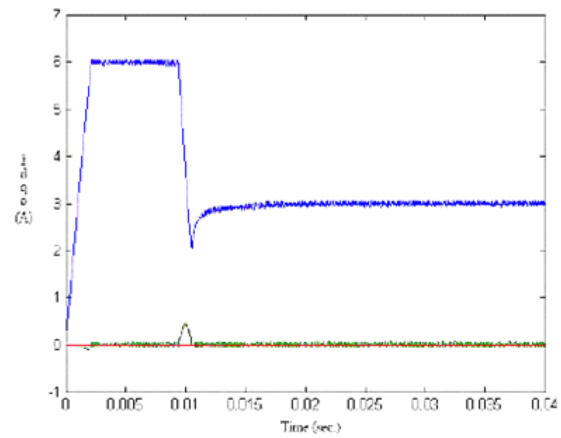


Fig- 11 Idqo Currents with Hysteresis Control at 200 rad/s

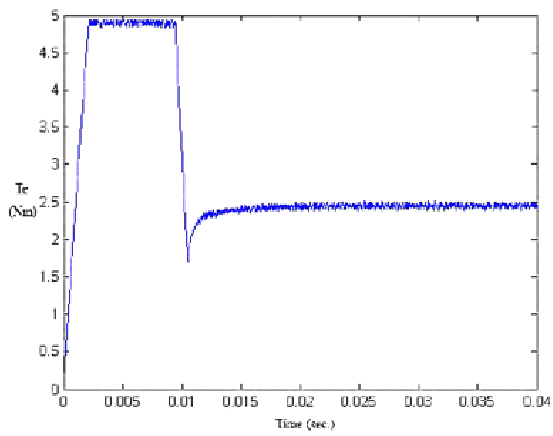


Fig- 12 Developed torque with Hysteresis Control at 200 rad/s

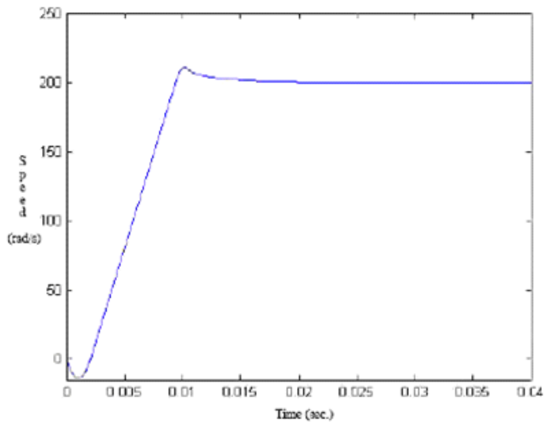


Fig- 13Motor Electrical speed with Hysteresis Control at 200 rad/s

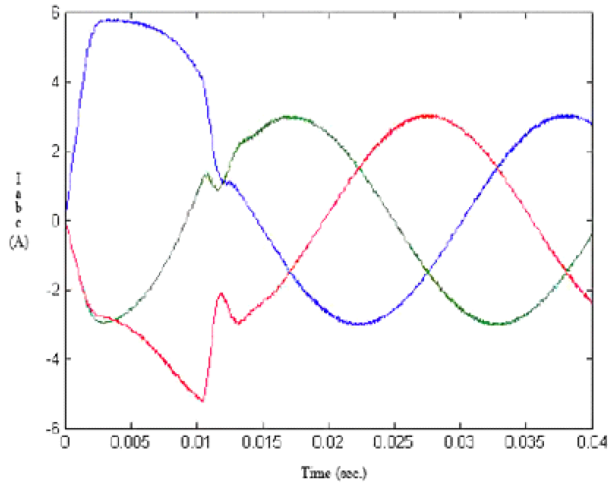


Fig- 14 Iabc Currents with PWM Control at 200 rad/s

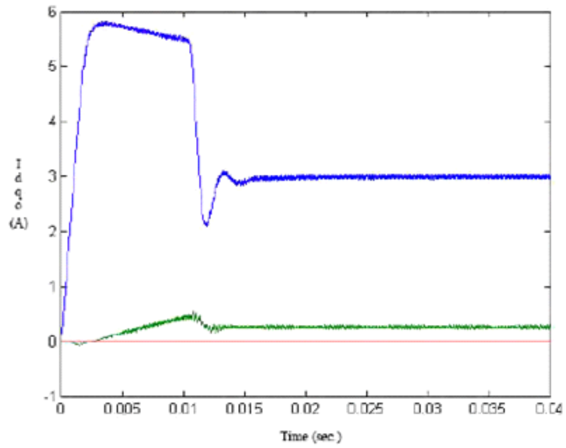


Fig- 15 Idqo Currents with PWM Control at 200 rad/s

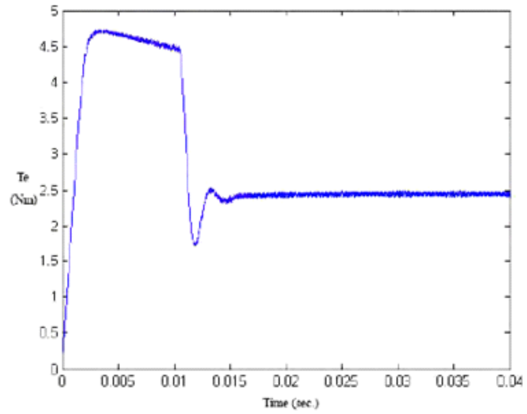


Fig- 16 Developed torque with PWM Control at 200 rad/s

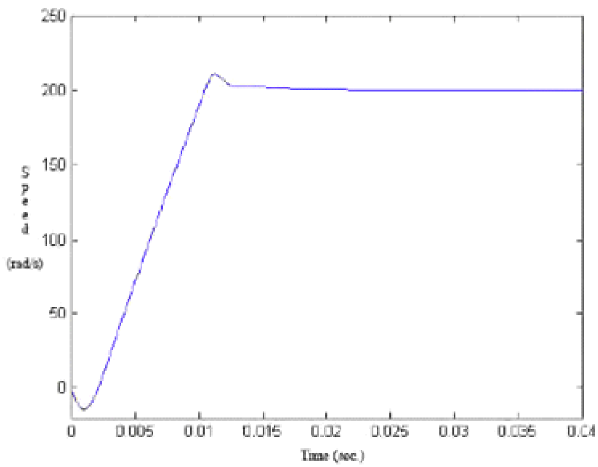


Fig- 17Motor Electrical speed with PWM Control at 200 rad/s

VI. CONCLUSION

Usually in such a drive system the inverter is driven either by hysteresis or by PWM current controllers. A comparative study has been made of the two current control schemes in terms of switching frequency, device losses, power quality, speed error and current control ability. This study proves that PWM current controllers are better than hysteresis current controllers because of having constant switching frequency and lower THD of the input voltage waveforms. The error between the speed command and the actual speed is also greatly reduced. Hysteresis current controllers have a variable switching frequency that depends of the hysteresis band and if the bandwidth is very small it may affect the device switching capability. However, the simulation with hysteresis current controller allows faster simulations with reduced time and computational resources. A speed controller has been designed successfully for closed loop operation of the PMSM drive system so that the motor runs at the commanded or reference speed. The simulated system has a fast response with practically zero steady state error thus validating the design method of the speed controller.

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