Cascaded H-Bridge Multilevel Inverter Fed Pmsm

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ABSTRACT

Permanent magnet synchronous motors are increasing applied in several areas such as traction,automobiles, robotics and aerospace technology. The power density of permanent magnet synchronous motor is higher than one of induction motor with the same ratings due to the no stator power dedicated to the magnetic field production. Multilevel inverters have drawn tremendous interest in the power industry. It is easy to produce a high-power, high voltage inverter with the multilevel structure because of the way in which device voltages stresses are controlled. The unique structure of multilevel inverters allow them to reach high voltages with low harmonics. Cascaded multilevel inverters has gained more interest because of its advantages over other MLI configurations like diode-clamped, flying capacitor inverter. In this paper high voltages required for Permanent Magnet Synchronous Motor which is used in traction, automobiles is fed using cascaded multilevel inverter andsimulation is done using MATLAB SIMULINK.

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1. Introduction

Permanent Magnet Synchronous Motor consists of permanent magnets in rotor assembly generating a steady magnetic fieldyielded many advantages. These advantages include

i) compact form with high torque density and less weight
ii) higher continuous torque over a wider range of speeds
iii) lower rotor inertia, higher dynamic performance under load
iv) higher operational efficiencies with no magnetizing current
v) absence of heat due to current in the rotor
vi) low torque ripple effect

Permanent magnet synchronous torque motors typically have 30%-60% higher torque capacity and 30% better torque utilization with faster acceleration and deceleration, compared to asynchronous induction type motors, hence used in traction and electric vehicles.

High power and high-voltage conversion systems have become very important issues for the power Bridges, each H-Bridge consists of four switches connected as in fig.1

electronic industry handling the large ac drive and electrical power applications at both the transmission and distribution levels. High power ratings is not possible for a two-level inverter (i.e. it gives +Vdc , -Vdc), as the semiconductor devices must be connected in series to obtain the required high-voltage operation, this can be achieved by summing the outputs of several two-level converters with transformers or inductors, or direct series connection, or by some topologies such as the diode clamped inverter and the flying capacitor inverter which are usually termed as multilevel voltage source inverters. The general structure of the multilevel converter, which has a multiple of the usual six switches found in a three-phase inverter, is to synthesize a sinusoidal voltage from several levels of voltages, typically obtained from capacitor voltage sources. The main motivation for such converters is that current is shared among these multiple switches, allowing a higher converter power rating than the individual switch VA rating would otherwise allow with low harmonics. As the number of levels increases, the synthesized output waveform, a staircase like wave, approaches a desired waveform with decreasing harmonic distortion, approaching zero as the number of levels increases.

There are three main types of transformer less multilevel inverter topologies, which have been received considerable interest from high-power inverter systems are the flying-capacitor inverter, the diode-clampedinverter, and the cascaded H-bridge inverter. In this paper we choose to work on cascaded H-bridge inverter due to its advantages:

1. It uses fewer components than the other types.
2. It has a simple control, since the converters present the same structure.
3. Soft-switching technique can be used to reduce switching losses and devices stresses.

Because of these advantages, the cascaded inverter bridge has been widely applied to such areas as HVDC, SVC, stabilizers, and high-power motor drives.

2.Cascaded H-Bridge MLI

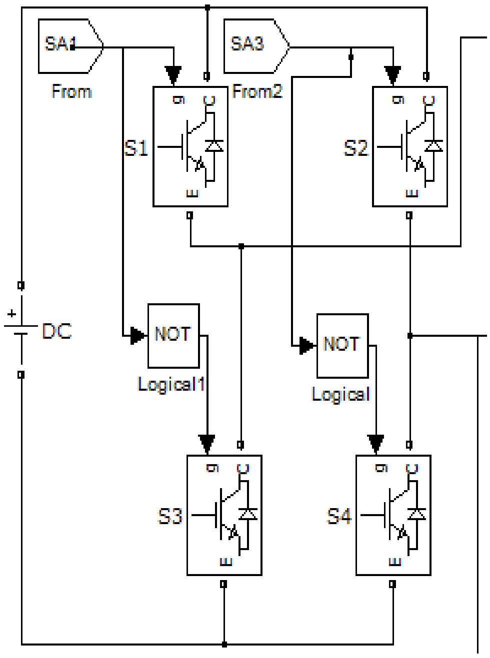

Figure 1. Single cascaded bridge

The output generated by each H-Bridge is of three different levels i.e, +Vdc, 0, -Vdc by connecting dc source to the ac output side by different combinations of the four switches, S1,S2,S3,S4. Turning on S1,S4 gives +Vdc. Turning on S2,S3 yields –Vdc. Turning off all switches gives 0V. In the same manner output at each level is obtained. The switching sequence for a single bridge is as follows, the firing pulse for upper switches S1,S3 has phase delay of 180^0 . The lower switches are compliments firing pulse given through NOT gate. The same holds good for any no of bridges connected either in single phase or three phase. Here three phase cascaded MLI is simulated. For N-level output no of bridges required per phase is given by N=2n+1.

Where n= no of bridges

For 5 level we require 2 bridges per phase.

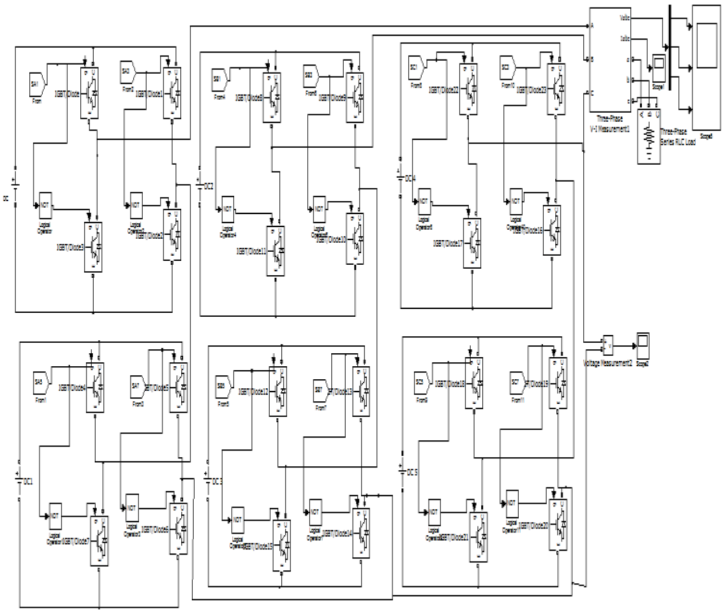

Figure 2.Three phase 5 level MLI

Controlling the conducting angles at different inverter levels can minimise the harmonic distortion of the output voltage. As the no of levels increases the output voltage tends to sinusoidal.

2.1 Switching Technique

Switching is implemented by sinusoidal pulse width modulation. In pulse width modulation the firing pulses required for semiconductor switches is obtained by comparing reference wave with carrier wave. In sinusoidal pulse width modulation technique sinusoidal wave is taken reference wave and triangular wave as carrier wave. The output of inverter i.e. amplitude and frequency can be varied by changing the reference wave amplitude and carrier wave frequency respectively. Amplitude modulation index is ratio of reference wave amplitude to carrier wave amplitude $m_a = V_r / V_c$. The frequency modulation is defined as ratio of carrier wave frequency to reference wave frequency $m_f = f_c / f_r$. In this paper the amplitude modulation is taken as $m_a = 1$ and the frequency modulation $m_f = 21$. The pulses are generated as below in figure

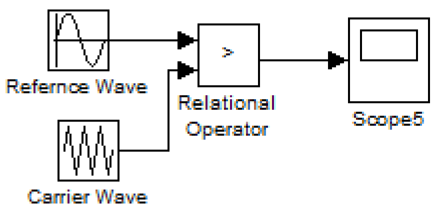

Figure 3.Pwm comparator

Here the MLI is three phase the firing pulses are given with phase delay of $120^0$to each leg. The switches in a single leg are connected as shown in fig.4

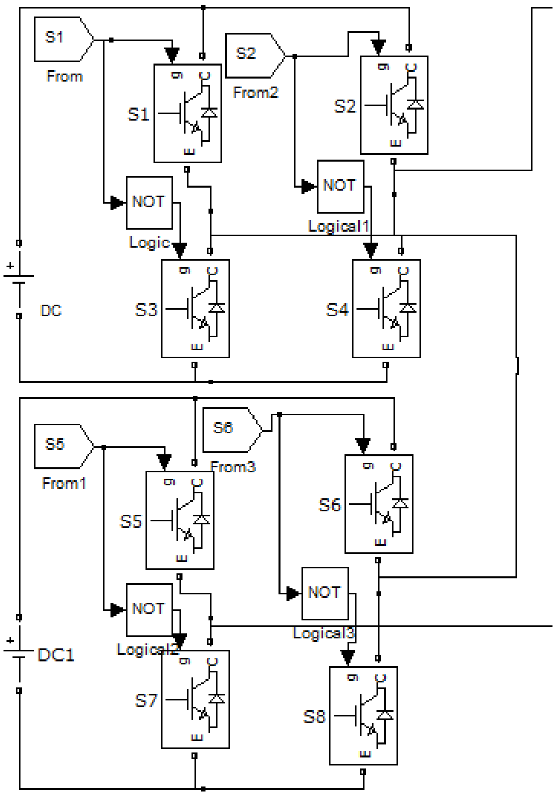

Figure 4. Single leg of three phase inverter

The switch S1 and S2 has phase delay of 180^0. Switch S1 and S5 has phase delay of 90^0. Switches S3,S4 are compliment for switch S1, S2 respectively and similarly S7,S8 are compliment to switch S5,S6. In the same the other two legs are connected and switching is done in the similar fashion.
The switching pattern is tabulated below is for one leg of three phase inverter.

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Table.1. Switching patterns(1(1-On, 0-Off)

SWItch	0	30	60	90	120	150	180	210	240	270	300	330	360
S1	1	1	1	1	1	0	0	0	0	0	1	1	1
S2	1	0	0	0	0	0	1	1	1	1	1	0	0
S3	0	0	0	0	0	1	1	1	1	1	0	0	0
S4	1	1	1	1	1	1	0	0	0	0	0	1	1
S5	0	0	0	1	1	1	1	1	0	0	0	0	0
S6	1	0	0	0	0	0	1	1	1	1	1	1	1
S7	1	1	1	0	0	0	0	0	1	1	1	1	1
S8	0	1	1	1	1	1	0	0	0	0	0	0	0

3.Modeling of PMSM

The dynamic model of the permanent magnet synchronous machine (PMSM) isderived using a two-phase motor in direct and quadrature (d-q) axes. This approach is desirable because of the conceptual simplicity obtained with only one set of two windings on the stator. The rotor has no windings, only magnets.The magnets are modeled as a current source or a flux linkage source, concentrating all its flux linkages along only one axis. The d- and q-axes stator voltages are derived as the sum of the resistive voltage drops and the derivative of the flux linkages in the respective windings as

Vqs = Rsiqs + iqspLqq + Lqqpiqs + Lqdpids +ids pLqd + λafpsinθr

Vds = Rs ids + iqspLqd + Lqdpiqs +Lddpids + ids p Ldd + λafpcosθr

where –

*p*is the differential operator, d/ d*t* .

*v*qs and *v*ds are the voltages in the q- and d-axes windings .

*i*qs and *i*ds are the q- and d-axes stator currents .

*R*q and *R*d are the stator q- and d-axes resistances.

λqs and λds are the stator q- and d-axes stator flux linkages.

The surface mounted magnet machines in stator reference frames is derived initially in which the inductances are rotor position dependent. The rotor position dependency is eliminated by transformation. The PMSM model in rotor reference frames is obtained as

$$\begin{bmatrix} Vrqs \\ Vrds \end{bmatrix} = \begin{bmatrix} Rs+Lqp & wrLd \\ -wrLq & Rs+Ldp \end{bmatrix} \begin{bmatrix} irqs \\ irds \end{bmatrix} + \begin{bmatrix} wr\lambda af \\ 0 \end{bmatrix}$$

Vrqs, Vrds – Stator voltages in rotor reference

irqs, irds - Stator currents in rotor reference

Where wr-rotor speed in electrical radians per second.

The electromagnetic torque is

$T_e=(3/2)(P/2)[\lambda_{af}+(L_d-L_q)i^r_{dr}]i^r_{qr}$ (N.m)

P- no of poles

λ- flux linkage

L_d,L_q- d,q axis inductances

The rotor mechanical speed is obtained as

$w_m = \int ((Te - Tl - Bw_m)/ J)\, dt$

Where T_e –Electromagnetic torque

T_l= load torque

B - Friction coefficient

J – Inertia of motor

Simulink model of PMSM

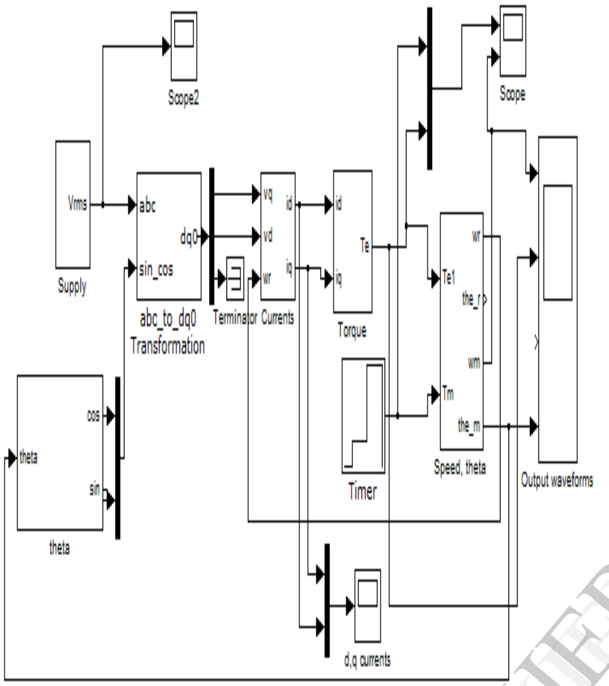

Figure 5.PMSM Simulink block.

The overall Simulink block consisting of Three phase five level MLI and PMSM

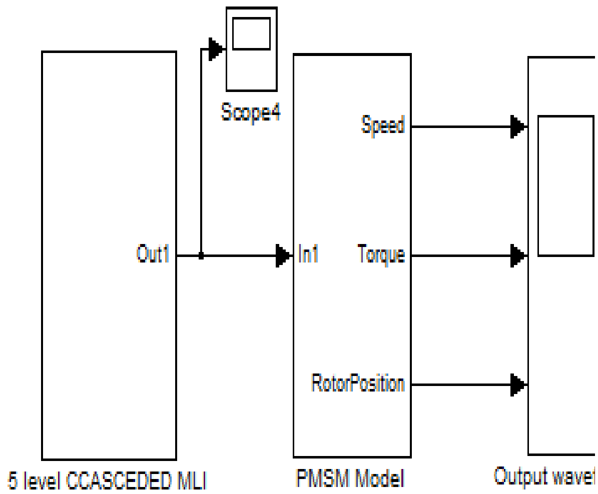

Figure 6. Complete simulation block

4.Simulation Results

4.1Firing pulses

The firing pulses for the switches provided for single leg are as shown in figure.7

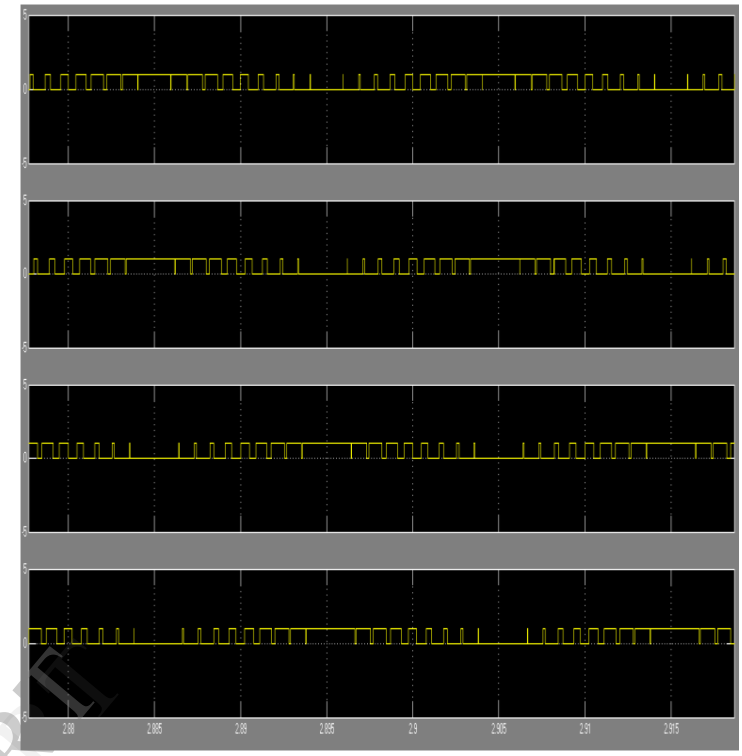

Figure 7.firing pulses

4.2Output Voltages

The output phase voltage waveforms of three phase 5 level of cascaded MLI are as shown

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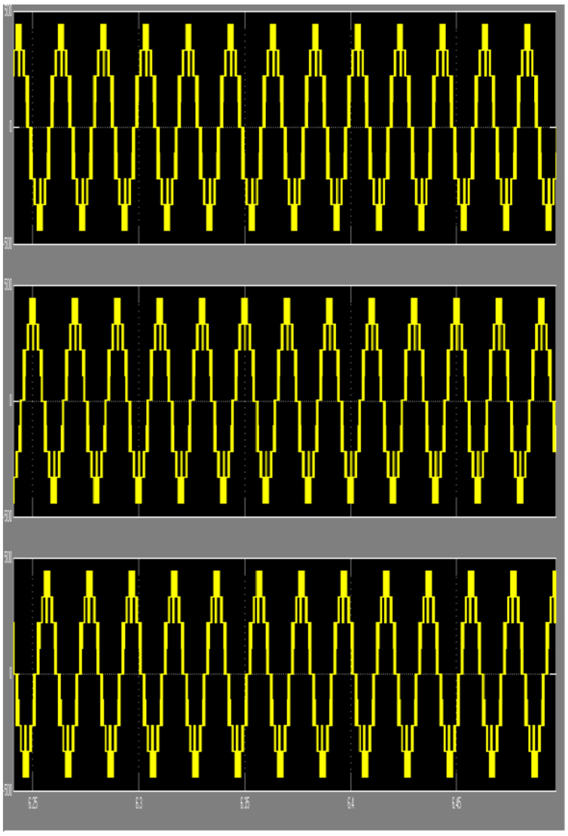
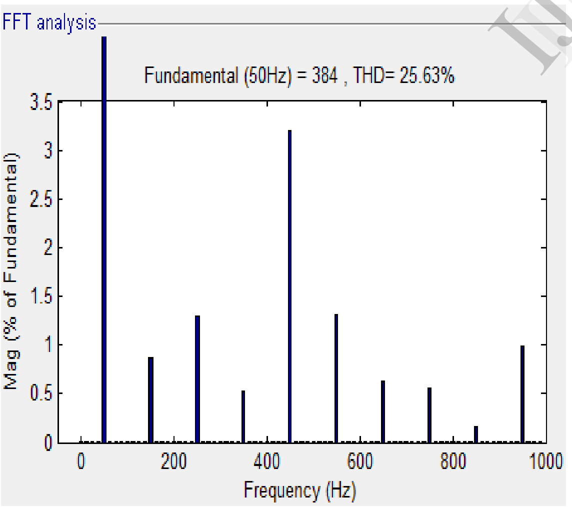


Figure 8. Three phase voltage waveforms

4.3 FFT Analysis of Output Phase Voltages

Total harmonic distortion of three phase voltages are as shown



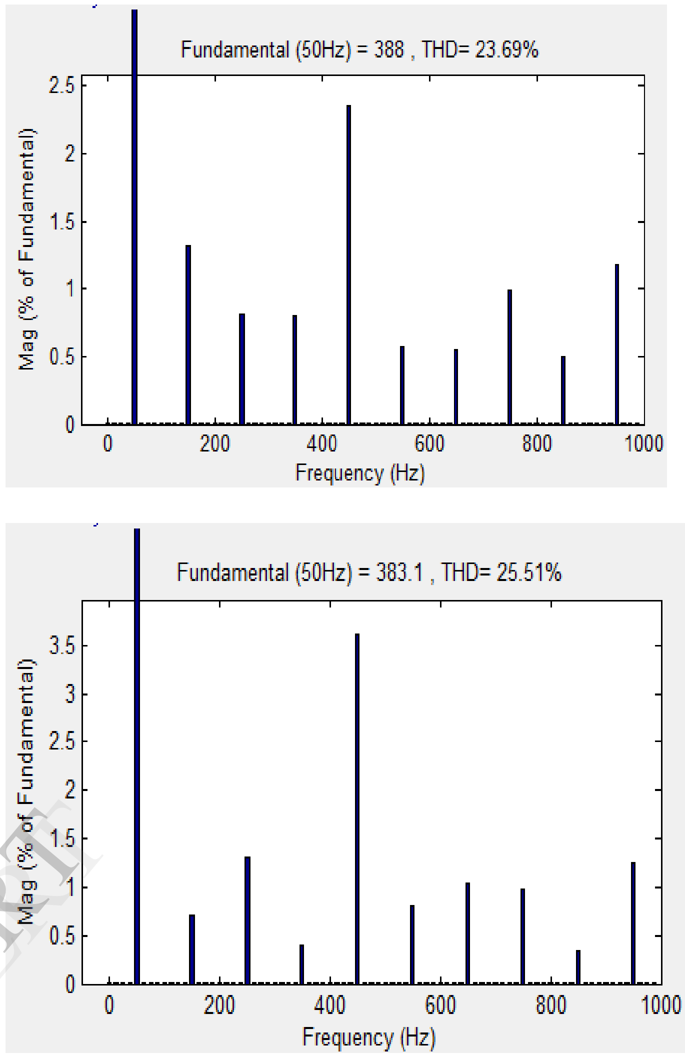


Figure 9. THD of three phase voltage

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4.3Simulation results of PMSM:

Motor values are
Stator Resistance Rs= 1.2Ω ,
B = 4.6752e-5 kg/m^2
J = 2.0095e-5 N-m s
Stator Resistance = 2.0357Ω
Direct axisInductance(Ld) =7.8e3H
Quadrature axis Inductance(Lq) = 7.8e-3 H
Flux (λ) – 0.154 mWb
Poles=4, Vrms = 440 V

4.3.1Statorcurrent

The quadrature axis and direct axis currents of PMSM

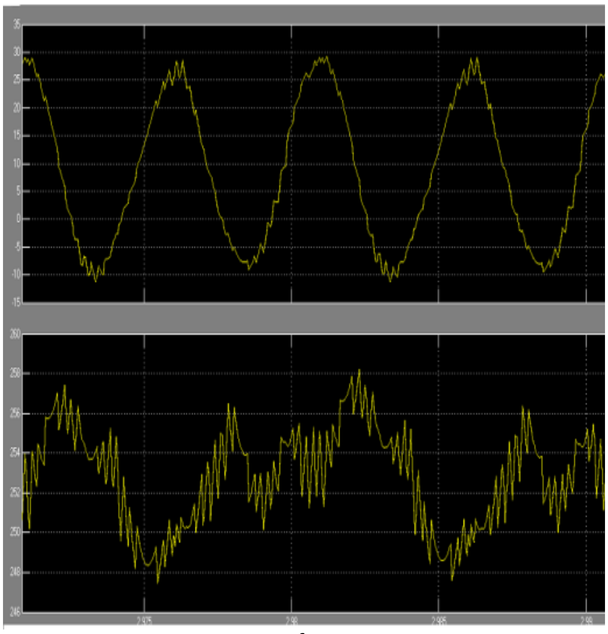

Figure 12. Stator currents of pmsm

4.3.2Speed,Electromagnetic torque, Rotor position:

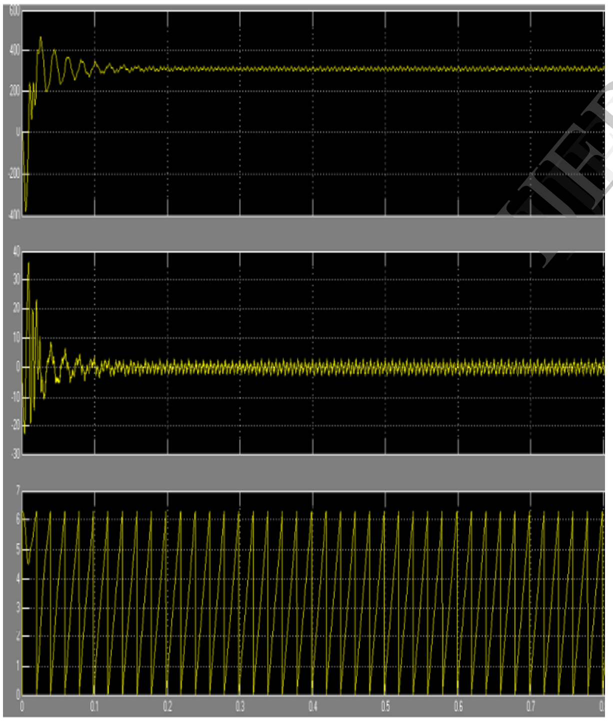

Figure 13.speed,torque,rotor position

5.Conclusion

In this paper three phase cascaded MLI is simulated and three phase output voltages are obtained. This output voltage is fed to mathematically modelled permanent magnet synchronous motor. The motor characteristics like electromagnetic torque, Speed, Rotor position, Stator current are observed. Motor speed is maintained constant with change in load torque which is the inherent property of PMSM is observed. In extension to this work a suitable drive with appropriate controller can be done.

6.References

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