MATLAB/Simulink Based Model for 25 kV AC Electric Traction Drive

Shubhra (MIEEE, LMIETE)
Assistant Professor
Indraprastha Engineering College
Ghaziabad, Uttar Pradesh, India

***Abstract*-- Advances in power Electronics have permitted Variable Voltage Variable Frequency (VVVF)controlled device for induction motors becoming immensely popular. These devices save power and permit the robust squirrel cage motor to drive from the smallest pump motors to fuel efficient hybrid drive cars and buses to the most powerful Diesel loco upto 4000 kW and Electric Locomotives up to 9000kW. This paper presents a novel method of modelling AC Traction drive using MATLAB. Power system Block set/simulation software focusingon Rectifier – Inverter – Motor systems. Three phase induction motor used in electric locomotive has been considered for the model. The inverter has been simulated to operate in two modes i.e. six step and Pulse Width Modulation (PWM) mode with rectifier block. The inverter fault condition has also been simulated to study the performance of electric traction drive under loaded condition. The model can be used to evaluate the load torque value for a particular speed of traction motor drive.**

***Keywords*-- Rectifier, inverter, MATLAB, Simulink, Traction, Induction Motor.**

I. INTRODUCTION

Railway electrification emerged as means of electrification in late years of nineteen centuries & it came to India in 1925 with DC traction. However AC traction started in Indian in late fifties. Major boost of electric traction was provided by the advancement in power electronics field. The overhead system supplies energy to the traction motors in a controlled manner, which is mounted on the electric locomotive. Locomotive in turn develop tractiveeffort to move the train from stationary position. In this process it overcomes the train air resistance, air drag, gradient& provides the desired acceleration to movethe train not only onstraight track but also on curved track. The State PowerUtilities,supply power at 220/132/110/66 kV Extra High Voltage (EHV) at each traction substation which is owned, installed, operated and maintained by the Railways.

With nanotechnology in place & cut throat competition, designs for traction drive have to be built with optimal cost. To achieve that model based design techniques are preferred to create implementable product specifications. Simulation tools help to optimally design the system & engineer can be benefitted by integration of simulation with the design process to reduce design time and cost. This is a great tool for industries to first design & then validates the test results [1, 2].

II. ELECTRIC TRACTION DRIVE SYSTEM

Block diagram for a typical electric traction drive is shown in “Fig. 1”. The electric power is supplied to the locomotive propulsion drives via overhead lines. Motor-end inverter can be a current source inverter or a voltage source inverter[3].The circuitry of the input converter which provides a DC supply for the load side converter depends on the following:

- Type of input power supply i.e. AC or DC
- Electricity utility’s limits on reactive power harmonics.
- Type of electric brakes; that’s regenerative, rheostatic or both.

AC voltage from the 25 kV catenary supply is reduced to the required voltage of the single phase rectifier. The properly filtered output of rectifier becomes the input to the inverter. A three phase inverter provides this high frequency controlled input to the motor. Depending upon the control scheme adopted, the firing pattern of three-phase inverter is established and the desired inverter output is achieved. The desired high frequency output of inverter is then fed to three-phase induction motor to get required value of torque and speed.

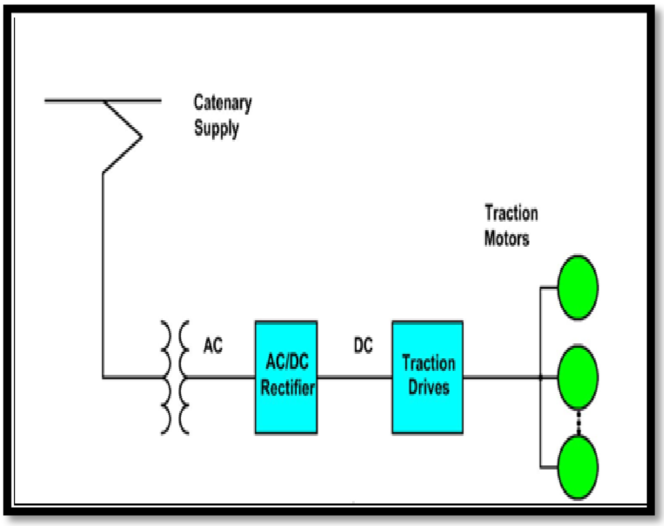

Fig. 1: Electric Traction Drive with Catenary Supply

III. MODEL DEVELOPMENT PROCESS

The Simulink based PWM inverter model has been used for the paper contains fault simulations blocks where various types of three–phase inverter faults can be simulated, transient conditions of current and torque has been displayed under Normal and Inverter Fault Conditions. Its performance is studied under PWM mode and Six Step Mode.

PWM inverter-fed induction motor drives are being used in large numbers throughout a wide variety of industrial and traction applications. Both voltage & frequency are varied by PWM inverter. As input voltage given to a PWM inverter should be constant and not variable, therefore an uncontrolled rectifier can be used so input power factor is much better as compared to scheme with a square wave inverter.

1. Simulation Model Blocks

The modelling of the rectifier system has been carried out by using universal bridge to provide a perfect DC signal. The rectifier model has been developed by making use of MATLAB/Power System Block (PSB) software. The rectified DC voltage is fed to a PWM inverter [4].

In AC Propulsion system, 25 kV single phase line voltages is fed to a transformer, whose secondary winding is connected to single-phase diode rectifier with a DC link capacitor which produces a DC output. The DC voltage is then passed to the inverter, which provides the controlled three phase supply to the traction motors. This forms the source for the two voltage source inverters that supply power to six AC motors. The models of the all individual systems are integrated in to one connected system for simulation purpose.

In traction locomotive, there are two inverters and each inverter feed, three induction motors which drive the axles and wheels through the gear boxes. The present work does a mathematical modeling of the inverter system including fault condition. The conditions of current imbalance & braking torque developed to estimate the induction machine maximum transient torque in the event of inverter fault [5].

2. Inverter Model Description

The inverter model is realized by generating voltage outputs of the inverter by algebraic calculations based on 'ON' or 'OFF' state of the pulses. At OFF state, switches are modeled as ideal open-circuits. The models consist of several blocks and each block is a combination of subsystems of smaller blocks. In the 'Inverter block'sine wave modulating signal and the carrier waveform are given to the modulator block, which compares the two waveforms and according to the sine PWM principle, generates thetwelve gate pulses.There are total twelve pulses, six for each inverter. The gating pulses are given to the 'Power Circuit Block' as shown in "Fig. 2", where 0.5 Vdc and -0.5 Vdc signals are also given. The outputs of the power circuit block are the required to be fed as three phase voltages for all the six motors.

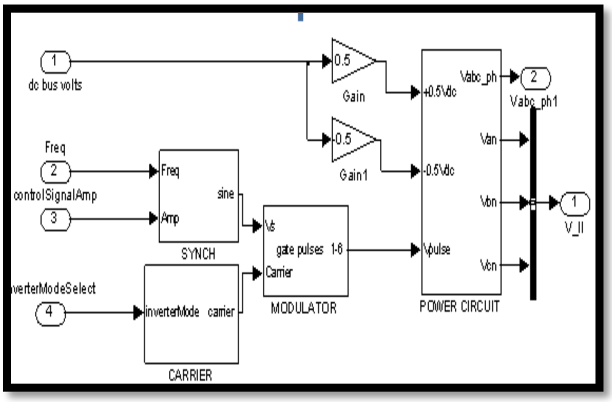

Fig. 2: Internal details of ' Inverter Block'

"Fig. 3", shows the details of the 'Power Circuit Block', in which there are six switches taken, whose threshold inputs are the gating pulses previously received. +0.5 Vdc and zero are the upper and lower signal inputs for the three top level switches and -0.5Vdc and zero are the upper and lower signal inputs for the three bottom level switches.

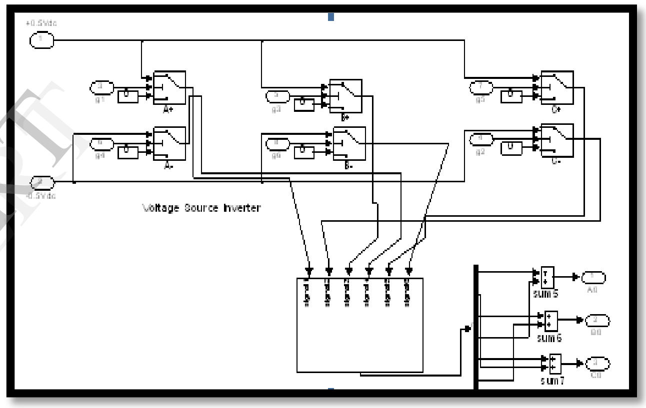

Fig. 3: Internal details of ' Power Circuit

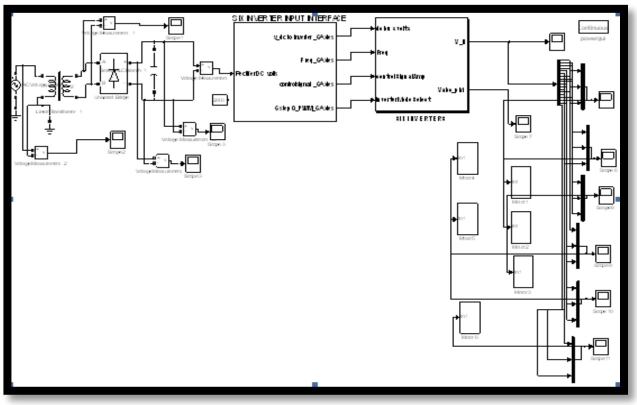

Fig. 4: Rectifier two inverter model with six motors

3. Inverter Fed Induction Motor Model Description

Rectifier - DC Link -Two inverter model with six motors is as shown in "Fig. 4",. The Rectifier - DC Link - inverter fed machine model shown in "Fig. 5".

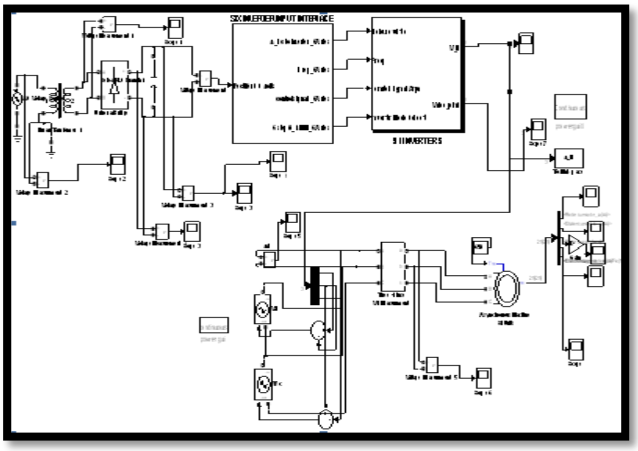

Figure 5: Rectifier inverter fed machine model

IV. OPERATION OF INVERTER MODEL

1. Inverter model with fault simulation capability

The inverter model has been built with the fault simulation capability to model the faults as shown in "Fig. 6". The block is a switch of SIMULINK, which has three inputs and one output. The first input here is an array, whose value is depends upon the type of fault that has to be simulated.

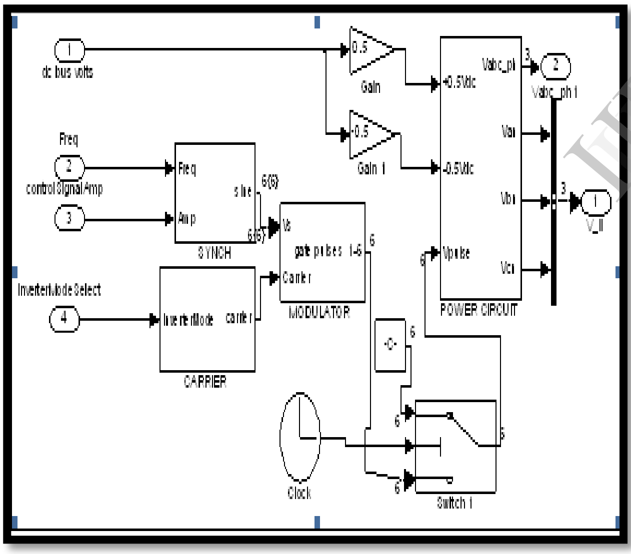

Fig. 6: Inverter model with fault simulation block

i)Six- Step Mode: The torque, speed, stator current and output voltage waveforms obtained for 6-step (square wave) mode of operation with rectifier are shown in "Fig. 7".

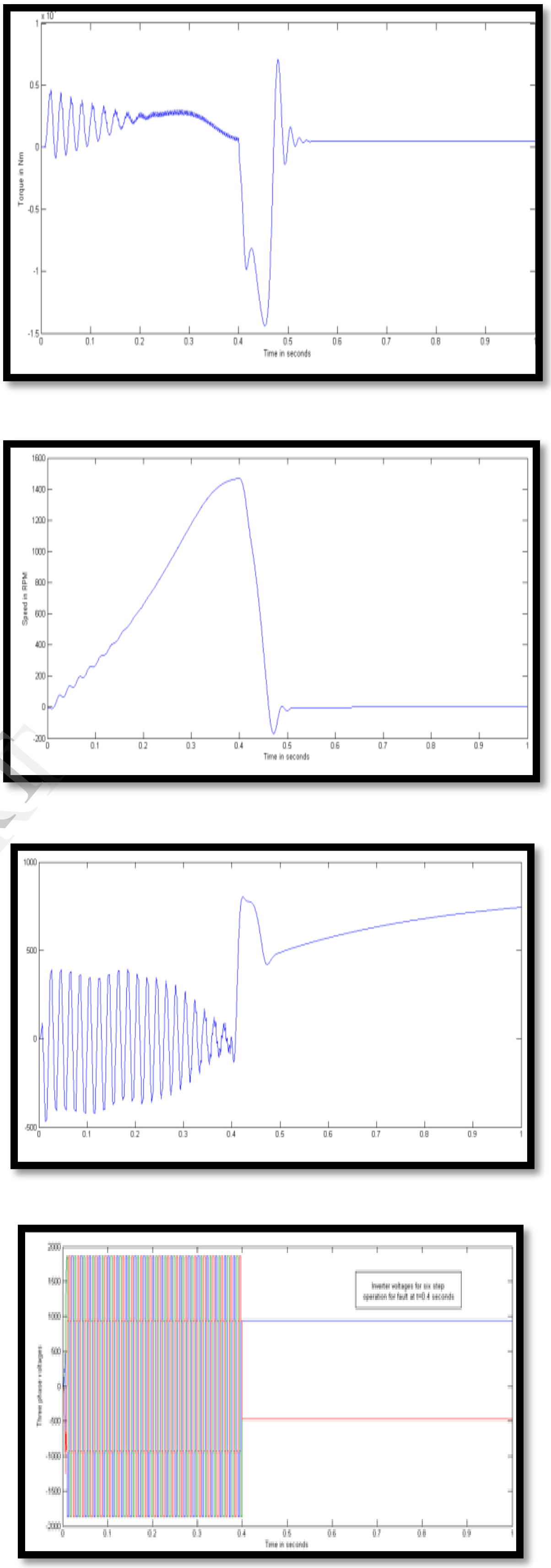

Fig. 7: Torque, Speed Current and Inverter Voltages for Six Step Operation with fault at 0.4 sec.

ii)PWM Mode: The PMW mode of operation of the inverter was obtained using sinusoidal pulse width modulation. The torque, speed, stator current and output voltage waveforms for PWM operation with rectifier are shown in "Fig. 8."

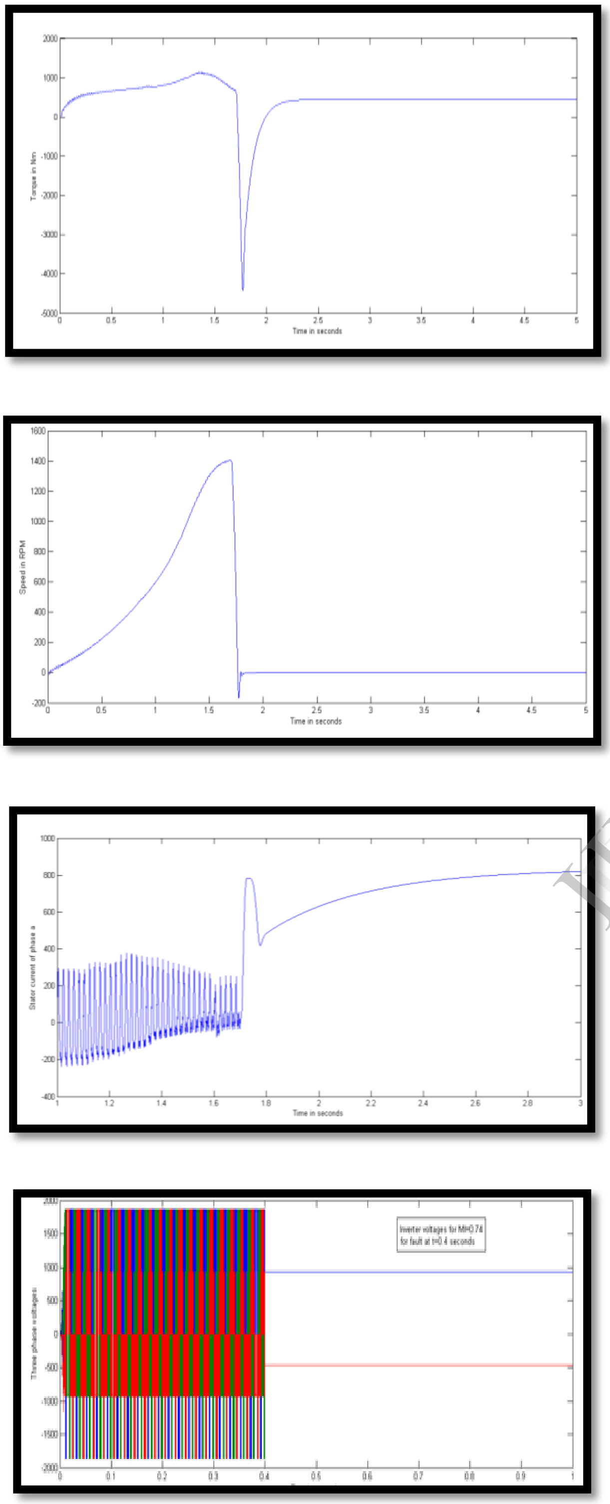

Fig. 8: Torque, Speed, Stator Current and Inverter Voltages PMW operan.

2.Inverter operation under normal condition

i) Six- Step Mode : The torque, Speed, currents and voltages developed by an induction machine drive during normal operation with rectified input supply to inverter at six-step mode with rectifier are shown in "Fig. 9a, b, c, & d".

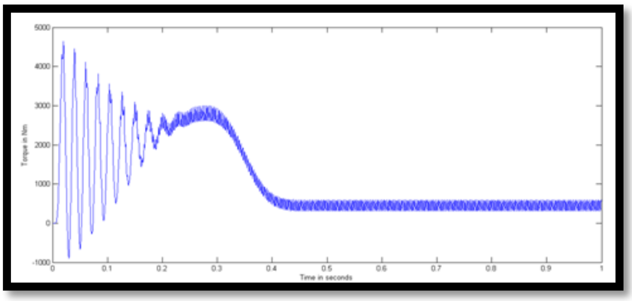

Fig. 9 a: Torque profile of motor in six step mode under normal operation

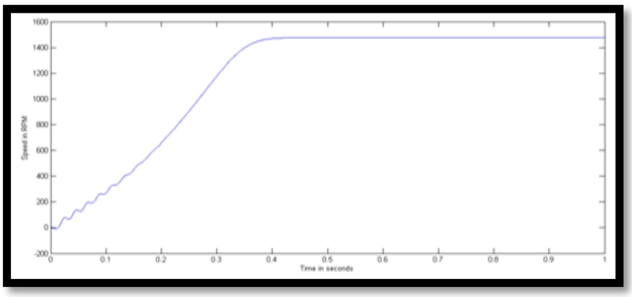

Fig. 9 b: Speed of motor in RPM in six step mode under normal operation

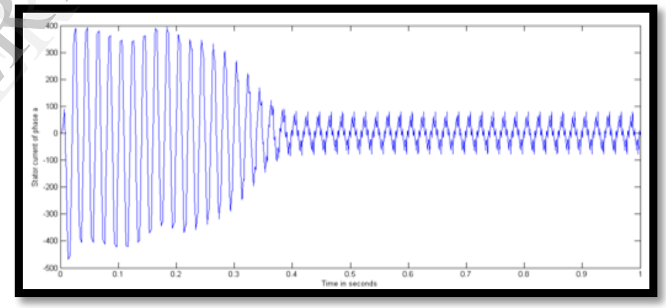

Fig. 9 c: Stator current of phase in six step mode under normal operation

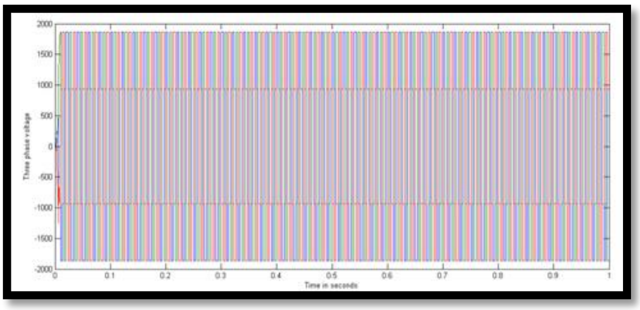

Fig. 9 d: Inverter voltages for six step operation under normal operation

ii) PWM Mode : The torque, Speed and voltages developed by an induction machine drive during normal operation with rectified dc supply to inverter at PWM Mode with rectifier are shown in "Fig. 10 a, b, & c".

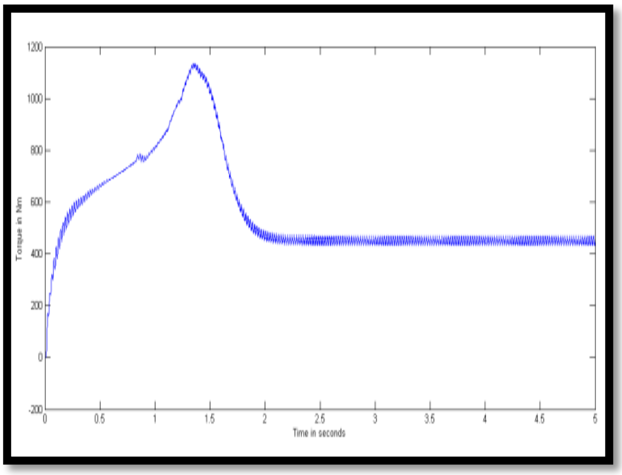

Fig. 10 a: Torque profile of motor in PWM mode under normal operation

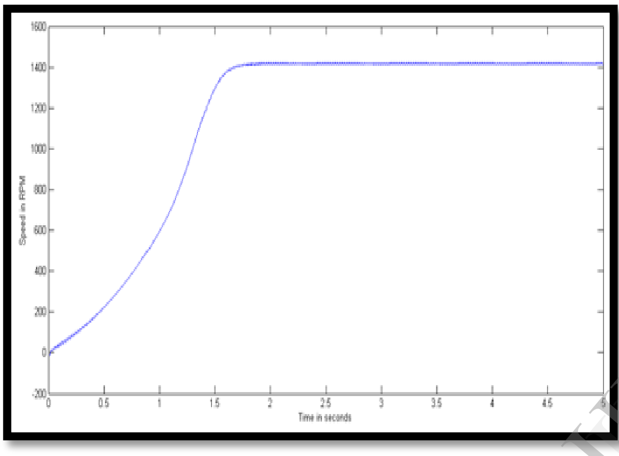

Fig. 10 b: Speed of motor in RPM in PWM mode under normal operation

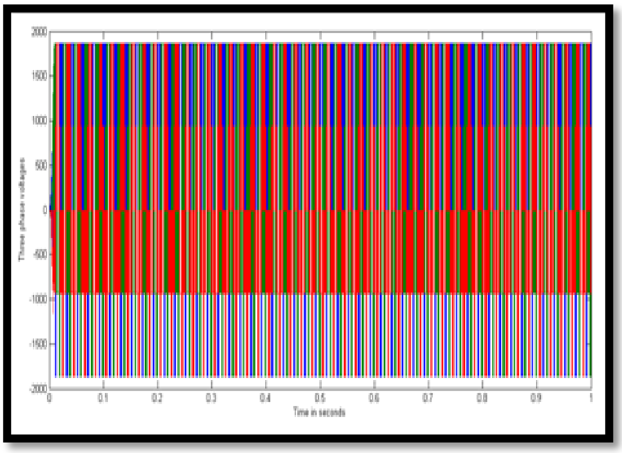

Fig. 10 c: Inverter voltages for PWM operation under normal operation

The rectifier, inverter and induction machine model in PWM mode was subjected to sudden variation in load [6]. The torque, speed responses after the machine settled at synchronous speed are obtained as shown in "Fig. 11". The initial torque is zero under these conditions. A load torque 450 Nm is applied at t = 2.25 seconds and removed at t = 4.25 seconds. The simulated wave form of electromagnetic torque shows that the torque produced by the motor has transients but dampens out quickly to settle to an equilibrium point and thus follow the changes in load torque.

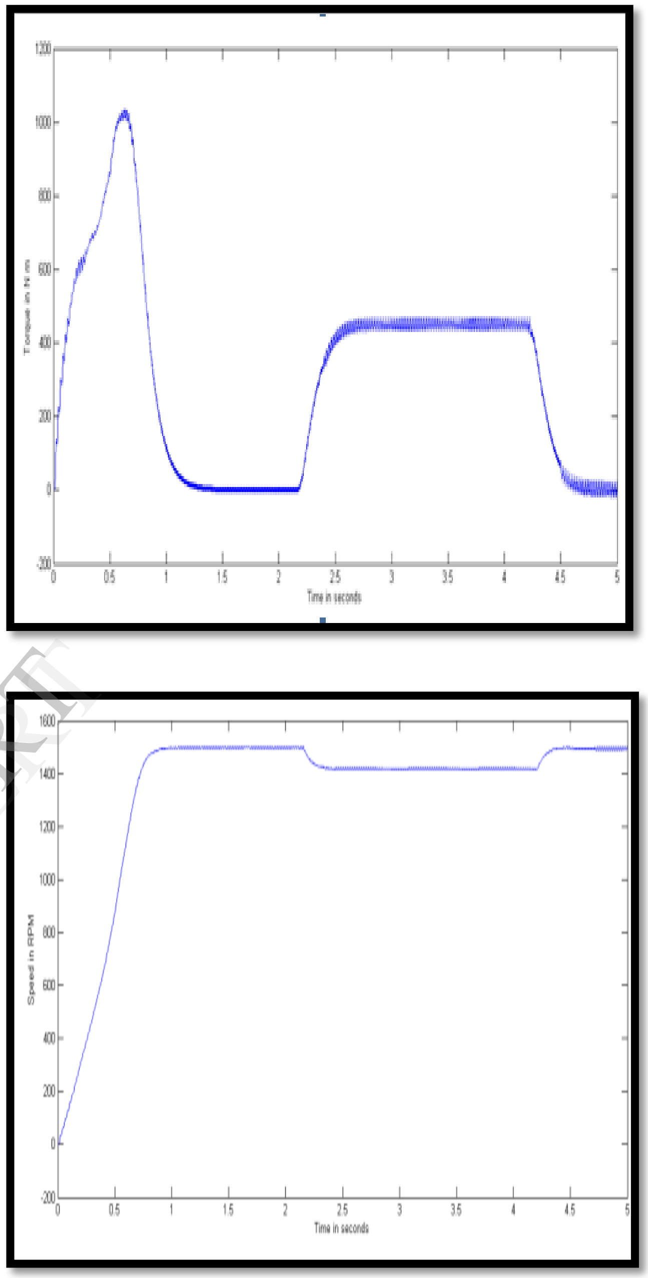

Fig. 11: Torque and speed profile of motor under normal condition in PWM mode with rectifier (Load disturbance)

V. CONCLUSION

The inverter model has been studied with rectifier output voltage. The simulation has further been carried put under two modes; PWM mode & Six Step Mode. The simulation for all these conditions has been carried for both normal & fault condition for electric traction drive under loaded conditions.

The inverter fault condition has been simulated by introducing the fault simulator block

The output of three phase inverter (under fault condition) is fed to motor. When locomotive is in operation, if one or more inverter switch fault occurs, a lot of kinetic energy is present at that instant of time, resulting into a large breaking torque, which may damage the motor shaft and several other associated parts The model has been subjected to sudden load variations and it was displayed in the simulation results that the torque and speed settled down to the requisite values after the transients were over.

REFERENCES

1. Bimal K.Bose, Modern Power Electronics and AC Drives, India, Prentic – Hall.
2. Krishnan R., Electric Motor Drives (Modelling, Analysis, and Control), Pearson.
3. Hoang Le-Huy, 2001, Modelling and simulation of electrical drives using MATLAB/Simulink and Power System Block set, Proceedings of the Industrial Electronics Society, 2001, IECON '01, The 27th Annual Conference of the IEEE, Vol.3, pp.1603-1611.
4. Shenoy U.J., Senior Member, IEEE, Sheshakri K.G., Parthasarathy K., Senior Member, IEEE, H.P. Khincha,Senior Member, IEEE, D.Thukaram, Senior Member, IEEE, Matlab/PSB based modelling and simulation of 25 kV AC Railway Traction System - A particular Reference to Loading and Fault Conditions.
5. Cristian Lascu, Ion Boldea, and Frede Blaabjerg, 2000, A Modified Direct Torque Control for Induction Motor Sensor less Drive,IEEE: Transactions on industry applications, Vol.36, Issue 1.
6. Han Zhengqing; Zhang Yuge; Liu Shuping; Gao Shibin, 2011, Modelling and Simulation for Traction Power Supply System of High-Speed Railway, Proceedings of the Power and Energy Engineering Conference (APPEEC), 2011, Asia-Pacific, 25-28 March 2011, pp. 1-4, 25-28.