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Simulation of ac/dc/ac converter for closed loop operation of three phase induction motor

Rajnikanth[1], Dr.Rohini Nagapadma[2]

M.Tech Student, Electrical& Electronics Engineering, NIE Mysore, India [1]

Professor, Electronics & Communication Engineering, NIE Mysore, India[2]

Abstract: The vector control analysis of an induction motor allows the decoupled analysis where the torque and the flux components can be independently controlled (just as in dc motor). This makes the analysis easier than the per phase equivalent circuit. The current control methods play an important role in power electronic circuits, particularly in current regulated PWM inverters which are widely applied in ac motor drives and continuous ac power supplies where the objective is to produce a sinusoidal ac output. The main task of the control systems in current regulated inverters is to force the current vector in the three phase load according to a reference trajectory.

Keywords: ac/dc/ac converter, induction motor, SPWM rectifier, step-down transformer, vector control.

I. INTRODUCTION

The AC induction motor is a rotating electric machine designed to operate from a three phase source of alternating voltage. Asynchronous motors are based on induction. The cheapest and most widely used is the squirrel cage motor in which aluminium conductors or bars are cast into slots in the outer periphery of the rotor. These conductors or bars are shorted together at both ends of the rotor by cast aluminium end rings. Like most motors, an AC induction motor has a fixed outer portion, called the stator and a rotor that spins inside with a well-optimized air gap between the two. A three-phase AC induction motor is the only type where the rotating magnetic field is generated naturally in the stator because of the nature of the supply. In an AC induction motor, one set of electromagnets is formed in the stator because the AC supply is connected to the stator windings. The alternating nature of the supply voltage induces an Electromagnetic Force (EMF) in the rotor as per Lenz's law, thus generating another set of electromagnets; hence the name "induction motors".

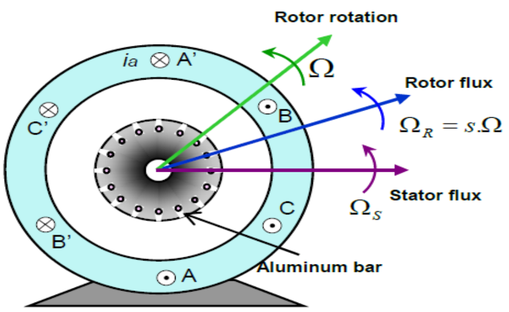

Fig.1: Squirrel cage rotor AC induction motor cutaway view

Interaction between two magnetic fields, these electromagnets generates a revolving force, or torque. As a result, the motor rotates in the direction of the resultant torque. For variable speed drives, the induction machine is one of the most widely used electrical machines in today's industrial sector. Because of its simple and rugged structure, it has been utilized for many applications. Development on machine control technique includes power electronic devices and a micro-computer made it possible to control its torque and speed as efficient as DC machine.

A. *Control strategies*

The control strategies of the inverter-motor combination may be classified into two broad categories, open-loop scalar control strategies for applications with moderate static and dynamic performance requirements, and closed-loop vector control strategies for high-performance applications. This paper presents a ac/dc/ac converter for a closed loop based speed control system for a current source PWM inverter fed indirect field oriented control of induction motors (IM). The performance of the controller is analyzed using a digital simulation in MATLAB/Simulink.

II. SINGLE PHASE SPWM RECTIFIER

B. *Single Phase full Bridge Rectifier*

Fixed DC voltage is one of the basic requirements of electronics' circuit in modern systems. Because of this, the conventional single-phase diode or thyristors rectifiers are used widely in many industrial applications where is required a high-power DC supply or an intermediate DC link of AC/AC converters. Generally, these type of AC/DC converters add a capacitor to the DC side for smoothing the DC bus voltage. The benefits of these circuits are low cost, simple structure, high safety and no need of control. The weakness of these circuits are low power factor, high harmonics in the input current, system size will increase and converters have a short lifetime in which this introduces several problems such as voltage distortion, heating of core of transformers, increased loss in distribution conductors and transformers, reduction of

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available power and lower rectifier efficiency due to large rms values of the input current, etc.

Decreasing the Total Harmonic Distortion (THD) of the input current, unity power factor and fixed DC output voltage with minimum ripple are the important parameters in single phase rectifier. Hence, in these systems, rectifiers are considered as an important element. PWM rectifier is the most common rectifier in which capable to transfer power flow bi-directional.

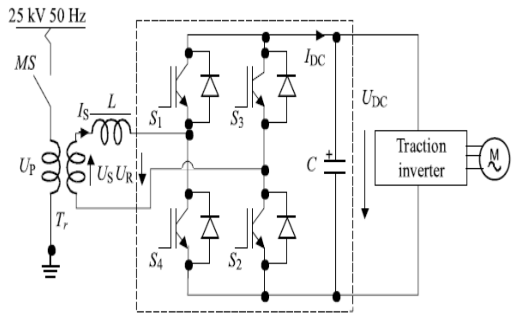

Fig. 2. Single-phase SPWM rectifier circuit

In Fig2. circuit of single phase SPWM rectifier is shown in which is ,Vs , Ls and RL are input current, supply voltage, input inductor and load resistance, respectively.

Assume that

$$U_s = V_s(t) = V_s \sin(\omega t) \quad 1$$

$$I_s(t) = I_s \sin(\omega t - \varphi) \quad 2$$

Where V^s and I^s are peak values of supply voltage and current, respectively. Mathematic model can be written as below ,

$$U_R = V_{ab} = V_s - L_s \frac{di_s}{dt} \quad 3$$

Vab is modulated voltage that by adjusting phase and amplitude of Vab , *is* can be controlled.

The SPWM single phase rectifier consists of 4 IGBTs connected in full bridge is shown in Fig.2.1. The source power is supplied through a transformer T_r and the input inductance L. The output DC link voltage V_c is filtered by capacitor C and fed into a 3-phase inverter that drives the traction. Supplied voltage V_s and the voltage at the rectifier input V_{ab} are sinusoidal waveforms separated by the input inductance. Therefore the energy flow depends on the angle between these two phases.

The power transferred from the supply to the input terminals of the rectifier is

$$P = \frac{V_s V_{ab}}{X_s} \sin\delta = V_s I_s \cos\varphi \quad 4$$

Where,

V_s −is RMS value of input supply voltage (V),

V_{ab} −RMS value of first harmonics consumed by AC rectifier input (V),

δ − phase displacement between phasors V_s and V_{ab} (deg),

X_s − input inductor reactance at 50 Hz .

φ −power factor.

The main features of SPWM rectifiers are:

- Bi-directional power flow
- Nearly sinusoidal input current
- Regulation of input power factor to unity

C. *Types of PWM techniques*

(a) Sinusoidal pulse width modulation(Carrier based Pulse Width Modulation Technique)

(b) Space vector pulse width modulation

D. Sinusoidal Pulse Width odulation(SPWM)

Instead of, maintaining the width of all pulses of same as in case of multiple pulse width modulation, the width of each pulse is varied in proportion to the amplitude of a sine wave evaluated at the centre of the same pulse. the distortion factor and lower order harmonics are reduced significantly. the gating signals are generated by comparing a sinusoidal reference signal with a triangular carrier wave of frequency fc .the frequency of reference signal fr controls the modulation index m,and Vrms output voltage vo. the number of pulses per half cycle depends on carrier frequency .The triangle waveform, Vtri, is at switching frequency fs; this frequency controls the speed at which the switches are turned off and on. The basic idea to produce PWM Bipolar voltage switching signal is shown in Fig.3. It comprises of a comparator used to compare between the reference voltage waveform V*r* with the triangular carrier signal Vc and produces the bipolar switching signal. If this scheme is applied to the full bridge single phase inverter as shown in Fig., all the switch S_{11}, S_{21}, S_{12} and S_{22} are turned on and off at the same time. The output of leg A is equal and opposite to the output of leg B.The output voltage is determined by comparing the reference signal, Vr *and* the triangular carrier signal, Vc.

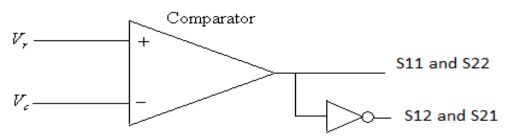

Fig..3: Bipolar PWM generator

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In this scheme the diagonally opposite transistors S_{11}, S_{21}, and S_{12} , S_{22} are turned on or turned off at the same time. The output of leg A is equal and opposite to the output of leg B. The output voltage is determined by comparing the control signal, Vr and the triangular signal, Vc.

Vr > Vc S_{11} is on == > $V_{ao} = \frac{V_d}{2}$ and S_{22} is on =>

$>V_{bo} = -\frac{V_d}{2}$

5

Vr < Vc S_{12} is on == > $V_{ao} = -\frac{V_d}{2}$ and S_{21} is on =>

$>V_{bo} = \frac{V_d}{2}$

6

Hence, $V_{bo}(t) = V_{ao}(t)$
7

E. Identifying the suitable power electronic switch:

Conditions Based

IGBT is preferred .	MOSFET is preferred .
Low switching frequency (<20kHz)	High switching frequency (>100kHz)
High power levels (above say 3kW)	Wide line and load conditions
High dv/dt needed to be handled by the diode	dv/dt on the diode is limited
High full load efficiency is needed	high light load efficiency is needed

Application based

IGBT	MOSFET
Motor drives(>250W)	Motor drives (<250W)
UPS and welding H bridge inverters	Universal input ac-dc flyback and forward converter power supplies
High power PFCs(>3kW)	Low to mid power PFCs(75W to 3kW)
High power solar/wind inverters(>5kW)	Solar micro inverters

F. Vector Control or Field Orientated Control (FOC):

An AC machine is not so simple because of the interactions between the stator and the rotor fields, whose orientations are not held at 90 degrees but vary with the operating conditions. We can obtain DC machine-like performance in holding a fixed and orthogonal orientation between the field and armature fields in an AC machine by orienting the stator current with respect to the rotor flux so as to attain independently controlled flux and torque. Such a control scheme is called flux-oriented control or vector control. Vector control is applicable to both induction and synchronous motors.

The cage induction motor drive with vector or field oriented control offers a high level of dynamics performance and the closed-loop control associated with this derive provides the long term stability of the system. Induction Motor drives are used in a multitude of industrial and process control applications requiring high performances. In high-performance drive systems, the motor speed should closely follow a specified reference trajectory regardless of any load disturbances, parameter variations, and model uncertainties. In order to achieve high performance, field-oriented control of induction motor (IM) drive is employed. However, the controller design of such a system plays a crucial role in system performance. The decoupling characteristics of vector-controlled IM are adversely affected by the parameter changes in the motor.

G. *Simulation and parameterization for inverter and induction motor*

The circuit diagram of three phase full bridge inverter is shown in Fig 2(a). The simulation circuit by Simulink in which a load torque changing over time is provided. The current hysteretic band PWM technology is adopted to get the pulse signal to control IGBTs being started or blocked. The modulating signal is got by the indirect rotor flux oriented vector control strategy. Parameters in the vector control strategy are affected by the motor. So the motor model is first constructed. The number of pole pairs is 2.

There are eight parts in the vector control module.

(1)"Switch". If speed is given constant speed control will run. Otherwise traction control is implemented. If train speed is v(km/h), first motor speed n(rpm) is calculated, then changed into angular velocity ω^*(rad/s). If train effort F(kN) is set, the corresponding torque Te^*(N.m) is calculated. The transformation equations are expressed a

$n=(v\times1000)/(\tau\times60\times2\times\pi\times R), \omega^*=n\times2\times\pi/60$ 8
$Te^*=(F\times1000\times R\times\tau)/(\eta\times10)$ 9

where, mechanical reduction ratio $\tau=1/2.5$, wheel radius at medium usage R=0.425m, efficiency of mechanical transmission $\eta=0.975$.

(2) "Speed controller". PI controller is adopted to generate reference torque.

(3) "iq* calculation". Calculate the torque current.

(4) "id* calculation". Field current is calculated.

(5)"Theta calculation". θ is electromagnetic angle that represents the rotor position.

(6) "Flux calculation". Calculate the flux from the field current from the eight part.

(7) "dq to ABC conversion". It completes conversion from dq two phase coordinate to abc three phase coordinate.

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Vol. 3, Issue 6, June 2014

(8) "abc to dq conversion" It finishes conversion from abc three phase coordinate to dq two phase coordinate.

H. abc to dq conversion:

The abc_to_dq0 Transformation block computes the direct axis, quadratic axis, and zero sequence quantities in a two-axis rotating reference frame for a three-phase sinusoidal signal. The following transformation is used:

I. dq to ABC conversion:

The dq0_to_abc Transformation block performs the reverse of the so-called Park transformation, which is commonly used in three-phase electric machine models. It transforms three quantities (direct axis, quadratic axis, and zero-sequence components) expressed in a two-axis reference frame back to phase quantities.

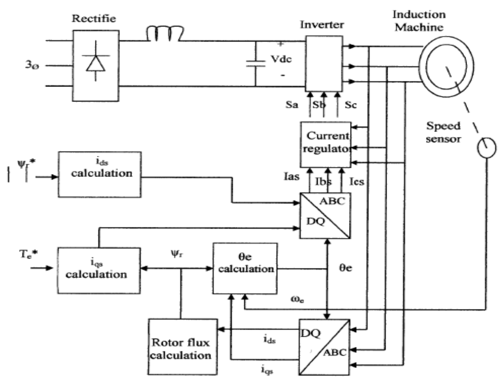

Fig..4: Block diagram of an indirect vector-oriented control system for an induction motor

Fig.4. shows a block diagram of an indirect vector-oriented control system for an induction motor. The control dq reference frame is fixed to the rotor flux position, which is defined by the rotor mechanical angle θ . The rotor position is sensed by a position detector and used in the conversion from dq to abc. The induction motor is fed by a current-controlled three phase inverter bridge. The stator currents are regulated by hysteresis regulators which generate inverter drive signals for the inverter switches. The motor torque is controlled by the quadrature-axis component of the stator current i^*_{qs}. The rotor flux is controlled by the direct-axis component i^*_{ds}. The motor speed is regulated by a control loop which produces the torque control signal i^*_{qs}. The i^*_{qs} and i^*_{ds} current references are converted into phase current references i^*_a, i^*_b, i^*_c for the current regulators.

For generating inverter gate pulses hysteresis current controller is implemented.

III SIMULATION CIRCUITS AND RESULTS

The complete simulation model of ac/dc/ac converter for closed loop operation of induction motor is shown in fig. 4.1. The block diagram contains the single phase ac supply, rectifier block and vector controlled induction motor .The specification for the rectifier, inverter and motor is shown in table1.

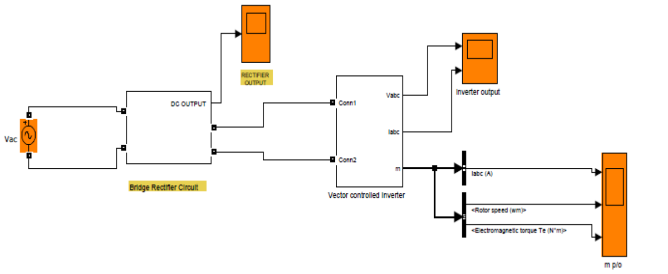

Fig. 5: simulink module for ac/dc/ac converter for closed loop operation of IM

sl.no	Block	input value	output value
01	transformer/supply	25kv	2770v(step down tr)
02	rectifier circuit	2770v, ac, 50hz	3600v, dc
03	inverter circuit	3600v, dc	2600v(phase volatages)

Table.1.Specifications for supply, rectifier, inverter

J. Rectifier circuit: Fig.6.shows the rectifier circuit using simulink blocks. In this transformer is used to step down the single phase voltage from transmision line of 25kv to 2.77kv . the output of transformer is connected to the rectifier as a input voltage. The rectifier circuit is built by using the IGBT block from simulink and gate signal for IGBTs are generated by SPWM technique. The waveform of SPWM signals and rectifier output are shown in fig.11 and fig.12.

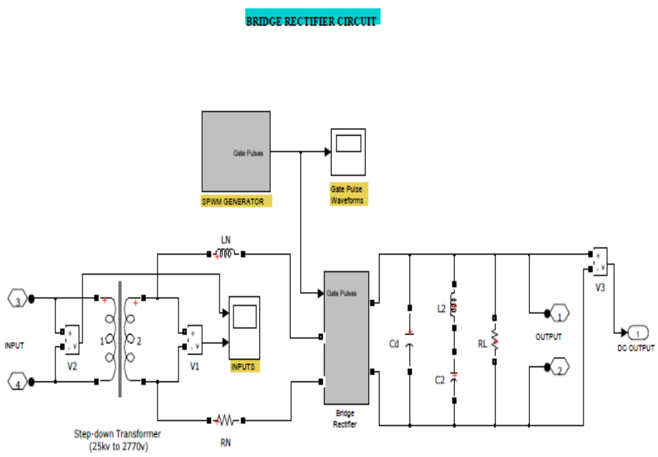

Fig. 6 Rectifier circuit[i]

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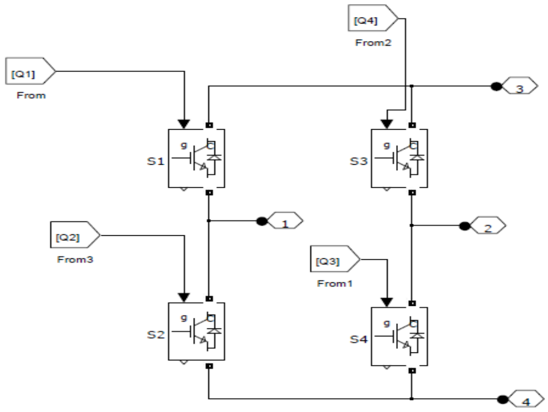


(a)

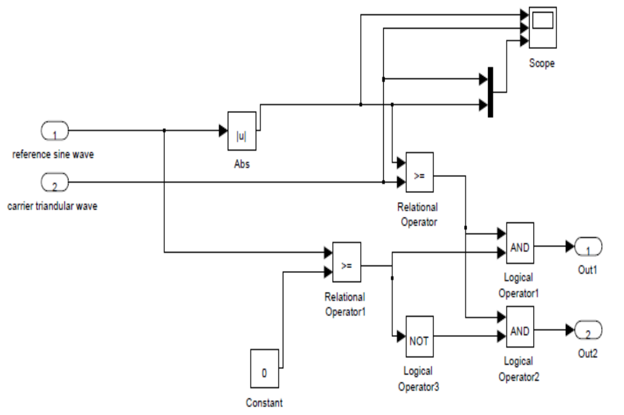
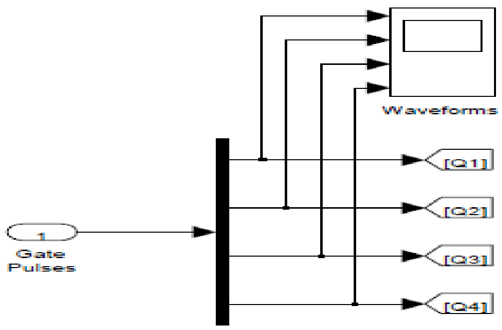


Fig.9:SPWM wave generation



(b)

Fig.7 (a)Bridge rectifier (b)IGBT gate pulses

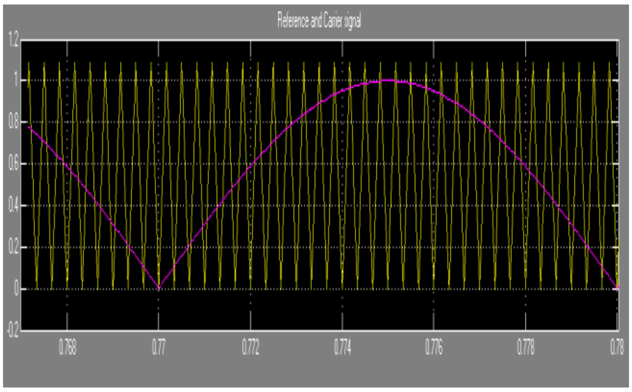


Fig.10: carrier and reference waves

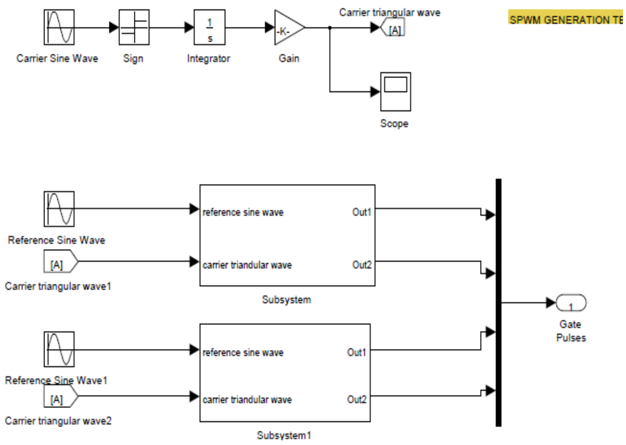


Fig..8: Carrier wave and reference wave

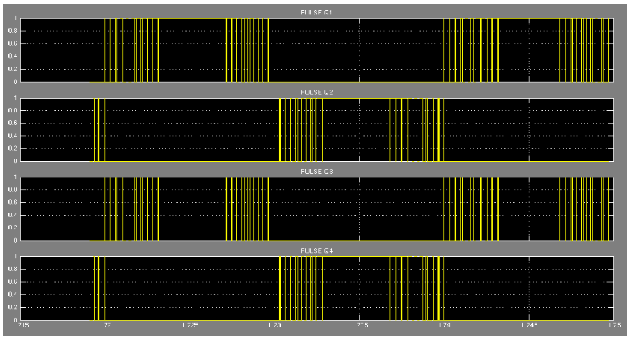


Fig..11: IGBT gate pulse

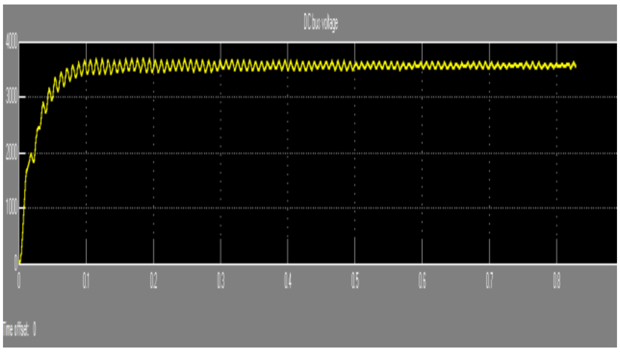


Fig..12: DC bus voltage

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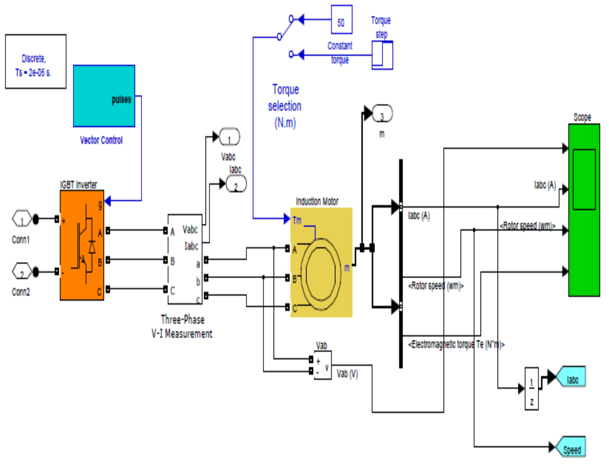

Fig.13: vector controlled inverter circuit

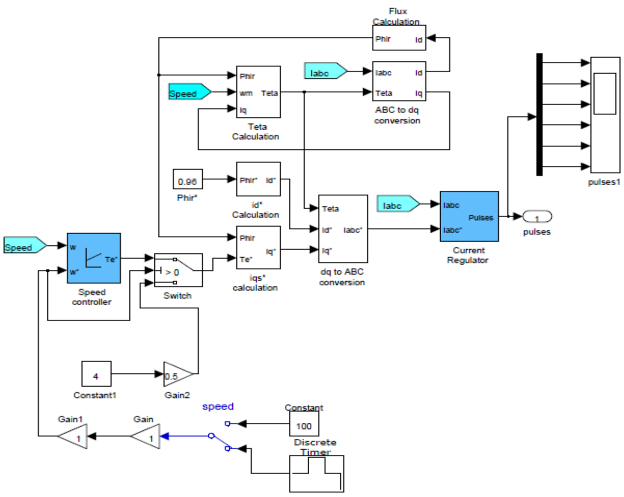

Fig.14. Simulink model for vector controller

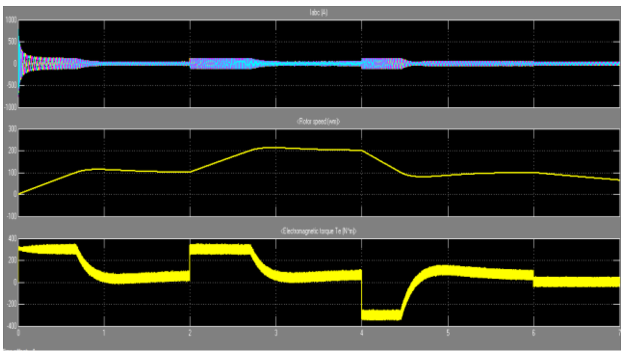

Fig.15 Output waveforms for different speed(100km/h, 200km/h, 100km/h at 0s, 2s, 4s)

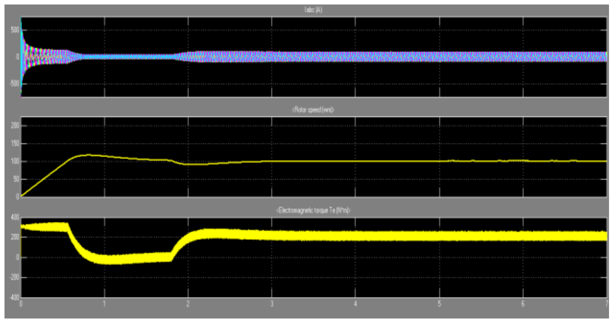

Fig..16: Output for constant speed(100km/h)

IV. CONCLUSION

This work has been an attempt to summarize the present closed loop operation using ac/dc/ac power conversion. Although numerous topologies and modulation methods were discussed, several more can be found in the references and in the literature. The choice of topology for closed loop operation of induction motor should be based on what is the usage of the inverter switching technique. Each inverter switching technique has its own mixture of advantages and disadvantages and for any one particular application, one topology will be more appropriate than the others. Often, topologies are chosen based on what has gone before, even if that topology may not be the best choice for the application. Vector control inverters can achieve zero speed regulation, wide speed control range and excellent dynamic response. The simulation results indicate that the system will complete the constant speed control well. The feature of proposed topology are it can be implemented for four quadrant operation of an induction motor can be implemented in domestic propose and to further develop an intelligent controller for better performance.

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