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The Implementation of Different Speed Control Methodsfor Three Phase Induction Motor Using MATLAB Simulation

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Abstract —*The rapid adoption of automation techniques in industry has increased the requirement for better process control. This has resulted in many new applications for AC variable speed drives (VSDs) to control the speed and torque of driven machinery.Variable speed drives (VSDs) are also used to meet particular starting and stopping requirements. The objective of this thesis is development of Voltage Source Inverter (VSI) using the MATLAB simulation environment for speed control of a 3-phase induction motor. We have the feasibility of injecting simulated real time analog and digital data into the MATLAB/Simulink model, process it to suit our model requirements, do the simulation, study the response in MATLAB. The standalone VSI control system is implemented in the MATLAB, which in our case, utilizes the constant Volts/Hz. strategy to generate & stabilize its sinusoidal AC output voltages. The Simulink model generates the sinusoidal pulse-width modulation (SPWM) control signals for the switching of the VSI's power devices, MOSFET's. This research paper is addresses the study of steady-state and dynamic control of 3 phase induction motor supplied from a power converter and its integration to the load.*

Keywords*-Variable Speed Drives (VSDs); Voltage Source Inverter; MATLAB; Sinusoidal Pulse Width Modulation (SPWM); 3 Phase Induction Motor*

I. INTRODUCTION

Three phase induction motor are most widely used ac motor in Industrial and commercial applications. The 3 – Phase Induction motors can be considered among the most reliable electrical machines. These motor find their application in the most different Industrial sectors such as food, chemical, textile, metallurgical and paper industries. These motor are widely used for most of the Industrial applications such as centrifugal pumps, conveyers, compressors, crushers, punch presses etc. in fact 3 – Phase induction motor find their application every where from small workshop to large industry.

A 3 – phase induction motor is approximatelt constant speed motor just like a dc shunt motor. The speed of dc shunt motor can be changed between wide range with good efficiency and good regulation but in an induction motors the speed control done at the cost of decrease in efficiency and power factor. It is very seriouse issue for controlling the speed of induction motor. Using treaditional method we do not overcome the above problem, for that we use some modern techniques and tryto overcome it. The huge availability of Thyristors, IGBT and GTO in recent years the speed control of induction motor is becoming in expensive, so now a day it is increasingly replacing the DC motors in high performance electrical motor drives. However the technique of vector control or field oriented control (FOC) based on the rotor fieldorientation applied to the IM provides thedecouplingbetween the torque and flux in a similar way to DCmachine.

In this paper comparative study between the scalar control and vector control is done. For the scalar control closed loop v/f control and direct field oriented vector control are selected. We make simulation model of both the algorithm in MATLAB and check it's performance. In the end of analysis we get fine results of both systems which are shown in Chapter: V.

II. EQUIVALENT CIRCUIT OF INDUCTION MOTOR

To study the behaviour of the induction motor at various operating condition, it is convenient to refer the equivalent circuit of the motor. Figure 1 shows the per phase equivalent circuit of induction motor. Counter emf V_m is generated from the synchronously rotating air gap flux. Then, it is converted to slip voltage V_r' in rotor phase. The stator voltage V_s differs from V_m because of the drop in stator resistance R_s and leakage inductance L_{is}.

The no load excitation current I_0 consists of two components which are a core loss component I_c and magnetizing inductance L_m, where R_m is the equivalent resistance for excitation loss and L_m is the magnetizing inductance. When the tree phase supply is connected to the stator, there will be a stator core loss (I_c). The rotor current I_r' is cearted from the rotor induced voltage V_r'. This current is limited by rotor resistance R_r' and leakage impedance L_{ir}'.

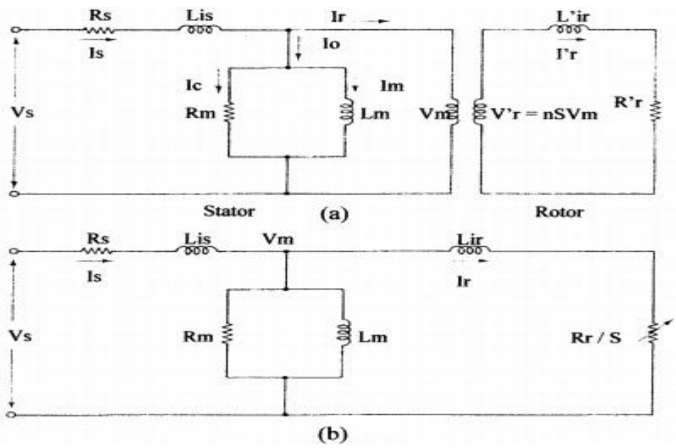

Figure 1. Per phase equivalent circuit of Induction motor

Figure 1 (b) shows the equivalent circuit with respect to the stator. The parameters R_r and L_{ir} are referred to the stator. Rotor reflected current Ir is given as

$$I_r = \frac{V_r'}{Z_r} = \frac{n^2 S V_m}{R_r + j\omega_{sl} L_{is}} = \frac{V_m}{\left(\frac{R_r}{S}\right) + j\omega_e L_{ir}} \quad (2.1)$$

Where, n is rotor to stator turn ratio, S is slip in pu, ω_{sl} is slip frequency and ω_e is stator frequency.

Now, we focus on speed control of induction motor. Speed control is achieved in the inverter driven induction motor by means of variable frequency. Apart from frequency, the applied voltage needs to be varied, to keep the air gap flux constant and not let it saturates. This is explained as follows. The air gap flux induced in an AC machine is given by,

$$E_1 = 4.44\, k_{\omega 1}\, \emptyset_m\, f_s\, T_1 \quad (2.2)$$

Where, $k_{\omega 1}$ is stator winding factor, Φ_m is peak air gap flux, f_s is supply frequency and T_1 is number of turns per phase in stator.Neglecting the stator impedance, the induced emf approximately equals the supply phase voltage.

Hence,

$$V_{ph} \cong E_1 \quad (2.3)$$

The flux is then written as,

$$\emptyset_m \cong \frac{V_{ph}}{K_b f_s} \quad (2.4)$$

Where,

$$K_b = 4.44\, k_{\omega 1}\, T_1 \quad (2.5)$$

If K_b is constant, flux is approximately proportional to ratio between the supply voltage and frequency. This is represented as

$$\emptyset_m \propto \frac{V_{ph}}{f_s} \propto K_{vf} \quad (2.6)$$

Where, K_{vf} is the ration between V_{ph} and f_s.From Equation (2.6), to maintain the flux constant, K_{vf} has to be maintained constant. Therefore, whenever stator frequency is changed to obtain speed control, the stator input voltages have to be changed accordingly to maintain the air gap flux constant.

III. SPEED CONTROL OF INDUCTION MOTORS

Classification of the speed control techniques for the induction machine depends on how the voltage-to-frequency ration is implemented:

1. Scalar control.
   1.1. Voltage/frequency (V/f) control.
   1.2. Stator current and slip frequency control.

Note: These techniques are implemented through direct measurement of the machine parameters.

2. Vector Control.
   2.1. Field orientation control.
      (1) Indirect method.
      (2) Direct method.
   2.2. Direct torque and stator flux vector control.

In this research paper we only discuss or compair Voltge/frequency (V/f) Control method and Direct Torque Control method.

3.1. Voltage/frequency (V/f) Control Method

In the constant Volts/Hz. control strategy, the air gap flux is kept reasonably constant over the constant torque region by keeping the ratio of stator voltage to excitation frequency constant, if the stator impedance is small or the air gap voltage is close to the inputvoltage applied to the stator. However, at low frequencies the stator resistance becomes dominant and the voltage drop across the stator is no longer negligible. Therefore, at low frequency voltage boost is required to compensate for the voltage drop across the stator resistance. This control strategy is often referred to as a scalar control strategy. If a small variation in rotor speed with a change in loading is tolerable, then a simple open loop control strategy would probably suffice.

However, if the application requires a togather control over rotor speed and torque while limiting stator current, then a closed loop control strategy with rotor speed as feedback is the better alternative. With rotor speed as feedback, the slip speed of the motor can be regulated.

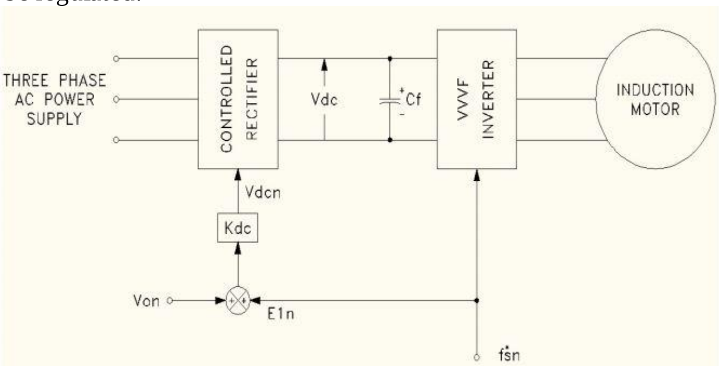

Figure 2. Implementation of Volts/Hz strategy in inverter fed induction motor drives

Figure 2 shows an implementation of the constant Volts/Hz control strategy in open loop mode. The frequency command $f_s^*$is enforced in the inverter and the corresponding DC link voltage is controlled through the front end converter. The offset voltage V_o, is added to the voltage proportional to the frequency, and they are multiplied by a constant gain, as decided by the slope of the voltage and frequency relationship, to obtain the DC link voltage.

Few issues to be taken care while using this drive scheme are:

1. Motor speed cannot be precisely controlled.
2. The slip speed cannot be maintained as a result because the rotor speed is not measured in this drive scheme. This can lead to operation in the unstable region of the torque-speed characteristics.

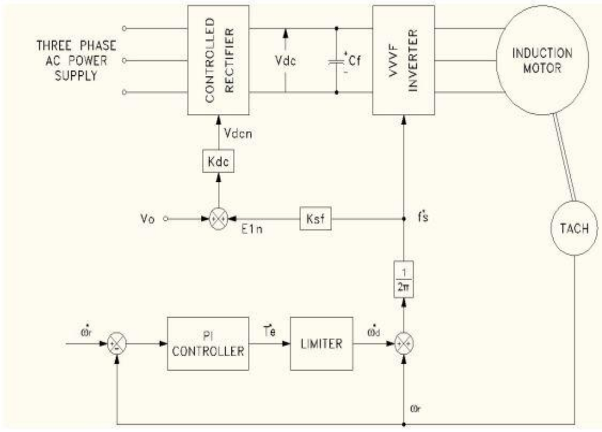

Figure 3. Closed-loop induction motor drive with constant Volts/Hz control strategy

The effect discussed in point 2, can make the stator currents exceed the rated value by many times, thus endangering the inverter-converter combination.The problems, to a certain extent, are overcome by having an outer speed loop in the induction motor drive as shown in Figure 3.The actual speed is compared with its ref. command value $\omega_r^*$and the error is processed through a controller, usually a PI controller and a limiter to obtain the desired slip-speed commandω_{s1}^*.The limiter ensures that the slip-speed command is within the maximum allowable slip speed of the inductor motor. The slip-speed command is added to the electrical rotor speed to obtain the stator frequency command. Thereafter, the stator frequency command is processed as in open loop drive. K_{dc} is the constant of proportionality between the dc load voltage and the stator frequency.

In closed loop induction motor drive, the limits on the slip speed, offset voltage and reference speed are externally adjustable variables. This external adjustment allows tuning and matching of the induction motor to the converter and inverter and the tailoring of its characteristics to match the load requirements.

3.2. Direct Torque Control Method

Direct torque control (DTC) is one method used in variable frequency drives to control the torque (and thus finally the speed) of three-phase AC electric motors. This involves calculating an estimate of the motor's magnetic flux and torque based on the measured voltage and current of the motor.

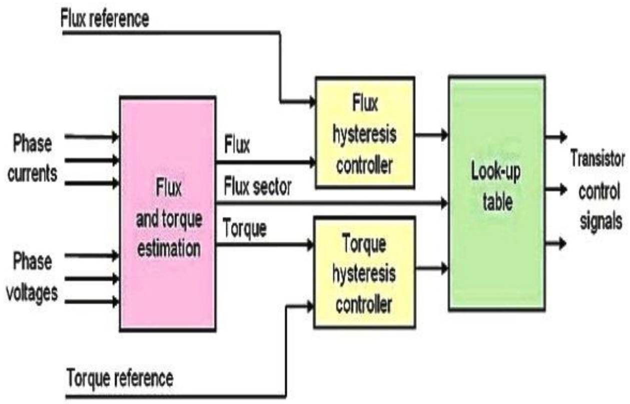

Figure 4. Direct Torque Control Method of an Induction Motor

Stator flux linkage is estimated by integrating the stator voltages. Torque is estimated as a cross product of estimated stator flux linkage vector and measured motor current vector. The estimated flux magnitude and torque are then compared with their reference values. If either the estimated flux or torque deviates from the reference more than allowed tolerance, the transistors of the variable frequency drive are turned off and on in such a way that the flux and torque will return in their tolerance bands as fast as possible. Thus direct torque control is one form of the hysteresis or bang-bang control. This control method implies the following properties of the control:

- Torque and flux can be changed very fast by changing the references.
- High efficiency and low losses-switching losses are minimized because the transistors are switched only when it is needed to keep torque and flux within their hysteresis bands.
- The step response has no overshoot. No coordinate transforms are needed; all calculations are done in stationary coordinate system.
- No separate modulator is needed; the hysteresis control defines the switch control signals directly.
- There are no PI current controllers. Thus no tuning of the control is required.
- The switching frequency of the transistors is not constant. However, by control-ling the width of the tolerance bands the average switching frequency can be kept roughly at its reference value. This also keeps the current and torque ripple small.
- Thus the torque and current ripple are of the same magnitude than with vector controlled drives with the same switching frequency.
- Due to the hysteresis control the switching process is random by nature. Thus there are no peaks in the current spectrum. This further means that the audible noise of the machine is low.
- The intermediate DC circuit voltage variation is automatically taken into account in the algorithm (in voltage integration). Thus no problems exist due to dc voltage ripple (aliasing) or dc voltage transients.
- Synchronization to rotating machine is straightforward due to the fast control; just make the torque reference zero and start the inverter. The flux will be identified by the first current pulse.
- Digital control equipment has to be very fast in order to be able to prevent the flux and torque from deviating far from the tolerance bands. Typically the control algorithm has to be performed with 10 - 30 microseconds or shorter intervals. However, the amount of calculations required is small due to the simplicity of the algorithm.
- The current measuring devices have to be high quality ones without noise because spikes in the measured signals easily cause erroneous control actions. Further complication is that no low-pass filtering can be used to remove noise because filtering causes delays in the resulting actual values that ruin the hysteresis control.
- The stator voltage measurements should have as low offset error as possible in order to keep the flux estimation error down. For this reason the stator voltages are usually estimated from the measured DC intermediate circuit voltage and the transistor control signals.
- In higher speeds the method is not sensitive to any motor parameters. However, at low speeds the error in stator resistance used in stator flux estimation becomes critical.

IV. SIMULATION MODELS

For check the performance of above method we make simulation model of both the algorithm in MATLAB and check it's performance.

4.1. Voltge/frequency (V/f) Control Method

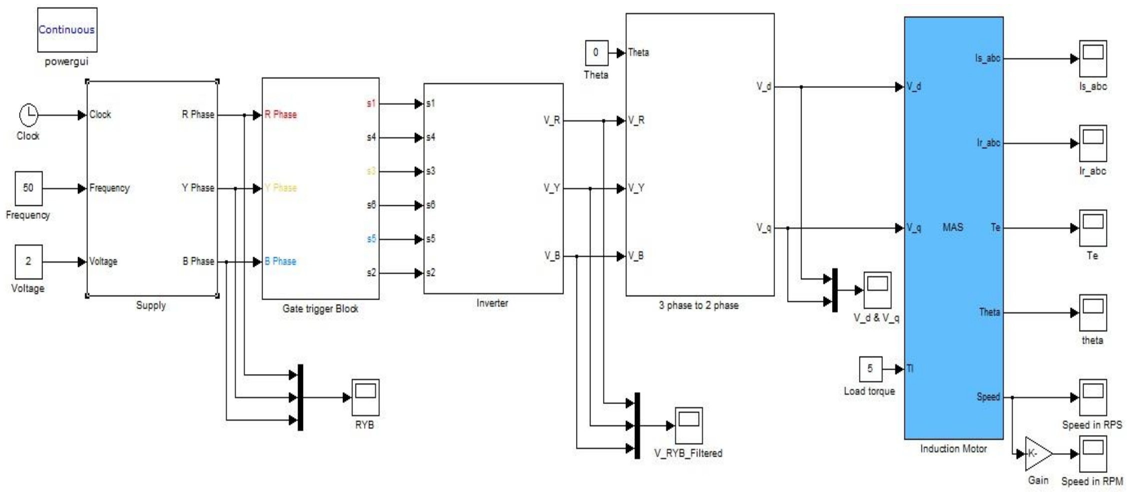

Figure 5.Simulink model of open loop IM drive; speed control using constant Volts/Hz. Strategy

5.2. Direct Torque Control Method

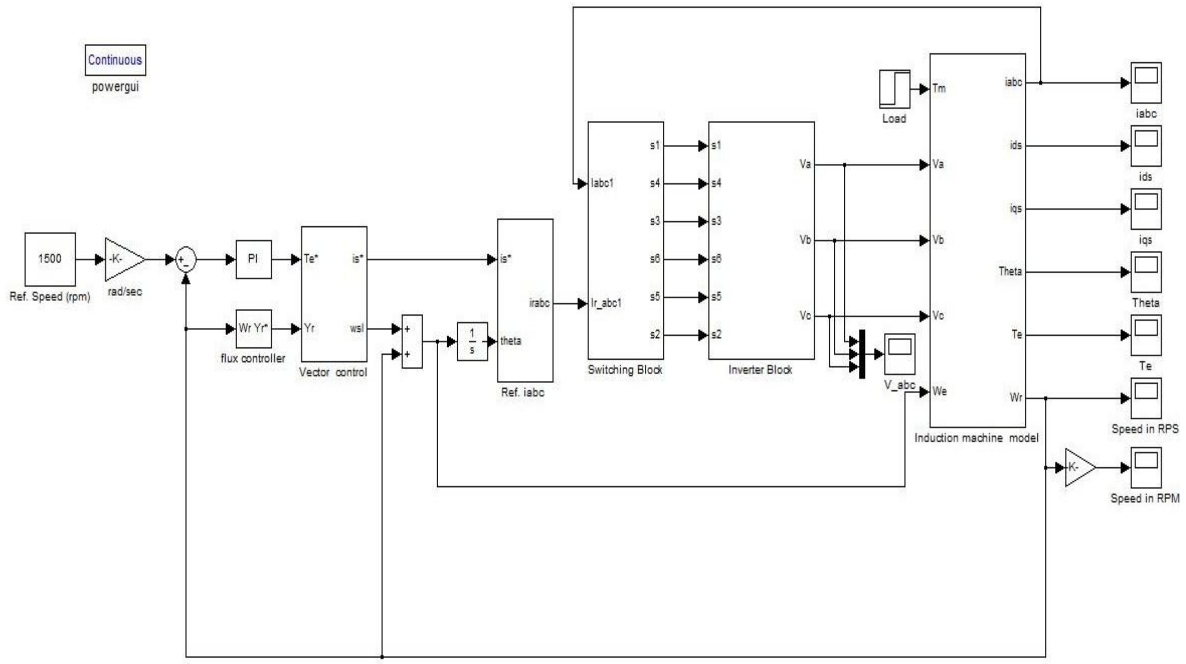

Figure 6. Simulink model of closed loop IM drive; speed control using Vector Oriented Controlled Strategy

V. RESULTS

5.1. Voltge/frequency (V/f) Control Method

5.1.1. Stator Current

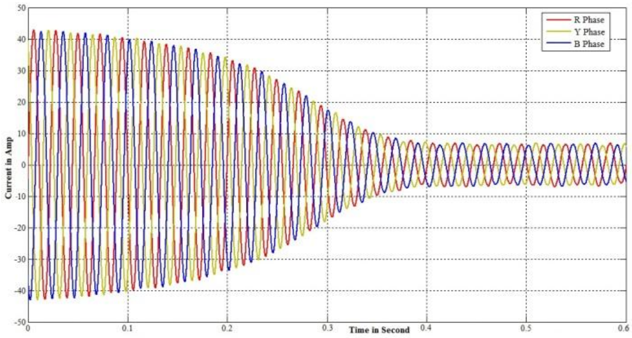

Figure 7. Stator current profile for given value of T_l and θ reference

5.1.2. Rotor Current

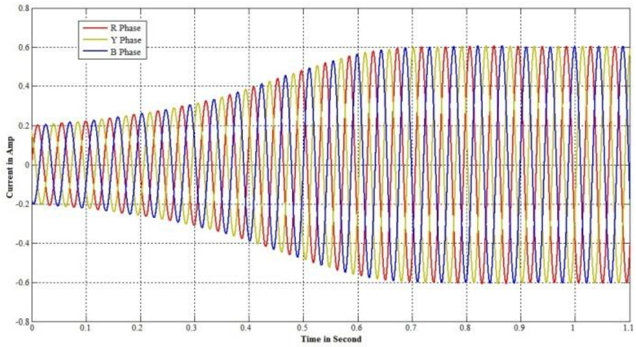

Figure 8. Rotor current profile for given value of T_l and θ reference

5.1.3. Torque

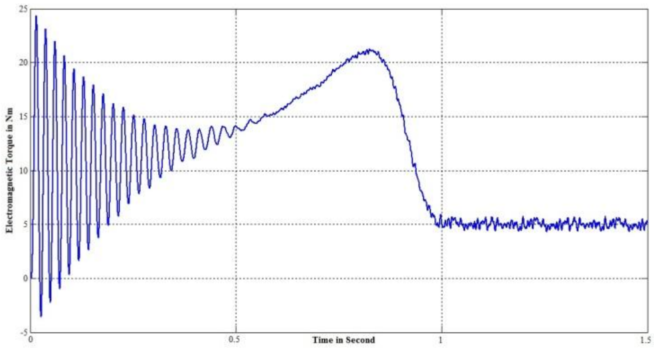

Figure 9. Torque profile for given value of T_l and reference

5.1.4. Angle Theta

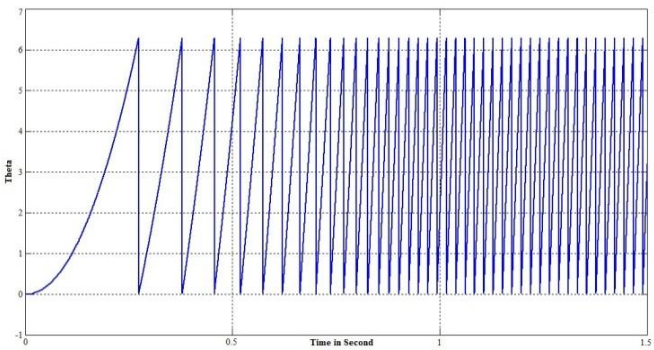

Figure 10. Variations in angle for changes in speed

5.1.5. Speed in RPM

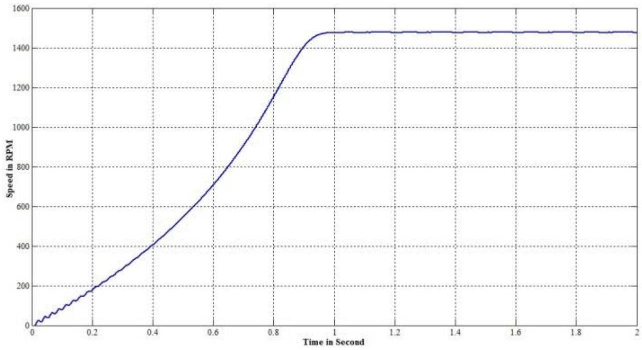

Figure11. Speed profile for given Volts/Hz ratio

5.2. Direct Torque Control Method

5.2.1. Output Signal of Inverter (Unfiltered Signals)

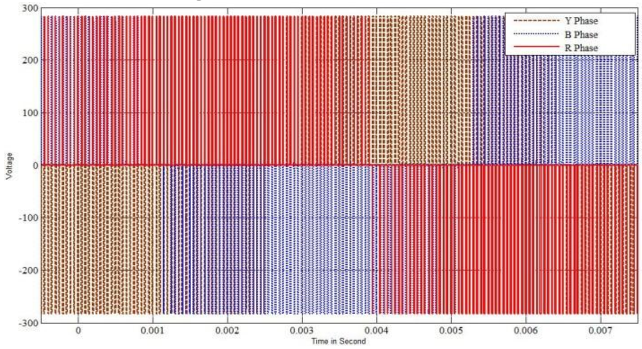

Figure12.Unfiltered AC Voltage-Current at the output of the inverter in Simulink

5.2.2. Output Signal of Inverter (Filtered Signals)

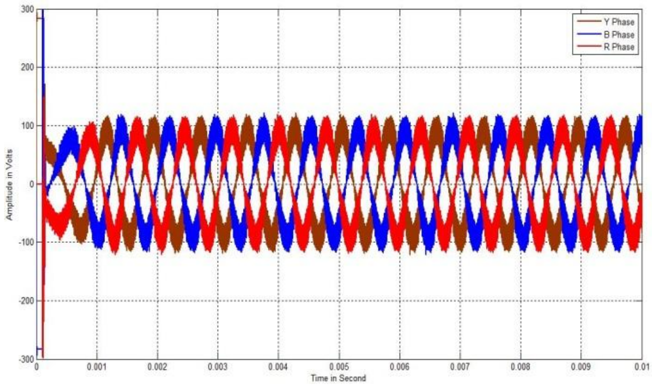

Figure13.Filtered AC Voltage-Current at the output of the inverter in Simulink

5.2.3. Three Phase Currents Signals

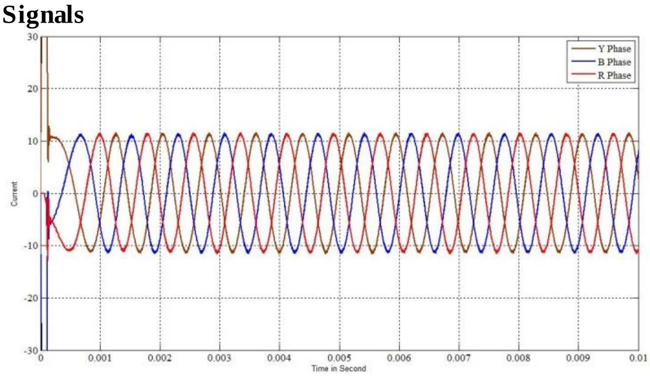

Figure14.Waveform of Three Phase Currents of an Induction Motor

5.2.4. I_{ds} Currents Signals of Induction Motor

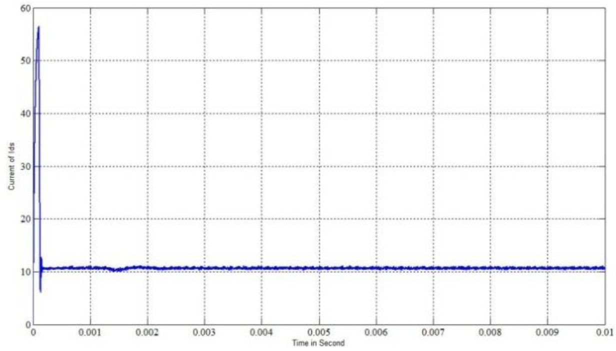

Figure15.Waveform of I_{ds} Currents of an Induction Motor

5.2.5. I_{qs} Currents Signals of Induction Motor

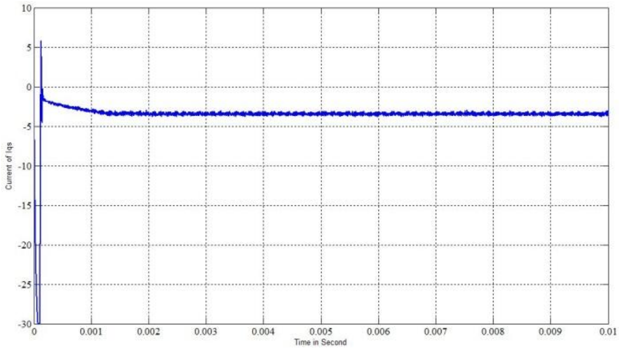

Figure16.Waveform of I_{qs} Currents of an Induction Motor

5.2.6. Angle Theta

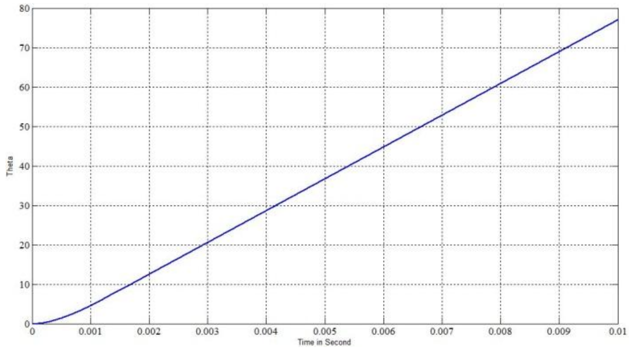

Figure17.Waveform of Theta

5.2.7. Electromagnetic Torque

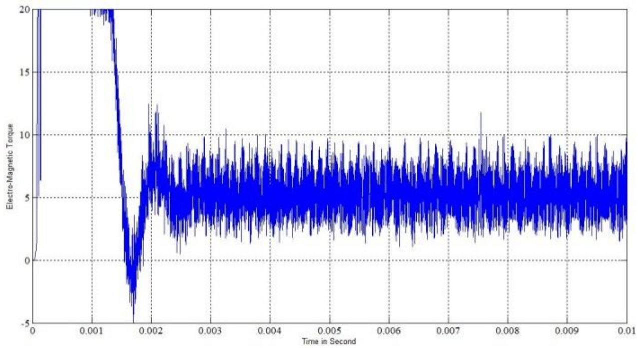

Figure18.Waveform of Electromagnetic Torque

5.2.8. Speed of Induction Motor

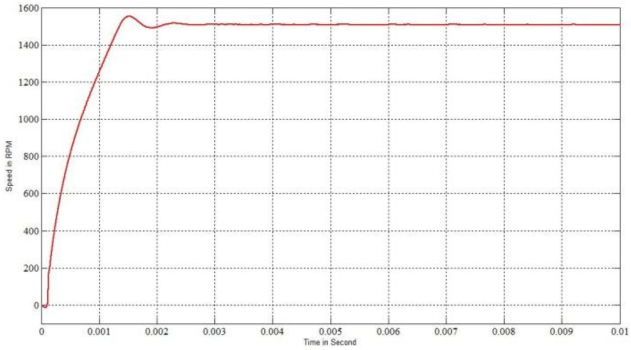

Figure19.Speed of Induction Motor

VI. CONCLUSION

From the preceding sections, it is obvious that to understand a motor drive system,one needs todo an extensive study of electricalmachines, power converters and controlsystems to have a stable motor drive system.

From this thesis, we have gained a fair degree of experience and have been ableto understand the problems associated with an implementation of a open loop SPWM and closed loop induction motor drive system.

The research involved three phases, viz.

- First was to simulate and evaluate the performance of the Volts/Hz. Control strategy. This involved development of mathematical model for induction motor.
- Second was to simulate and evaluate the performance of Vector Control strategy for speed control of Induction motor using PID controller.
- Third was, this research presented the concept of Field-Orientated Control (FOC) and vector control method. FOC was elected to be the motion control technique because it produces controlled results that have a better dynamic response to torque variations in a wider speed range compared to other scalar methods.

The benefits and limitations of each algorithm were examined through theoreticalanalysis. Verification of the analysis was performed by simulating various strategiesusing MATLAB/Simulink toolbox.

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