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Indirect Vector Control of Three Phase Induction Motor using PSIM

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Abstract

This paper presents the implementation of indirect vector control of three phase induction motor using Hysteresis Band PWM current control and Synchronous Current Control in PSIM environment. In any machine drive system, current control directly influences both flux and torque developed directly. In Hysteresis current control method, actual current tracks the command current within a hysteresis band. There is no difficulty in current control tracking when CEMF is low, but at higher speeds, current controller gets saturated due to higher CEMF and hense becomes difficult to track due to which there will be a phase lag with respect to command current. All such problems are solved using Synchronous Current Control.

Keywords: Hysteresis band current control, CEMF, Synchronous current control, PSIM, Pulse Width Modulation

1. Introduction

The control and estimation of induction motor drives has been the work horses in industry for variable speed applications from fractional horsepower to multi-megawatts. These applications include pumps and fans, paper and textile mills, subway and locomotives propulsions, electric and hybrid vehicles, machine tools and robotics, home appliances, heat pumps and air conditioners, rolling mills, etc. Basically there are two control techniques: Scalar Control and Vector Control.

Scalar control is somewhat easy to implement but due to inherent coupling effect, very sluggish response is obtained and the system is easily prone to instability because of high order system effect. Torque is influenced by incremental of slip and flux tends to decrease. This sluggish nature lengthens the response time.

These problems can be solved using vector control or field oriented control. Vector controlled induction motor drive operates like a separately excited dc drive. DC Machine like performance can be extended to induction motor if machine control is considered in synchronously rotating frame. The construction of a dc machine is such that field flux produced by the current If is perpendicular to armature flux, which is produced by armature current. These vectors which are stationary in space are orthogonal or decoupling in nature. This mens that when torque is controlled by controlling armature current, flux ψf is not affected and we get fast transient response. Because of decoupling, when field current is controlled, it affects field flux only but not armature flux. Because of this problem, an induction motor can never give fast transient response.

The fundamental of vector control implementation can be explained by help of figure below where the machine model is represented in synchronously rotating reference frame.

There are essentially two general methods of vector control, one is called Direct or Feedback method invented by Blaschke[1] and the other is calledIndirect or Feedforward method invented by Hasse[2]. These methods are essentially different by how the unit vectors are generated.

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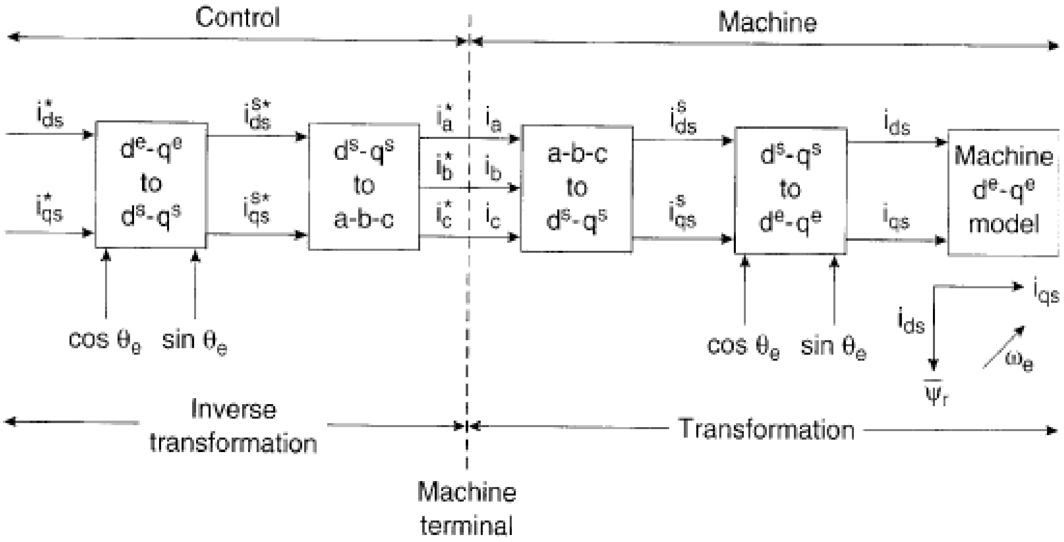

Figure 3. Vector Control implementation principle

The Direct method of Vector Control is difficult to operate successfully at very low frequency because of following problems: At low frequencies, voltage signals are very low and integration becomes very difficult. The parameter variation effect of resistances and inductances tend to reduce accuracy of estimated signals. There are many methods adapted for vector control.[9][10][12][14][15][16][24][28][29][30][31].

2. Indirect or Feedforward Vector Control

Indirect vector control is essentially the same as Vector control except the unit vectors are generated in feedforward manner. Figure below explains the fundamental principle of indirect vector control with the help of phasor diagram.

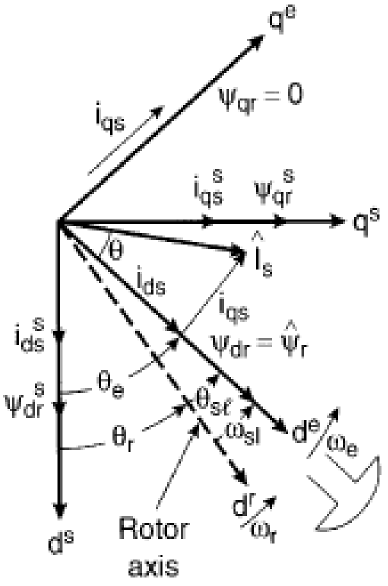

Figure 3. Phasor Diagram explaining indirect vector control

Indirect vector control strategy has been implemented using following equations:

$$\theta_e = \int \omega_e d = \int (\omega_e + \omega_{st})dt = \theta_r + \theta_{sl}$$

$$\frac{d\psi_{dr}}{dt} + R_r i_{dr} - (\omega_e - \omega_r)\psi_{qr} = 0 \qquad \frac{d\psi_{qr}}{dt} + R_r i_{qr} - (\omega_e - \omega_r)\psi_{dr} = 0$$

$$\psi_{dr} = L_r i_{dr} + L_m i_{ds} \qquad \psi_{qr} = L_r i_{qr} + L_m i_{qs}$$

$$i_{dr} = \frac{1}{L_r}\psi_{dr} - \frac{L_m}{L_r} i_{ds} \qquad i_{qr} = \frac{1}{L_r}\psi_{qr} - \frac{L_m}{L_r} i_{qs}$$

3. Hysteresis band PWM current control Method

Figure belows show the indirect vector control of three phase induction motor using Hysteresis band PWM current control. The speed control loop generates torque component of iqs* and the flux component of current ids* is also determined using the equations above. The slip frequency ωsl* is generated from iqs* in feedforward manner from equations above to satisfy the phasor diagram. The corresponding expression of slip gain Ks is given by

$$K_s = \frac{\omega_{sl}^*}{i_{qs}^*} = \frac{L_m R_r}{L_r \psi_r}$$

Signal ωsl* is added with speed signal ωr to generate frequency signal ωe. The unit vector signals cosθ_e and sinθ_e are then generated from ωe by integration and look up tables as shown below.

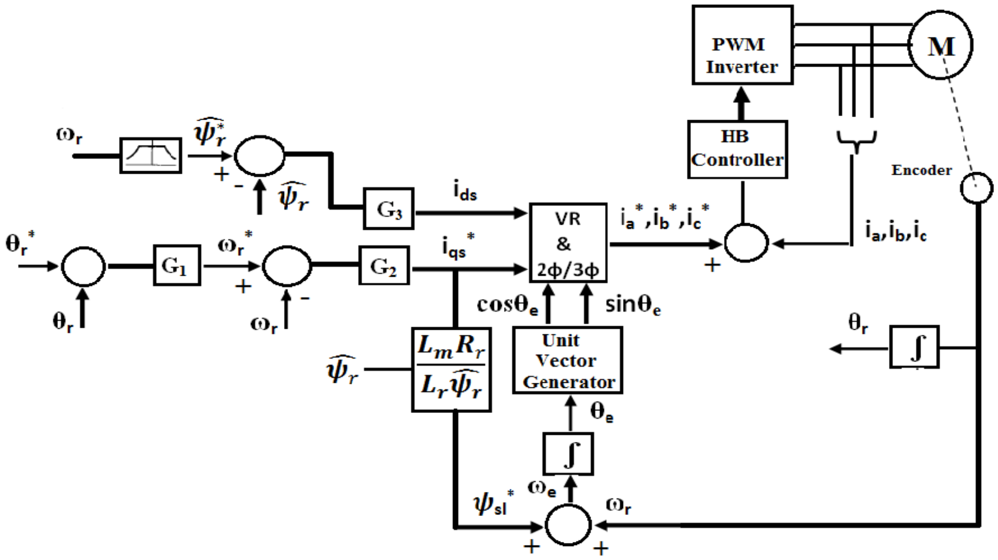

Figure 3. Block Diagram of Indirect Vector Control with Hysteresis Band Current Controller

The VR and 2φ-3φ transformation are done. By using Hysteresis band PWM current control, the harmonic content is not optimum. Besides the current controller will tend to saturate due to high CEMF.

4. Synchronous Current Control

Command currents i_{ds}^* and i_{qs}^* in vector control are compared with respective i_{ds} and i_{qs} generated by transformation of phase currents (3φ-2φ) with the help of unit vectors. The respective errors generate the voltage command signals V_{ds}^* and V_{qs}^* through P-I compensators.

These voltage commands are converted into stationary frame phase voltages. The synchronous current control with P-I controller assure amplitude and phase tracking of currents.

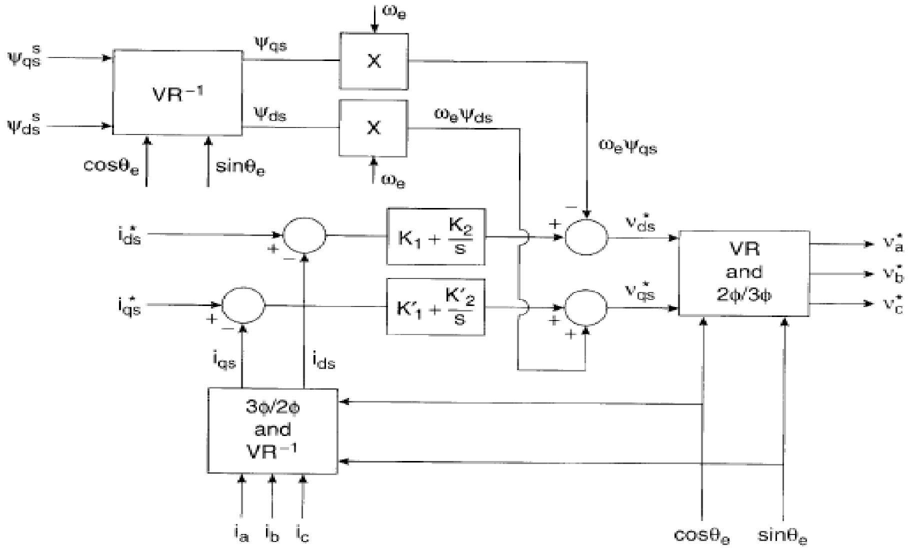

Figure 3. Synchronous current control with feedforward CEMF compensation

The introduction of feedback loops brings with it a small amount of coupling effect. To enhance the loop response, feed-forward CEMF signals are injected in the respective loops. Signal $\omega_e\psi_{ds}$ is added in i_{qs} loop, whereas signal $\omega_e\psi_{qs}$ subtracts from i_{ds} loop. The block diagram for estimating CEMF signals is added in above proposed figure. The stator fluxes and actual d-q axes currents are estimated as shown below.

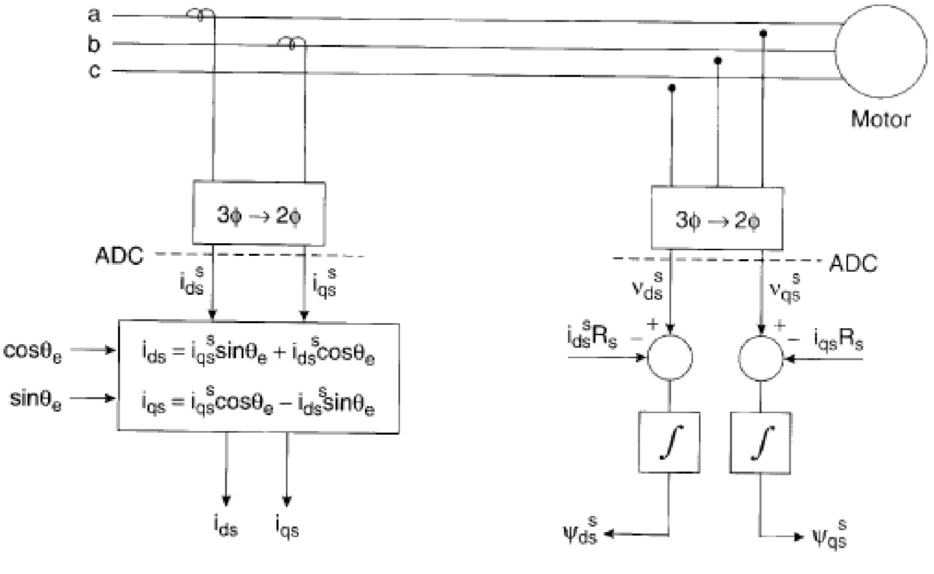

Figure 3. Block Diagram of estimating stator fluxes and actual currents

Feed forward CEMF signals are injected in their respective loops using these equations

$$\widehat{\psi_s} = \sqrt{(\psi_{ds}^{s^2}) + (\psi_{qs}^{s^2})}$$

$$\omega_e = \frac{(V_{qs}^s - i_{qs}^s R_s)\psi_{ds}^s - (V_{ds}^s - i_{ds}^s R_s)\psi_{qs}^s}{\widehat{\psi_s^2}}$$

5. Simulation Results

Both Hysteresis Current control & Synchronous Current Control (Proposed method) are implemented using PSIM. The speed responses of Induction motor using both methods are compared.

Also Total Harmonic Distortion (THD) of Input Current and Input Voltage of Three phase Induction Motor using Hysteresis Current Controller and Synchronous Current Controller are also compared.

It can be observed that the response of three phase induction motor using HB controller is very sluggish and takes a lot of time for speed to settle down. Dynamic performance of three phase induction motor has improved using Hysteresis current control.

Total Harmonic Distortion of Input Current as well as Input Voltage of Three phase Induction Motor using Hysteresis Current Controller is 41.4% and 13.69% respectively.

Total Harmonic Distortion of Input Current as well as Input Voltage of Three phase Induction Motor using Synchronous Current Controller is 3.8% and 2.69% respectively. All the obtained results are tabulated in the table.

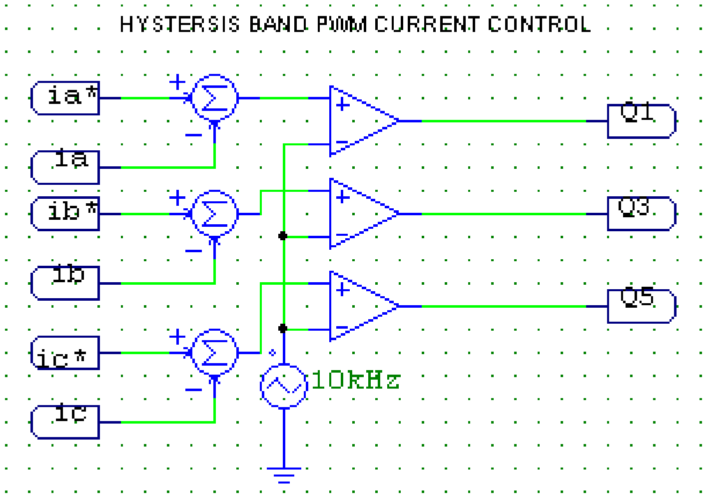

Figure 3. PSIM model of Hysteresis Band PWM Current Control

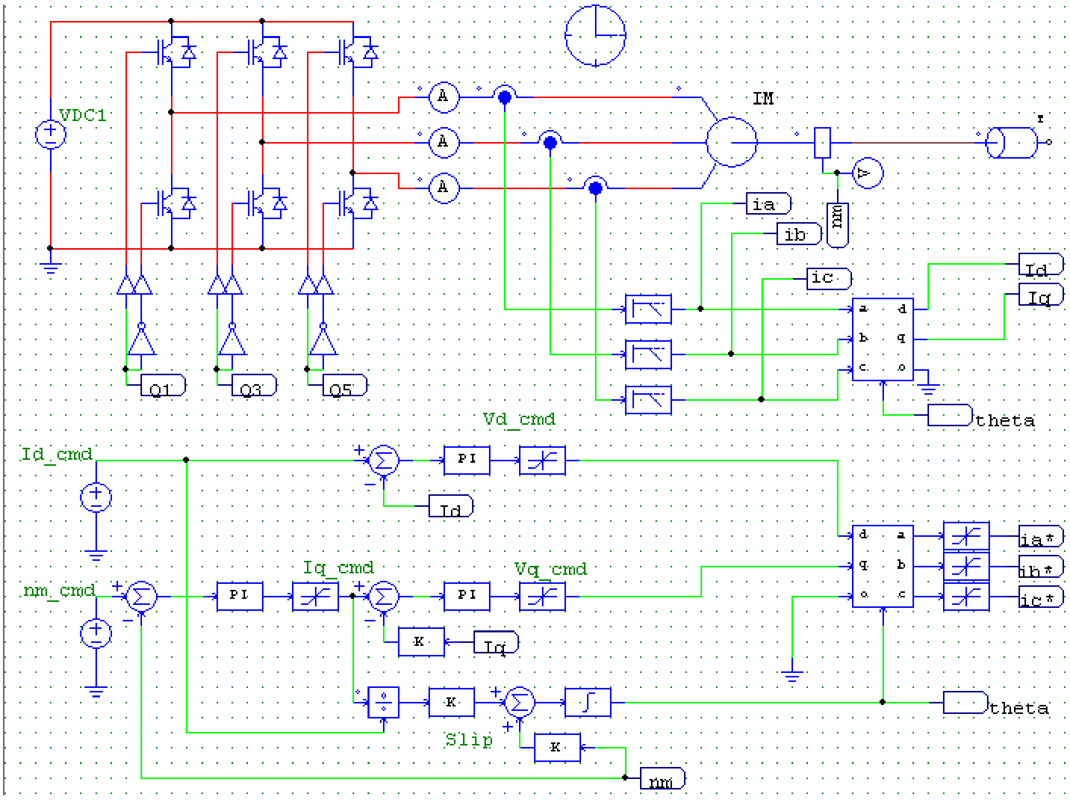

Figure 3. PSIM model of Indirect vector control of Induction motor using HB current control

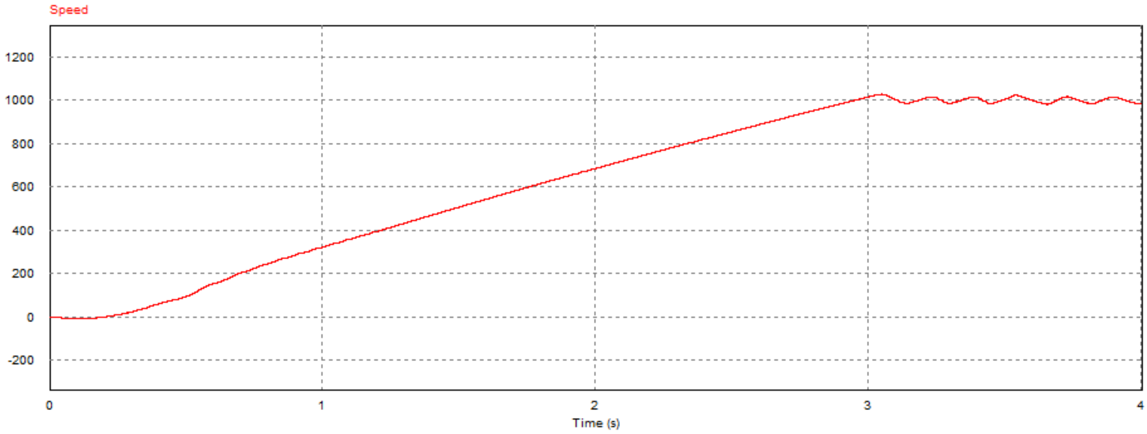

Figure 8. Speed response of Induction Motor using HB controller

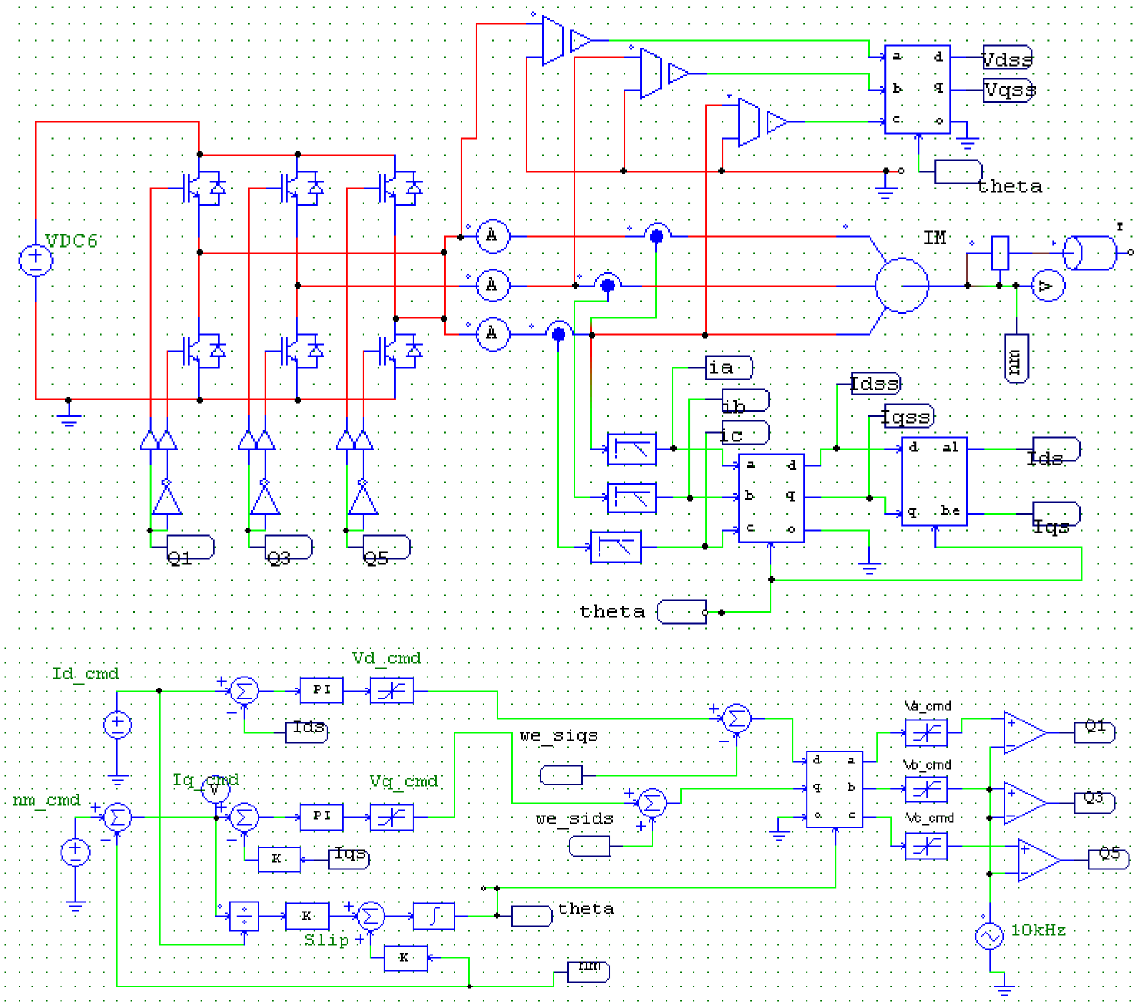

Figure 3. PSIM model of Indirect vector control of Induction motor using synchronous current control

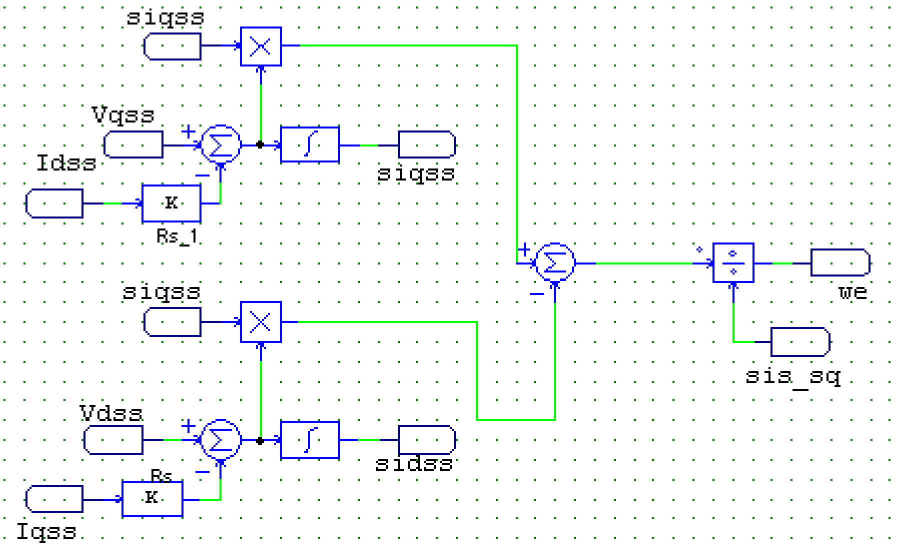

Figure 10. Subsystem of frequency signal we

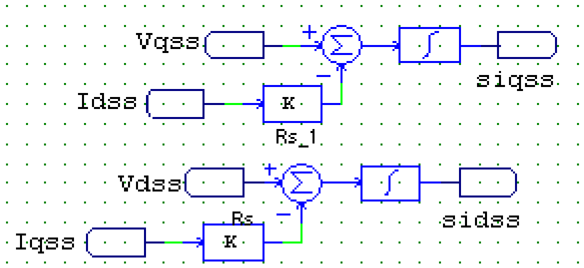

Figure 10. Subsystem of estimating stator fluxes

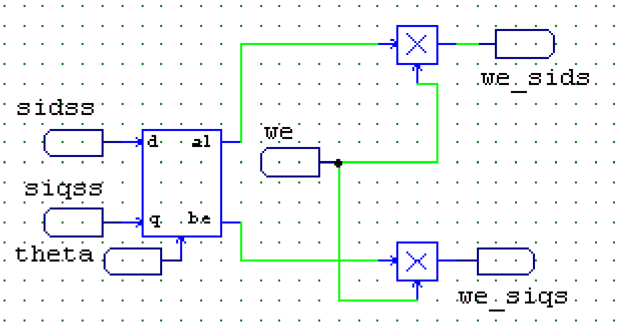

Figure 10. Subsystem of estimating feedforward CEMF signals

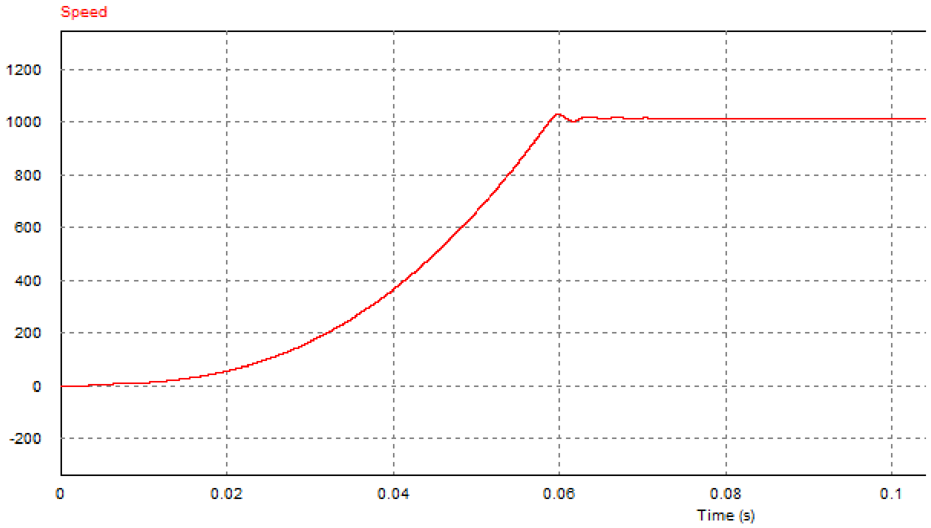

Figure 11.Speed response of indirect vector control using synchronous current controller

6. Conclusion

Indirect Vector Control of Three phase Induction Motor using Hysteresis Current Controller and Synchronous Current Controller has been simulated using PSIM. It can be observed from the obtained results that the dynamic response has improved by using Synchronous Current Controller. THD values of Input Current and Input Voltage has also decreased. All obtained results are tabulated below:

Current Control Method	Speed Response (Steady State Time)	THD (Input Current to Induction Motor)	THD (Input Voltage to Induction Motor)
Hysteresis Current Controller	3 sec	41.4%	13.69%
Synchronous Current Control	0.06 sec	3.8%	2.69%

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