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A Robust Control Algorithm for Speed Sensorless Induction Motor Drive with SVPWM and Estimation

D. Pavankumar[1], S. Sridhar[2]

PG Scholar, Power & Industrial Drives, Dept. of EEE, JNTU College of Engg., Ananthapuramu, Andhra Pradesh, India.[1]

Assistant Professor, Dept. of EEE, JNTU College of Engg., Ananthapuramu, Andhra Pradesh, India.[2].

ABSTRACT: Sensorless speed control of Induction Machine (IM) drives became a mature technology for a wide speed range because of their advantages like reduced hardware complexity, lower costs etc. This paper presents a sensorless control algorithm of flux estimator and speed estimator which is robust for the stable operation of the sensorless induction motor drive for high as well as low speed regions. The motor operates with SVPWM inverter in sensorless mode. The dynamic performance of the drive system and sensitivity analysis for the motor parameter change is presented. Voltage and Current model based Model Referencing Adaptive System (MRAS) is presented for the estimation. The induction motor is modelled in stationary reference frame. The sensorless control algorithm performs satisfactorily even for the slight detuning of the motor parameters. The simulation is performed using MATLAB-Simulink software.

KEYWORDS: Sensorless Induction motor, Vector control, MRAS, Estimation, SVPWM.

I. INTRODUCTION

The requirement of low-cost, low maintenance, robust electrical motors has resulted in the emergence of the Induction Motor as the industry leader. Traditional speed control methods of induction motor control the frequency and amplitude of the motor drive voltage [1]. In contrast, vector control methods control the frequency, amplitude and phase of the motor drive voltage [2]-[4]. With vector control and other control strategies like DTC the major drawback of the scalar control can be overcome because these control schemes are based on a model of the IM which is considered valid for transient conditions [5], [6]. The use of encoders in conventional speed control drives is expensive and a problematic factor. In general, the operation in explosive, corrosive, or chemically aggressive environments requires a motor without a speed sensor. The literature survey reveals some of the information regarding the work behind the research in sensorless speed control of IM drives [7]. The approaches used are basically two types. The first method is to model the induction motor by its state equations [8], second is the signal injection technique for low speed sensorless operation [9]. Space vector pulse width modulation technique can enhance the stability of sensorless drives [10].

II. DYNAMIC MODEL OF INDUCTION MOTOR

For the analysis and the performance prediction at steady state condition, a simple per phase equivalent circuit model of an IM is sufficient. The transient behaviour of the IM has to be taken into account for the vector control and other schemes. So, the dynamic d-q model of the IM based on the Park's transformation is considered. It is possible to obtain the following set of equations by applying the usual space vector transformation to a three phase system. The equations are as follows:

$$V_s = R_s \,.\, i_s + \frac{d\psi_s}{dt} + j \,.\, \omega_1 \,.\, \psi_s \quad (1)$$

$$V_r = 0 = R_r \,.\, i_r + \frac{d\psi_r}{dt} + j \,.\, (\omega_1 - P.\Omega_r) \,.\, \psi_r \quad (2)$$

$$\psi_s = l_s \,.\, i_s + L_m \,.\, (i_s + i_r) \quad (3)$$

$$\psi_r = l_r \,.\, i_r + L_m \,.\, (i_s + i_r) \quad (4)$$

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where ω_1 is the rotational speed of the d-q reference frame, V_s and V_r are the stator and rotor voltages, i_s and $.\, i_r$ are the stator and rotor currents and ψ_s and ψ_r are the stator and rotor fluxes respectively.

The electromagnetic torque is

$$T_e = \frac{3}{2} . P . \frac{L_m}{L_r} . [\psi_r \times i_s] \quad (5)$$

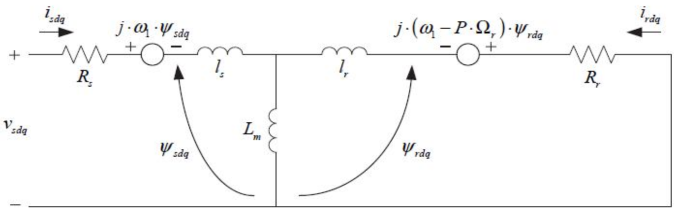

Fig.1 Dynamic model of IM

VECTOR CONTROL:

The objective of vector control is to control the IM similar to a separately excited and fully compensated DC machine. The reference frame is so chosen that it is attached to the rotor flux vector ψ_r.The equations for vector control can be as follows:

$$V_{dr}^e = 0 = R_r . i_{dr}^e + \frac{d}{dt}\psi_{dr}^e \quad \text{(d – axis rotor)} \quad (6)$$

$$V_{qr}^e = 0 = R_r . i_{qr}^e + \omega_{sl} . \psi_{dr}^e \quad \text{(q – axis rotor)} \quad (7)$$

and the torque expression can be finally expressed as

$$T_e = \frac{3}{2} . \frac{P}{2} . \frac{L_m^2}{L_r} . i_{qs}^e . i_{ds}^e \quad (8)$$

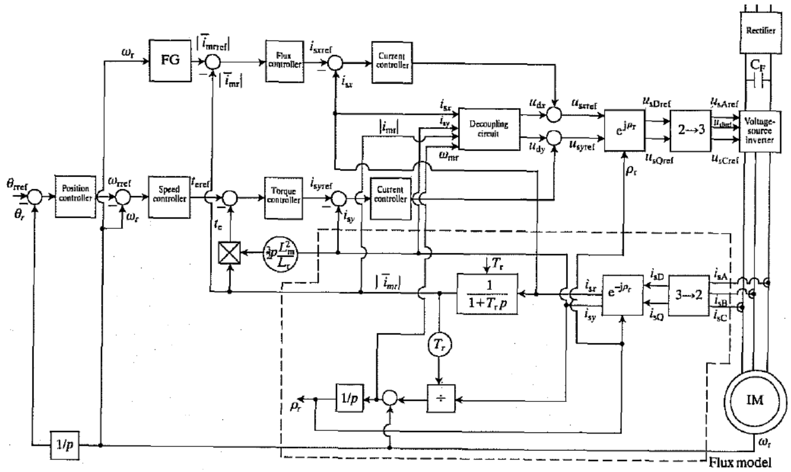

Fig.2 block diagram of vector control of IM

III. SPEED SENSORLESS VECTOR CONTROL OF INDUCTION MOTOR

The main idea behind this control method is to estimate the rotor speed from terminal variables i.e. voltage and currents. Equations required are as follows (in stationary reference frame):

Stator equations:

$$V_{ds} = R_s . i_{ds} + \sigma . L_s . \frac{d}{dt} i_{ds} + \frac{L_m}{L_r} . \frac{d}{dt}\psi_{dr} \quad (9)$$

$$V_{qs} = R_s . i_{qs} + \sigma . L_s . \frac{d}{dt} i_{qs} + \frac{L_m}{L_r} . \frac{d}{dt}\psi_{qr} \quad (10)$$

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Rotor equations:

$$0 = R_r \,.\, i_{dr} + \frac{d}{dt}\psi_{dr} + \omega_r \,.\, \psi_{qr} \quad (11)$$

$$0 = R_r \,.\, i_{qr} + \frac{d}{dt}\psi_{qr} - \omega_r \,.\, \psi_{dr} \quad (12)$$

The expression for rotor speed to be estimated is finally expressed as

$$\omega_r = \frac{\left(\psi_{dr} \cdot \frac{d}{dt}\psi_{qr} - \psi_{qr} \cdot \frac{d}{dt}\psi_{dr}\right) - \frac{L_m}{\tau_r}\left(\psi_{dr} \,.i_{qs} - \psi_{qr} \,.i_{ds}\right)}{\psi_{dr}^2 + \psi_{qr}^2} \quad (13)$$

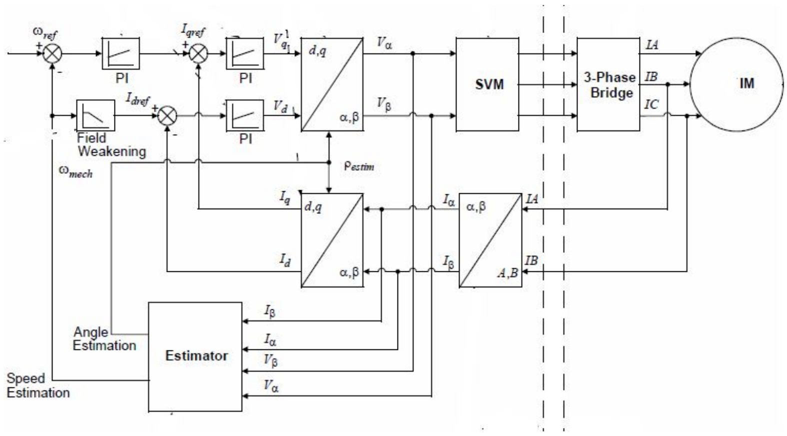

Fig.3 block diagram of sensorless IM

IV. SPACE VECTOR PULSE WIDTH MODULATION (SVPWM)

The SVPWM technique is one of the most popular PWM techniques due to a higher DC bus voltage use and easy digital realization. The output voltages of the inverter are realized by representing space vectors for the implementation of SVPWM. The reference voltage can be synthesized by using vectors V_1, V_2 and V_0 (zero vector), applied for time t_x, t_y and t_0 respectively. Hence, for sector 1 using the volt-second principle

$$v_s^* T_s = V_1 t_x + V_2 t_y + V_0 t_0 \quad (\text{where } T_s = t_x + t_y + t_0) \quad (14)$$

the space vectors are given as

$$v_s^* = |v_s^*| e^{j\alpha}, \quad V_1 = \frac{2}{3} V_{dc} e^{j0}, \quad V_2 = \frac{2}{3} V_{dc} e^{j\frac{\pi}{3}}, \quad V_0 = 0 \quad (15)$$

the time of applications t_x and t_y can be obtained by solving above equations as follows:

$$t_x = \frac{\sqrt{3}|v_s^*|}{V_{dc}} \sin\left(k\frac{\pi}{3} - \alpha\right) T_s \text{ where } \alpha = \frac{\pi}{3} \text{ and k = 1, 2, 3, 4, 5, 6 is the sector number}$$

$$t_y = \frac{\sqrt{3}|v_s^*|}{V_{dc}} \sin\left(\alpha - (k-1)\frac{\pi}{3}\right) T_s$$

$$t_0 = T_s - t_x - t_y \quad (16)$$

The MATLAB-Simulink model for SVPWM can be developed using different approaches, either using all simulink blocks or all MATLAB coding. Here coding based SVPWM technique is presented for the implementation of SVPWM.

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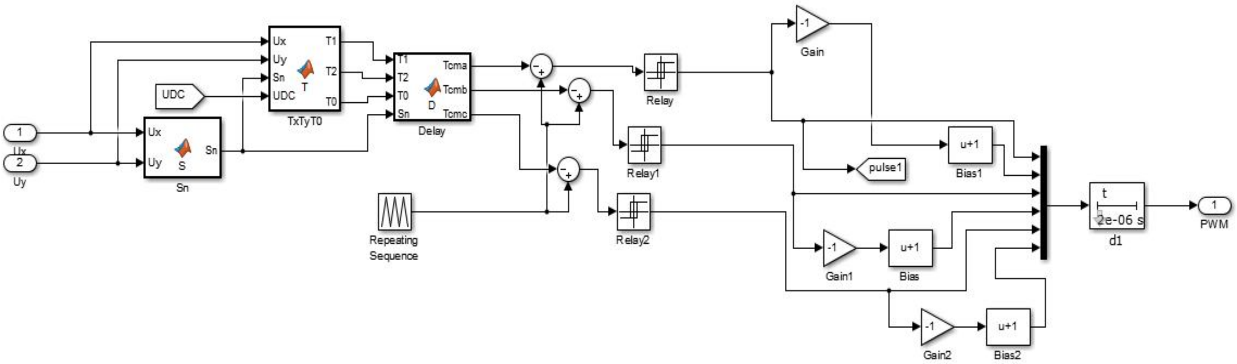

Fig.4 Simulink implementation of SVPWM

V. PROPOSED CONTROL ALGORITHM

1. Flux Estimator:

Voltage model:

The machine terminal voltages and currents are sensed thereby fluxes are calculated from the stationary reference frame. The equations are as follows:

$$\psi_{dr}^{s} = \frac{Lr}{Lm}(\psi_{ds}^{s} - \sigma.L_s\, i_{ds}^{s}) \quad (17)$$

$$\psi_{qr}^{s} = \frac{Lr}{Lm}(\psi_{qs}^{s} - \sigma.L_s\, i_{qs}^{s}) \quad (18)$$

Where σ is the leakage factor given by $= 1 - \frac{L_m^2}{L_r L_s}$. The direct vector control with voltage model signal estimation cannot be used in industrial applications because vector drives are often required to operate from zero speed (including zero speed start up). Hence voltage based estimation is preferred for speed greater than 10 % of the base speed.

Current model:

The rotor flux component can be more easily synthesized in the low speed region with the help of speed of current signals. The equations are:

$$\frac{d}{dt}\psi_{dr}^{s} = \frac{Lm}{\tau_r}.i_{ds}^{s} - \omega_r.\psi_{qr}^{s} - \frac{1}{\tau_r}.\psi_{dr}^{s} \quad (19)$$

$$\frac{d}{dt}\psi_{qr}^{s} = \frac{Lm}{\tau_r}.i_{qs}^{s} - \omega_r.\psi_{dr}^{s} - \frac{1}{\tau_r}.\psi_{qr}^{s} \quad (20)$$

It is possible to have a hybrid model because the above models are suitable for high as well as low speed ranges.

2. Speed Estimator:

The MRAS has become a popular scheme for sensorless operation of a vector controlled drive because of its simplicity. The model reference approach takes advantage of using two independent machine models for estimating the same state variable. The estimation error between the outputs of two computational blocks is used to generate a proper mechanism for adapting the speed. The difference between the two estimated vectors i.e. $\psi_r^{(1)}$ *and* $\psi_r^{(2)}$ is used to feed a PI controller whose output is used to tune the adjustable model. The PI controller algorithm is given by,

$$\omega^{est} = K_p\varepsilon + K_i \int \varepsilon\, dt \quad (21)$$

where the input of the PI controller is

$$\varepsilon = \psi_{\beta r}^{(1)}\psi_{\alpha r}^{(2)} - \psi_{\alpha r}^{(1)}\psi_{\beta r}^{(2)} \quad (22)$$

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The developed Simulink models for the above estimators are as shown below.

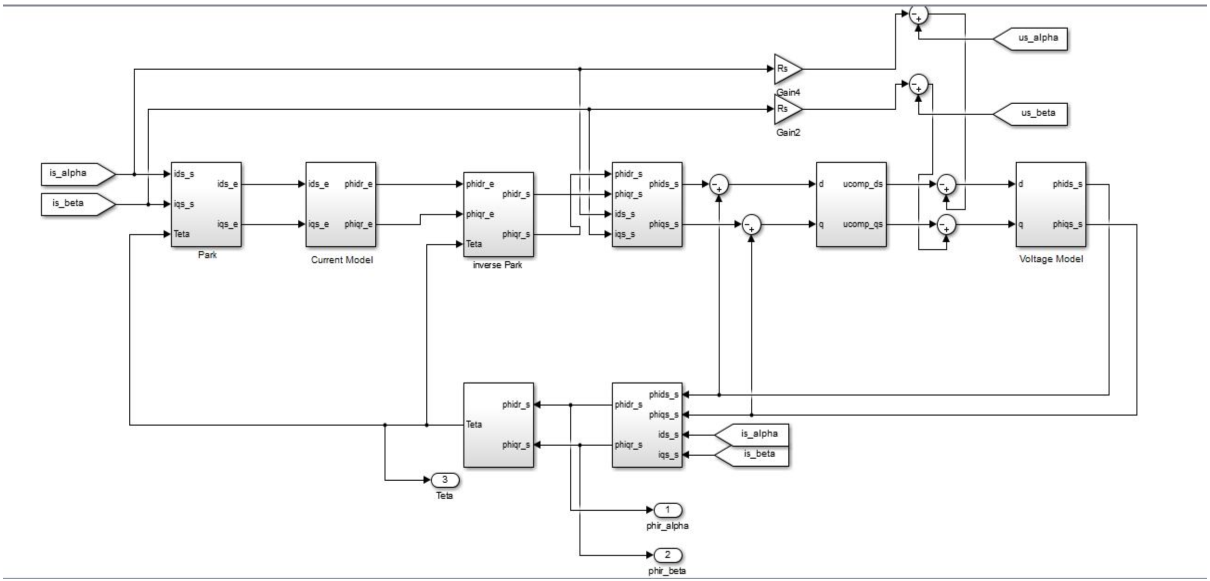

Fig.5 Simulink model of flux estimator

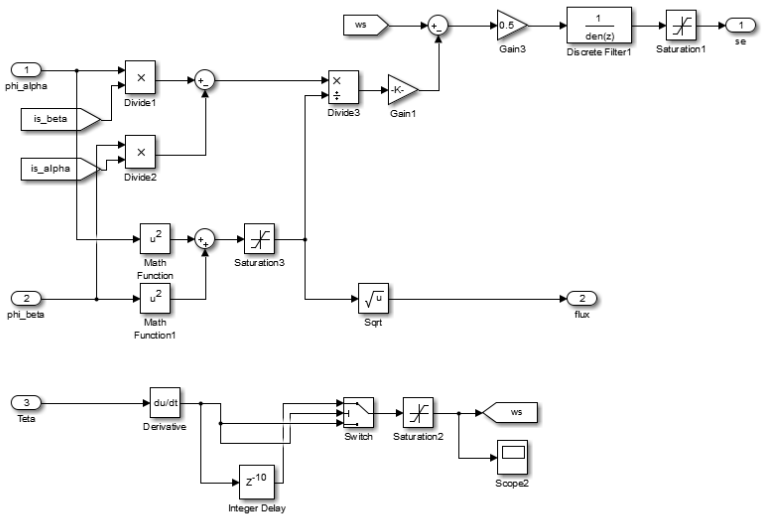

Fig.6 Simulink model of speed estimator

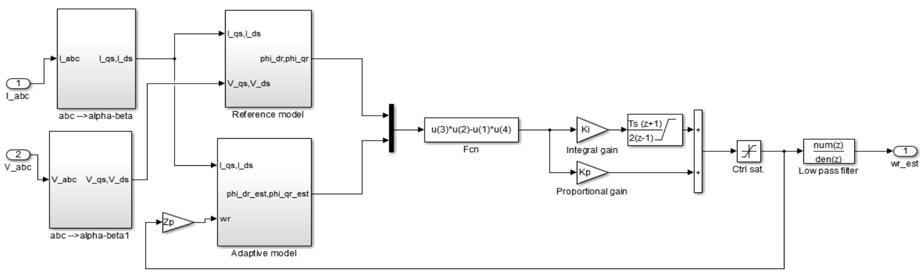

Fig.7 Simulink implementation of MRAS model

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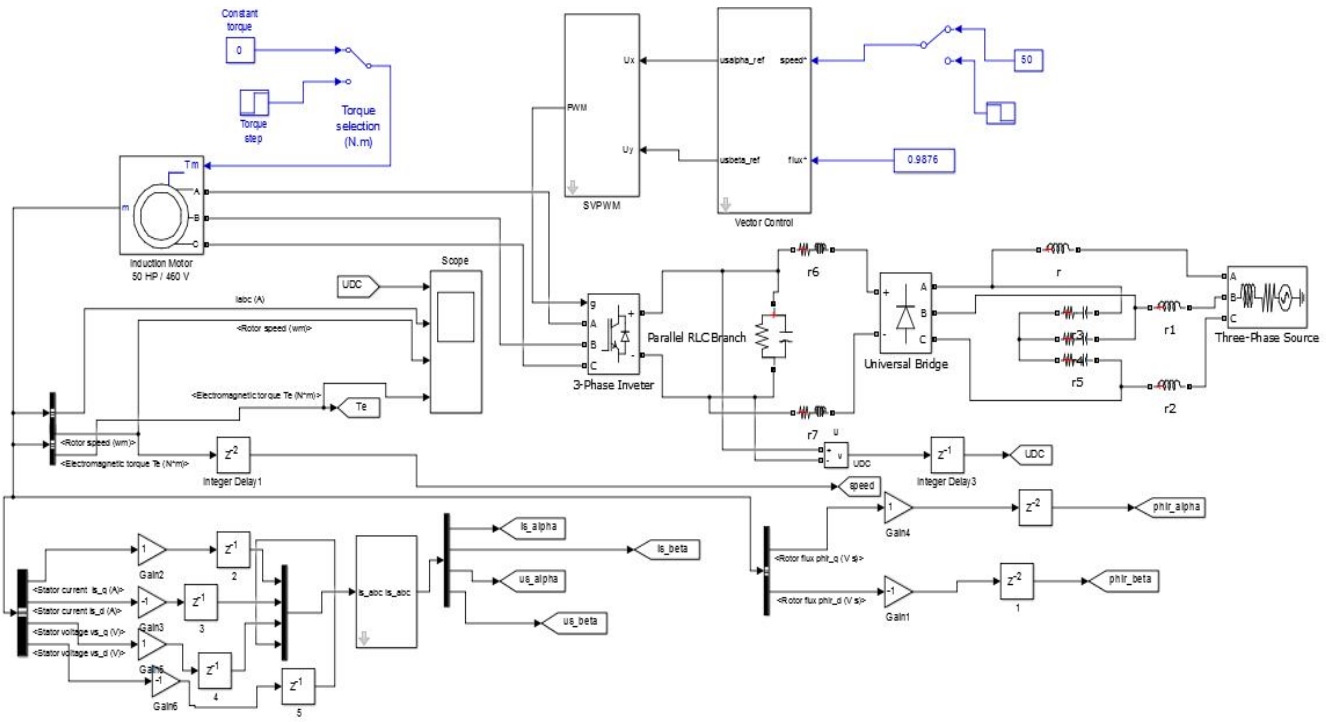

Fig.8 Complete model of sensorless IM drive with proposed control algorithm

VI. SIMULATION RESULTS

The developed models of IM, SVPWM, Sensorless Vector Control, MRAS and Proposed Estimators are simulated using MATLAB-Simulink software and the performance analysis is carried out.

1. Speed response:

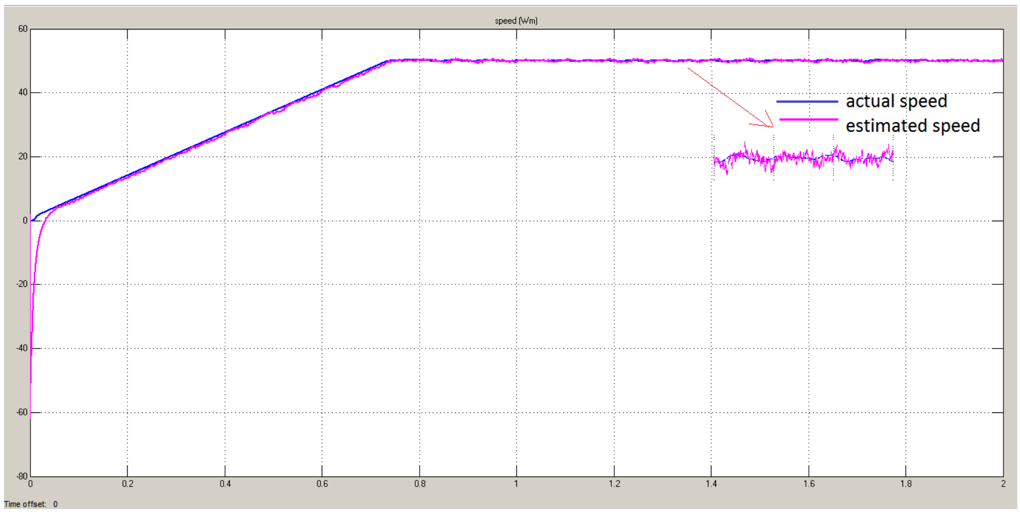

Fig.9 Response of the system when the speed is 50 (rpm)

From Fig.9 it is evident that when a speed of 50 rpm is given (i.e. at low speed range), the system reaches to its steady state at 0.75 sec. The estimated speed follows the actual speed during the transient condition with very less distortions and within considerably less ripple range. The response of the system during start up at low speed range is studied here.

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2. Dynamic response when load torque applied is zero:

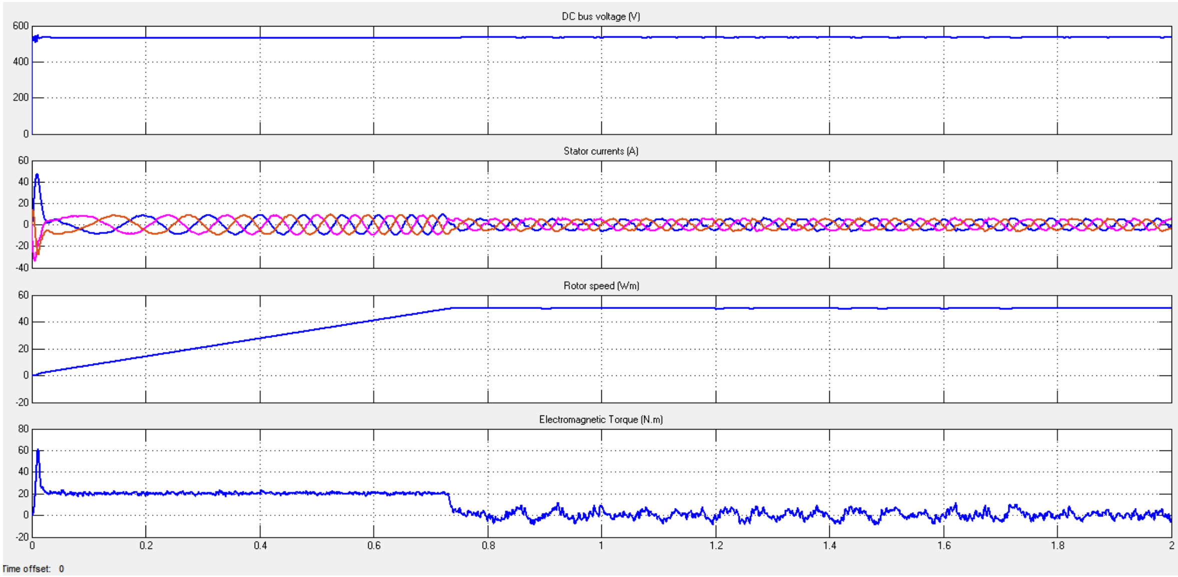

Fig.10 No-Load response of the system

For the same speed (50 rpm) applied, the system is started under no load i.e. the torque applied is 0 N.m. A brief analysis is shown in Fig.10 to show the performance of the system during transient condition. At time 0 sec to 0.75 sec the speed is attained to its set value while the torque is being constant at 20 N.m during this period. The torque reached zero with distortions after 0.75 sec (steady state).

3. Dynamic response of the system when a constant load torque is applied:

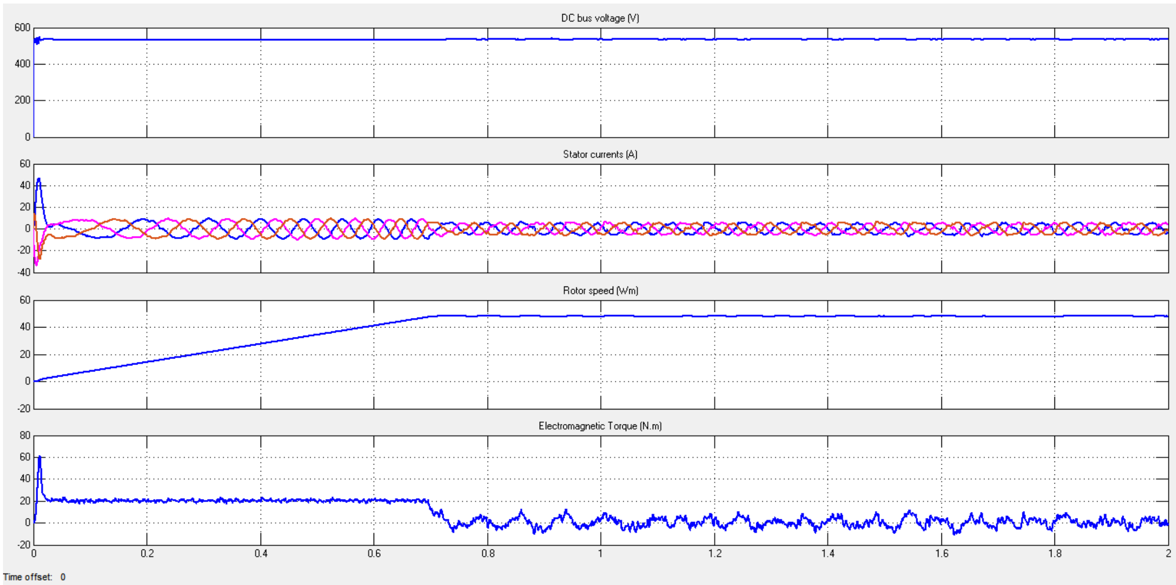

Fig.11 Response of the system when a constant torque is applied

From Fig.11 it is observed that under load condition, the steady state torque ripple range is increased but during transient condition the response is same as that of no load. The machine parameters for this response are as follows: Stator resistance (Rs) is 2.76 ohms, Stator inductance (Ls) is 0.2 H, Total leakage coefficient (σ) is 0.1183 and Rotor time constant (τr) is 0.0645.

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4. Response of the system when the parameters are changed:

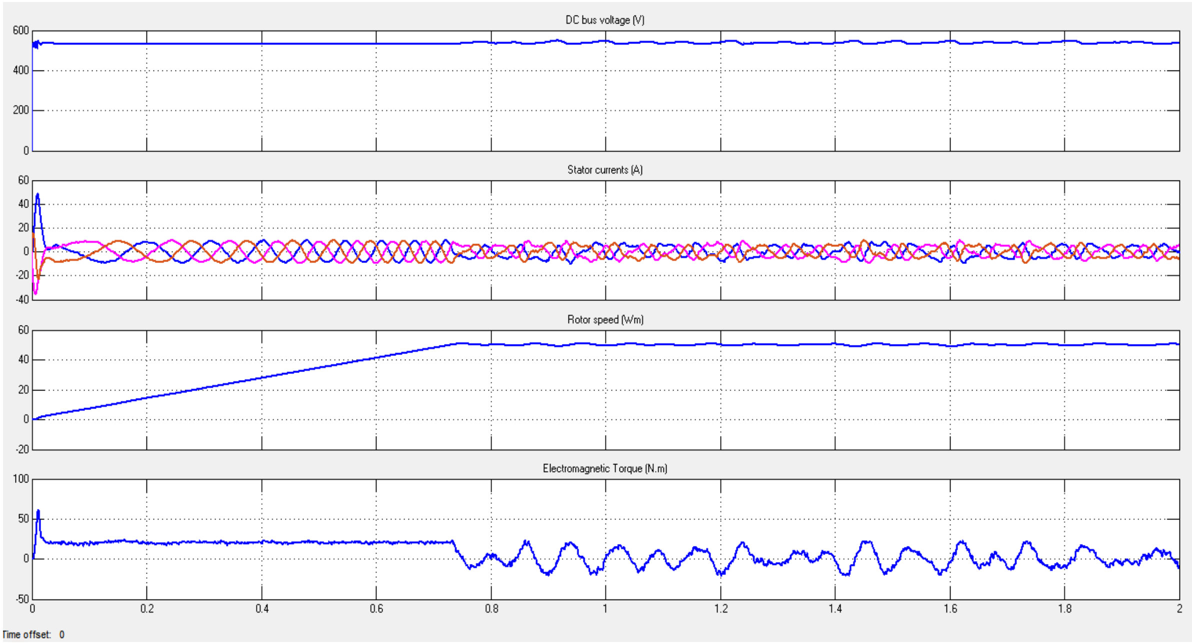

Fig.12 Dynamic behaviour of the system for the detuned parameters

A slight detuning of parameters is performed with the values as Stator resistance (Rs) is 2.82 ohms, Stator inductance (Ls) is 0.2 H, Total leakage coefficient (σ) is 0.12 and Rotor time constant (τr) is 0.059 for which the steady state performance is affected slightly but transient response remain almost unchanged as shown in Fig.12 which shows the robustness of the system.

5. Response of the system for high speed range:

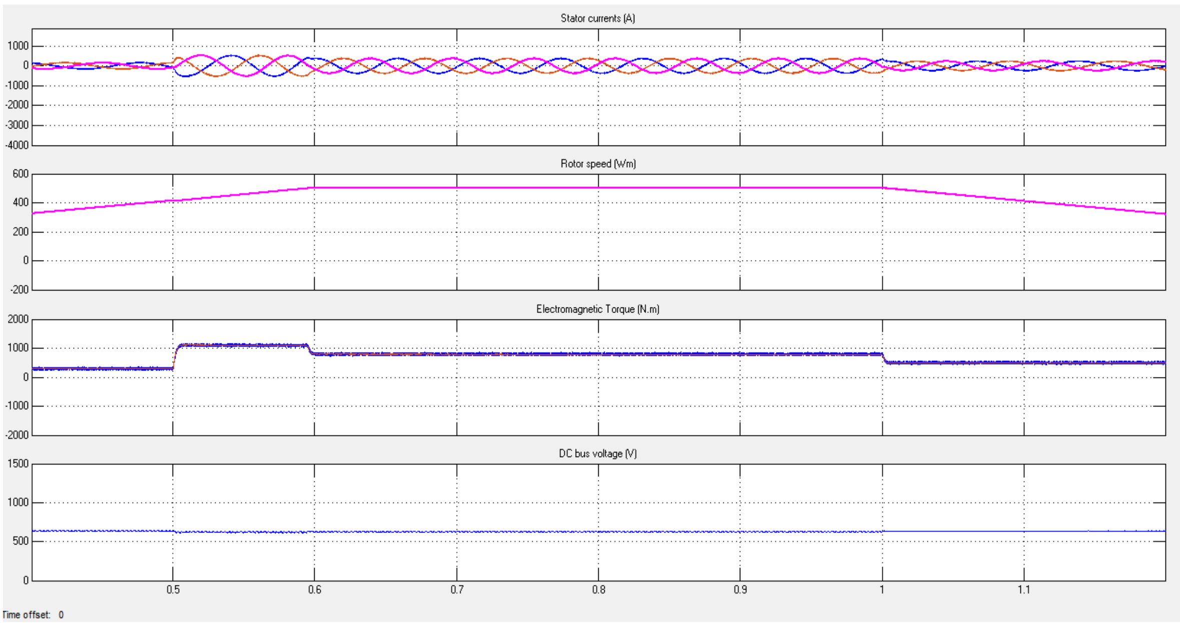

Fig.13 Dynamic response for high speed range

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Fig.13 shows the performance of the system when the speed given is increased to 500 rpm and the corresponding torque change is applied. Both transient and steady state responses of the system are studied and observed similar performance as for the low speed range. Hence, it can be concluded that the proposed control algorithm is robust for the sensorless operation of the Induction Motor Drive systems at low as well as high speed ranges.

VII. CONCLUSION

In this paper a robust control algorithm for the speed sensorless Induction Motor drive is presented. The system response for low as well as high speed ranges is analysed. The dynamic response of the system for the actual parameters and detuned parameters has been studied and the robustness of the system is observed during the transient condition. Methods like Fuzzy and ANN techniques are proposed for the increased robustness but increase in the complexity as well for the sensorless Induction Motor Drive system which leads to the future scope of the research.

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BIOGRAPHY

Mr. D. Pavankumar completed his B.Tech in Electrical and Electronics Engineering and M.Tech in Power and Industrial Drives branch at JNTU Anantapur. His areas of interest includes Power electronics and Drives and Network Analysis

Mr. S. Sridhar is an Asst. Professor in Electrical and Electronics Engineering Department at JNTU Anantapur. His research work includes Power Electronics, Electrical Machines and Electrical Drives.