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SCALAR CONTROL MODELING OF INDUCTION MOTOR USING PI CONTROLLER

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ABSTRACT

Three phase induction motors are generally used in the industries more than other types of motors. Due to their importance in industrial processes, there is a need for control strategies, depending on the mode of operation. Machine control is mostly achieved in recent times through electronic circuitry, called drives. Induction motor speed can be controlled by; varying; supply voltage, frequency, slip and poles. Changing the number of poles is possible from the design stage of the motor. In this research, a microprocessor based controller is designed and simulated for induction machine control. Particularly, a conventional P.I. controller is used, which results in good speed control of the motor performance, as it eliminates forced oscillations and steady state error, robust and reliable, has the ability to improve damping and reduce maximum overshoot. It also decreases the bandwidth and improves the rise time. This paper displays a hand full of advantages of the P.I. controller which also includes cheaper and easily afforded rates, simple and efficient that makes it more preferable in control technology. The simulation was done using MATLAB/SIMULINK. Result under various conditions were compared and discussed.

Keywords: *Induction Motor, PI controller, v/f scalar technique, modeling.*

I. INTRODUCTION

Induction motor is an Asynchronous AC motor. This motors are mostly used in the industry because it is reliable, cheap, vigorous, efficient, and has good self-starting capability, The speed control of the motor is very important because it helps to achieve maximum torque and efficiency as reported in [1]-[3]. Several methods on speed and torque with different techniques are deployed for induction motor control. These methods mostly are scalar control, vector or field-oriented control, direct and flux control, sliding mode control, Fuzzy logic Control (FLC) and adaptive control [4]-[7]. However, in addition to the fact that a mathematical framework is desirable for a systematic controller design with conventional methods, the emergence of PI controllers have been able to solve several control problems with simple but effective control methodology. For V/f speed control, a reference speed has been set, and the control architecture includes several rules. These rules depict a non-enthusiastic relationship between two inputs that is speed error (e) change in speed error (Δe) and output that is change of control (ωsl).

[8] - [12]. The speed loop controls the pulse width modulator PWM inverter frequency & voltage of a voltage source inverter VSI fed Induction machine. A PI controller is used which responds to the error signal and attempts to adjust the controlled quantity to achieve the desired system response. The parameters to be controlled can be that of any of the following measurable system quantities such as; speed, torque or flux. The merit of a P.I. controller is that it can be adjusted verifiably by adjusting one or more gain values and seeing the change in system response. It is assumed that the controller is performed regularly so that the system can be properly controlled. The sign of the error indicates the direction of change required by the control input [13] - [15].
The P.I. controlled system is passive to real (non-noise) when there is no derivative action.

II. INDUCTION MACHINE MODELING

The dynamic machine model in stationary reference frame is readily written below as in [17]

$$V_{ds}= R_s\, i_{ds} + \frac{d}{dt}\,\lambda_{ds} \qquad (1)$$

$V_{qs} = R_s i_{qs} + \frac{d}{dt}\lambda_{qs}$ (2)

$0 = R_r i_{qr} + \frac{d}{dt}\lambda_{qr} - r\, \lambda_{dr}\omega_r\lambda_{dr}$ (3)

$0 = R_r i_{qr} + \frac{d}{dt}\lambda_{qr} - \omega_r\lambda_{qr}$ (4)

Where

$V_{dr} = v_{qr} = 0$

Equations for Rotor circuit are:

$V_{qr} = R_r i_{qr} + (\omega - \omega_r)\lambda_{ds} + p\lambda_{qr}$ (5)

$V_{dr} = R_r i_{dr} - (\omega - \omega_r)\lambda_{qr} + p\lambda_{dr}$ (6)

The fluxes are combined with the currents occurring to the following expressions

$\lambda_{ds} = L_{Is}\, i_{ds} + L_M\,(i_{ds} + i_{dr}) = L_s\, i_{ds} + L_m i_{dr}$ (7)

$\lambda_{qs} = L_{Is} i_{qs} + L_M\,(i_{qs} + i_{qr}) = L_s i_{qs} + L_m i_{qr}$ (8)

$\lambda_{dr} = L_{Ir}\, i_d + L_M\,(i_{ds} + i_{dr}) = L_r i_{dr} + L_m\, i_{ds}$ (9)

$\lambda_{qr} = L_{Ir} i_{qr} + L_M\,(i_{qs} + i_{qr}) = L_r i_{qr} + L_m i_{qs}$ (10)

The development of torque is by the interaction of air - gap flux and rotor current. Therefore, the torque can be generally expressed in the vector form as;

$Te = \frac{3}{2}\left(\frac{P}{2}\right)\lambda_m \times I_r$ (11)

$Te - T_l = \left(\frac{2}{p}\right) J \frac{d\omega r}{dt}$ (12)

$Te = \frac{3}{2}\left(\frac{p}{2}\right)(\lambda_{dm} i_{qs} - \lambda_{qm}\, i_{ds})$ (13)

III. MECHANICAL MODEL

In trying to model the mechanical side of the Induction motor, the equation of motion of the machine and load is given as:

$J_m p^2\theta_m = Te - T_L$ (14)

Breaking Equation (14) into first-order differential equations, we have

$J_m p(\omega_m) = (T_e - T_L)$ (15)

Because,

$p\theta_m = \omega_m$ (16)

Given that,

$\omega_r = \omega_m p,\ \theta_r = \theta_m p$ (17)

Where, all the variables maintain their usual meanings.

IV. PI CONTROLLER

The P.I. controller calculates the controlled output by means of computing the proportional and integral errors and adding the two components to determine the output.

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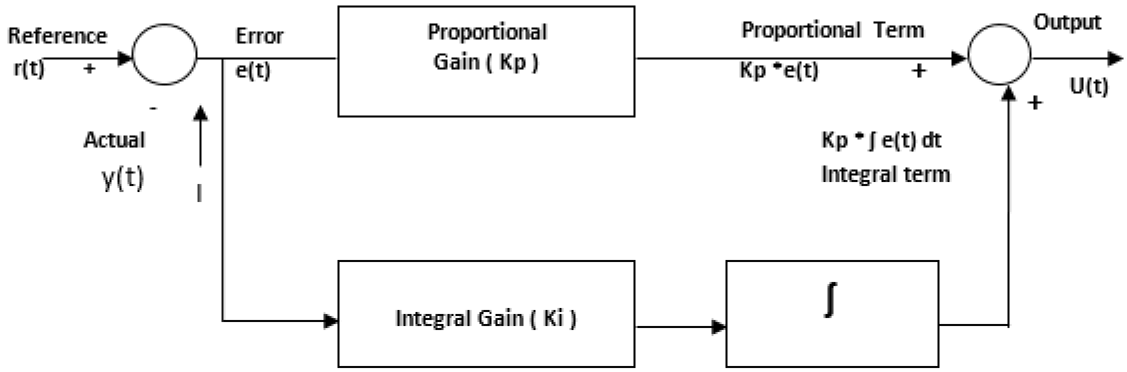

Fig. 1: PI controller block diagram

Because of the existence of the integral term in PI controller, steady state error of speed is insignificant, meaning its zero, causing the system to act quite accurately. The integral does not require high gain as required in proportional gain controller. However it has certain disadvantages like if very fast response is needed, the price paid is a higher overshoot which is unpleasant. PI controller provides a very efficient solution to various control problems in the real world. PI controller expels the forced oscillations and steady state error of P controller. However bringing in the integral mode will have unfavorable effect on the stability of the system and speed of response. Therefore, the PI controller will not increase the response speed and is not capable of predicting what will happen with the error in near future. PI controllers are normally used when there's no issue in the speed of response. In addition, this controller can be used when there is a wide transmission delay in the system, and when only a single energy storage process is available. PI controller can successfully work when there is presence of a noise or large disturbance in the cause of operation of a process. The PI speed gains are selected conventionally by observing their reaction on the response of the drive.

V. PI CONTROL CLOSED LOOP V/F CONTROL.

Applying a variable magnitude and variable frequency voltage to the motor is the background of constant V/F speed control of induction motor. The voltage source and the current source inverters are used in a modifiable speed ac drives. The block diagram below represents the closed loop V/F control using a VSI.

The closed-loop method provides a more specific solution to controlling the speed than the open-loop method. Moreover, the closed-loop method controls the torque too. A major drawback of the open-loop control method is that this method does not control the torque, so the preferred torque is only attainable at the nominal operating point. The speed of the machine changes when the torque changes as a result of induced load

VI. PI CONTROL OPEN LOOP V/F CONTROL

The open-loop V/F control of an induction motor is the commonest method of controlling speed because of its simple nature. These motors are commonly used in the industry. The control of this type of motor has some merits, which are; low cost, easy and uncomplicated to design, has the ability to resist errors of feedback signals. Conventionally, induction motors have been used with open loop 50Hz power supplies for constant speed applications. For variable speed drive applications, frequency control is normal. Although voltage is expected to be proportional to frequency to enable the stator flux remain constant.

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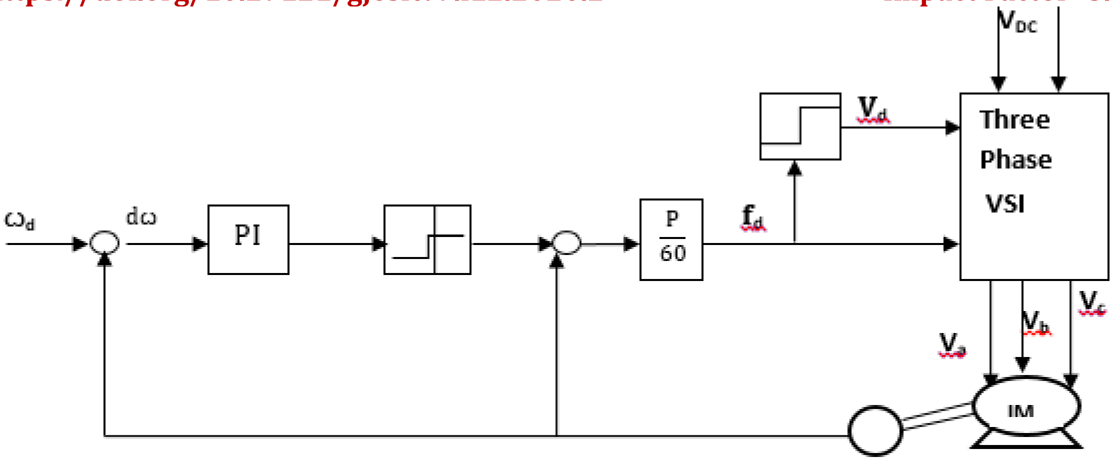

Fig. 2 Closed loop V/F constant control

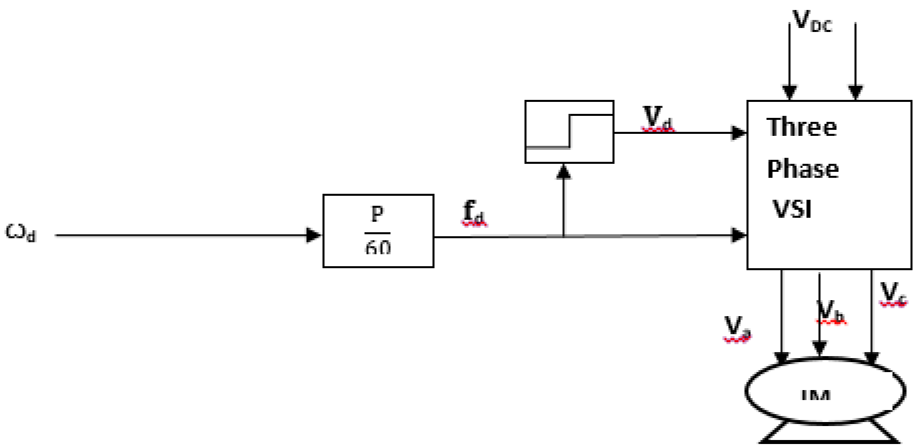

Fig. 3 Open loop constant V/F speed control

VII. TORQUE-SPEED ANALYSIS

The slip of an induction machine is given as; $S=(Ns-Nr)/Ns$

Performing these calculations can help the designer provide a motor that is best suited to a particular application. We can evaluate the capabilities of a three phase induction motor using the parameters of its equivalent circuit the normal way. The mechanical torque developed from the complete equivalent circuit is given by:

$T_{mech}=1/\omega_s * (3V)^2/([R_1+(R_2 \div S)]^2+(X_1+X_2)^2)=R_2 \div S$ (18)

$T_{mech} \approx 1/\omega_s * (3V_1)^2/((X_1+X_2)^2)=(R_2)^1/S$ (19)

$T_{mech} \approx 1/\omega_s * (3V_1)^2/((R_2)^1)*S$ (20)

At high values of slip:

The maximum pullout or breakdown torque is developed by

$T_{max}=1/(2\omega)_s * (3V_1)^2/(R_1+\sqrt{([(R_1)^2+(X_1+X_2)^2])})$ (21)

The maximum torque does not depend on the rotor resistance, but the gain of the rotor resistance determines the speed at which the maximum torque is developed.

VIII. SIMULINK MODELING

The equations (1) to (17) together makes up the model of the induction motor used in the representation of the SIMULINK model of figure 4

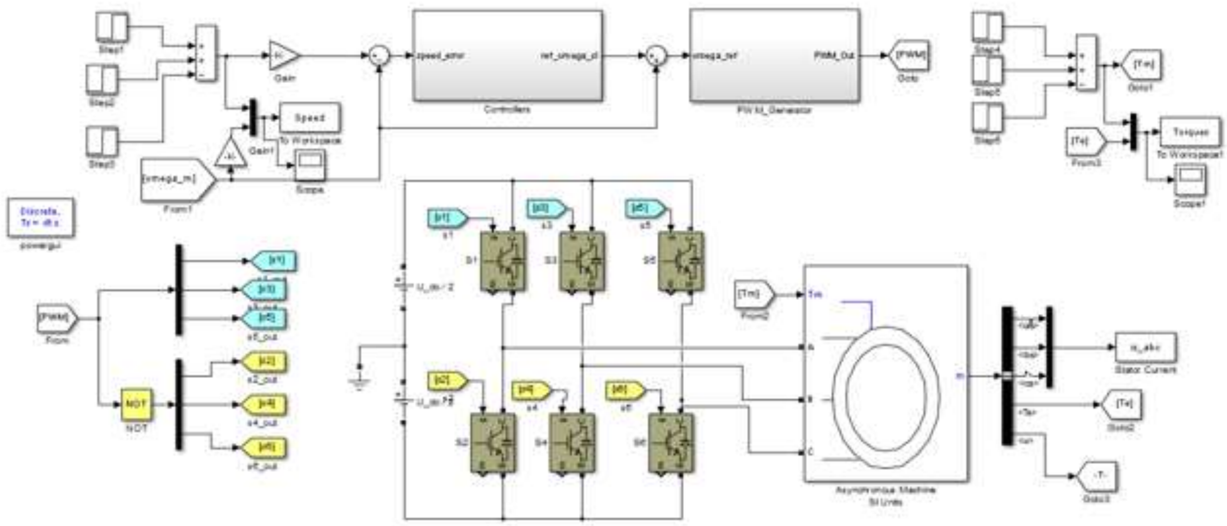

Fig. 4 The resultant Simulink model of the induction motor

Induction motor parameters

Table 1

S/N	Parameter	Value
1	Rated power	7.5KW
2	Supply frequency	60Hz
3	Rated voltage	400V
4	Rated speed	1440rpm
5	DC burse voltage	460V
6	Stator resistance	0.09961
7	Stator inductance	0.000867
8	Rotor resistance	0.05837
9	Rotor inductance	0.000867
10	Mutual inductance	0.03039
11	Inertia	0.4kg.m^2
12	Number of pole pairs	2
13	Ki	15
14	Kp	0.0001

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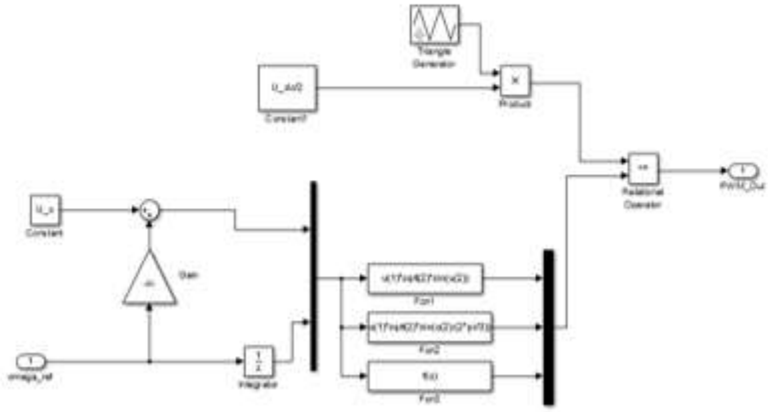

Fig. 5 subsystem of the PWM generator

Figure 5 represents PWM generator subsystem of the SIMULIMK model of induction motor in figure 4.

IX. RESULTS AND DISCUSSION

The SIMULINK model of an induction motor is seen in fig. 4, the output simulated result is achieved in MATLAB environment, and the simulation results are presented as computer traces in Figures 9, 10, 11, 12 and 13. Fig. 9 is a graph of no-load response of speed against time with 1500rpm reference speed, 0.5 rising time, 0.8 settling time and a maximum shoot of zero percent. Fig. 10 shows that the electromagnetic torque has a lot of ripples due to the effect of higher order harmonics which are not visible in the speed response as a result of inertia. It has a load torque of zero and average value of the motor torque also zero because of no load in the machine. Normally, an induction motor has a very high initial torque. This high initial torque is as a result of the high current – due to zero back e.m.f. – and high slip at the start. In figure 11 there is no back e.m.f. at the starting of the machine because the speed is low, and because there is no back e.m.f. it causes an extremely high value of current.

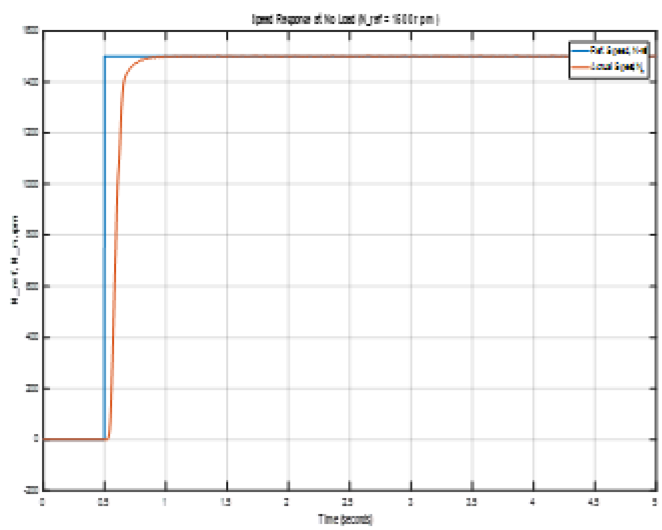

Fig. 9 Speed Response at no load

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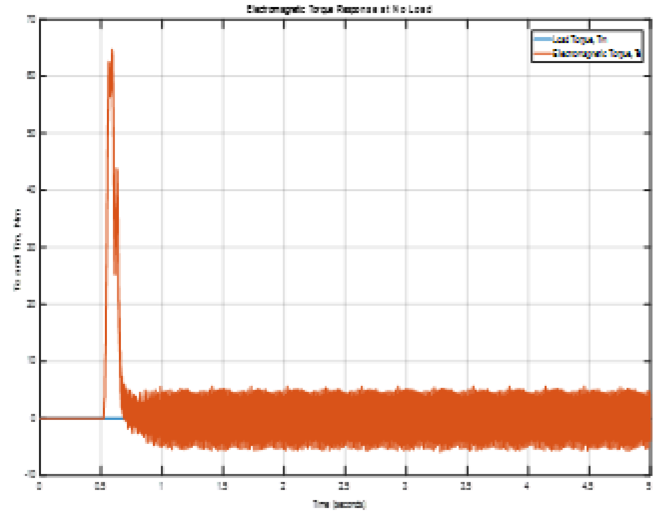

Fig. 10 Electromagnetic Torque at no load

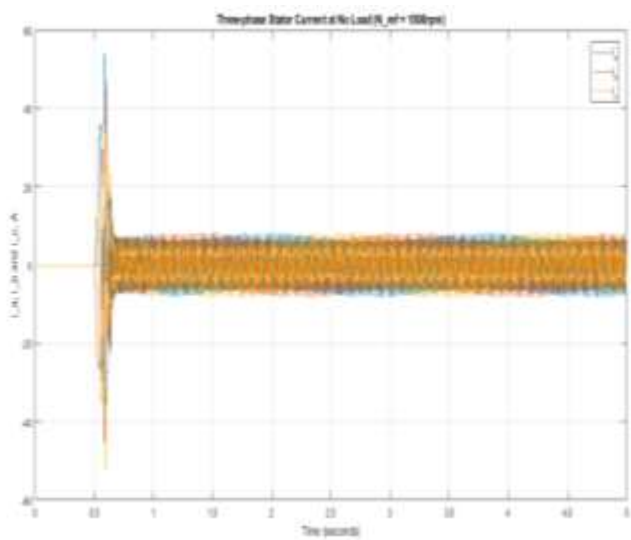

Fig. 11 Three-phase Stator Current at No Load

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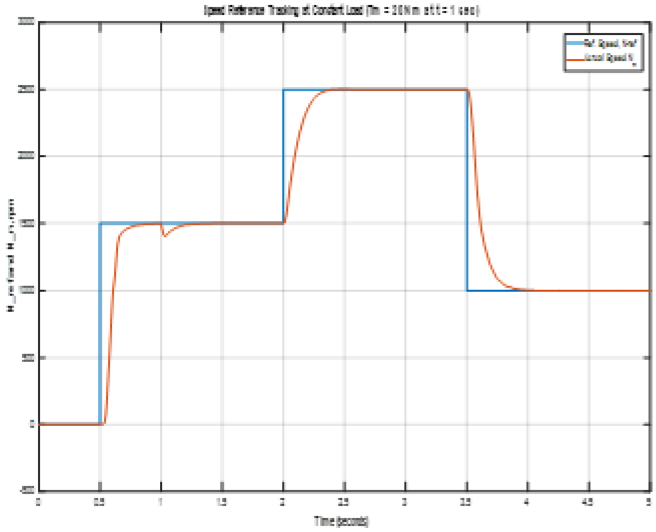

Fig 12 Speed Reference Tracking at constant load

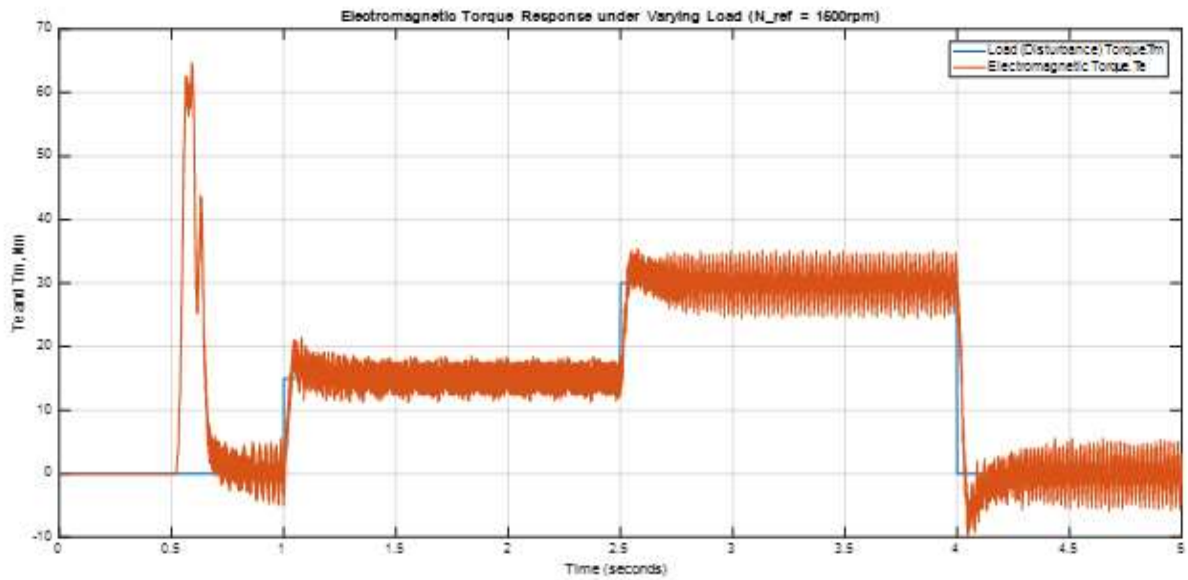

Fig.13 Electromagnetic torque under varying load

Figure 12 and **13** are cases where the machine is loaded with a particular load. They both have initial starting of 0.5 and reference speed of 1500rpm. At 1s a step load of 20Nm was introduced in **figure 12**, which causes an undershoot in the speed response, after 2 seconds the speed was increased to 2500rpm, and then after 3.5 seconds the speed was stepped down to 1000rpm, making the PI controller to provide a very good reference tracking with little or no overshoot and minimal undershoot. In **figure 13** the machine simply develops a torque that matches the load torque while maintaining the reference speed of 1500rpm, the torque settles at the steady state values and under 1.0s. At 0.5 the machine produces a high electromagnetic torque without load, at 1s the machine was loaded with the load of 20Nm, at 2s the electromagnetic torque reduces, with a steady state performance. Between 3.5 and 4.0s the load was removed and the electromagnetic torque reduced minimally.

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X. CONCLUSION

Scalar control method is a low cost method simple and immunity to errors of feedback signals, open loop deals with constant speed applications, many applications in the industry operate with this control technique .The indirect field oriented control induction motor drive has to do with disintegrating the stator current components which generates torque and flux. It can be controlled by using a PI speed control. The PI controller enhances the dynamic response of the system and reduces the steady state error, the error susceptibility, high performance and speed response. The simulation results shows a good dynamic performance and this can be obtained from the PI controller compared with the V/F. The PI controller catches the reference speed very fast. From the results it is seen that the PI controller is a good controller for the control of an induction motor.

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