VECTOR CONTROL SCHEME FOR INDUCTION MOTOR WITH DIFFERENT CONTROLLERS FOR NEGLECTING THE END EFFECTS IN HEV APPLICATIONS

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Abstract - This paper develops the application of a different control strategy to the vector control of the voltage-fed induction motor. The proposed model decomposes the control task into three loops, namely, the speed loop, the d-axis flux loop and the q -axis flux loop. Then, tracking of speed with different controllers is designed for each loop. Proportional-Integral update laws are used to adjust the control parameters, which increases the tracking performance (Z-N Method) .Simulations are obtained shows good robustness against parameter variations, high tracking performance and simplicity of implementation.

Keywords- *Induction motor, vector control, Proportional Integral Derivative controller, Neural Network controllers.*

I. INTRODUCTION

Even though it requires highly much more complex control strategies , the induction machine is traditionally and for a long time used in fixed speed applications for reasons of cost, efficiency, reliability and size. when compared with the AC machine, DC machine for a variable speed application is required, appears to be the most appropriate electromechanical device where torque and flux are naturally decoupled and can be controlled independently, thus allowing a fast torque response and high precision of speed regulation to be achieved.

The vector control for induction motors was introduced for the first time by Blaschke in the early1970s [1]. The main objective of this control method is, as in separately excited DC machines, to independently control the speed, torque and the flux; this is done by choosing d–q rotating reference frame synchronously with the rotor flux space vector (or stationary frame). Once the orientation is correctly obtained, the torque is controlled by the torque producing current, which is the q -component of the stator current space vector. At the same time, the flux is controlled by the flux producing current, which is the d-component of the stator current space vector.If the electrical parameters set in the field-orientation scheme cannot be tuned according to their actual values, the torque generating characteristics will become sluggish and oscillatory(since highly sensitive)[5]. On the other hand, in many industrial applications the drive operates under a wide range of varying load characteristics and the mechanical system parameters vary substantially.

In order to cope with the problems mentioned above, various, vector control schemes with fuzzy estimation (AI) of the induction motor parameters were developed. In recent years, the reference model controls for dynamic systems have been a topic of considerable interest. Thus, the application of the fuzzy logic control to the induction motor drive was only considered for the speed control due to the linearity of the mechanical part, and facility to realize matching conditions by conventional controllers.
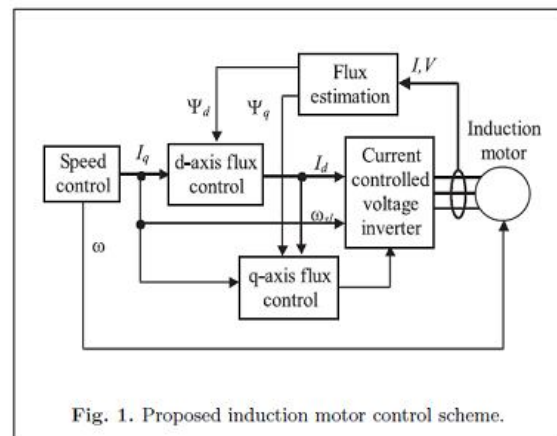

Fig. 1. Proposed induction motor control scheme.

Based on soft computing technique, this paper proposes a new robust architecture to realize vector control of the induction motor drive. The control problem is namely, the speed loop, the d-axis flux loop and the q -axis loop. Then, for each subsystem, an control input is designed to achieve the tracking objective with compensation of the coupling due to the other loops.

The major contributions of the work presented in this paper are: (1) considering the whole voltage-fed drive dynamics, ie, no simplification is made, which permits mastering of both the transient and steady state dynamics (2) considering all the electrical and mechanical parameters as unknown, and designing the control loops to account for this situation; (3) Proportional-Integral update laws are used to tune the control parameters, which, compared with simple

Integral update laws, provides faster tracking and convergence performance.

This paper is organized as follows. In Section 2, we briefly review the voltage-fed induction motor model and the vector control principle. The proposed control of the induction motor speed and fluxes is discussed.

II. INDUCTION MOTOR MODEL

The Voltage-fed induction motor model established in d-q synchronously rotating frame is given by the following equations

$$\dot{\psi}_d = -\alpha\psi_d + \omega_{sl}\psi_q + \beta I_d \qquad (1)$$

$$\dot{\psi}_q = -\alpha\psi_q - \omega_{sl}\psi_d + \beta I_q \qquad (2)$$

$$\dot{\omega} = -a\omega + b\big(\mu(\psi_d I_q - \psi_q I_d) - T_l\big) \qquad (3)$$

where

ω is the electrical rotor speed; ω_{sl} is the slip frequency;
I_d, I_q are the d, q axis stator currents;
ψ_d, ψ_q are the d, q axis rotor fluxes;
R_r is the rotor resistance; L_r is the rotor inductance;
M is the mutual inductance; J is the moment of inertia;
f is the viscosity coefficient;
P is the number of pairs of poles; T_l is the load torque;
$\alpha = R_r/L_r$ is the rotor time constant,
$\beta = \alpha M$, $\mu = PM/L_r$, $a = f/J$ and $b = P/J$.

In the vector control, speed is controlled by the torque producing current Iq to track the speed reference command. The d-axis flux is forced to follow some reference flux command using the flux producing current Id. Further, the slip frequency Wsl is used as the third control input to force the q-axis flux to zero, i.e to achieve the correct flux orientation.

III. DESIGN OF PID CONTROLLERS

The characteristics of the each of proportional (P), the integral (I), and the derivative (D) controls, and how to use them to obtain a desired response. In this paper following unity feedback system is considered:
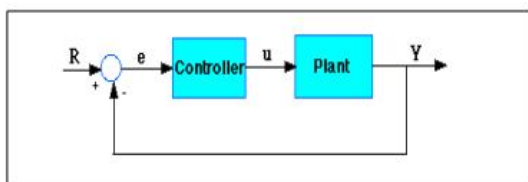

Fig2:PID controller

Plant: A system to be controlled Controller: Provides the excitation for the plant; Designed to control the overall system behavior.

A. The three-term controller

The transfer function of the PID controller looks like the following:

$$K_p + \frac{K_I}{s} + K_D s = \frac{K_D s^2 + K_p s + K_I}{s} \qquad (4)$$

Kp = Proportional gain
KI = Integral gain
Kd = Derivative gain

First, considering the PID controller working principle in a closed-loop system using the schematic shown above. The variable (e) represents the tracking error, the difference between the desired input value (R) and the actual output (Y). This error signal (e) will be sent to the PID controller, and the controller computes both the derivative and the integral of this error signal. The signal (u) just past the controller is now equal to the proportional gain (Kp) times the magnitude of the error plus the integral gain (Ki) times the integral of the error plus the derivative gain (Kd) times the derivative of the error.

$$u = K_p e + K_I \int e\, dt + K_D \frac{de}{dt} \qquad (5)$$

This signal (u) will be sent to the plant, and the new output (Y) will be obtained. This new output (Y) will be sent back to the sensor again to find the new error signal (e). The controller takes this new error signal and computes its derivative and its integral again. This process goes on and on.

B. The characteristics of P, I, and D controllers

A proportional controller (Kp) will have the effect of reducing the rise time and will reduce ,but never eliminate, the steady. An integral control (Ki) will have the effect of eliminating the steady-state error, but it may make the transient response worse. A derivative control (Kd) will have the effect of increasing the stability of the system, reducing the overshoot, and improving the transient response. Effects of each of controllers Kp, Kd, and Ki on a closed-loop system are summarized in the table shown below.

CL response	Rise time	Overshoot	Settling time	S-s error
Kp	Decrease	Increase	Small Change	Decrease
Ki	Decrease	Increase	Increase	Eliminate
Kd	Small Change	Decrease	Decrease	Small Change

Table 1: Comparison between controllers

A PI controller responds to an error signal in a closed control loop and attempts to adjust the controlled quantity to achieve the desired system response. The controlled parameter can be any measurable system quantity such as speed, torque, or flux. The benefit of the PI controller is that it can be adjusted empirically by adjusting one or more gain values and observing the change in system response.

A digital PI controller is executed at a periodic sampling interval. It is assumed that the controller is executed frequently enough so that the system can be properly controlled. The error signal is formed by subtracting the desired setting of the parameter to be controlled from the actual measured value of that parameter. The sign of the error indicates the direction of change required by the control input. The Proportional (P) term of the controller is formed by multiplying the error signal by a P gain, causing the PI controller to produce a control response that is a function of the error magnitude.

As the error signal becomes larger, the P term of the controller becomes larger to provide more correction. The effect of the P term tends to reduce the overall error as time elapses. However, the effect of the P term reduces as the error approaches zero. In most systems, the error of the controlled parameter gets very close to zero but does not converge. The result is a small remaining steady state error.

The Integral (I) term of the controller is used to eliminate small steady state errors. The I term calculates a continuous running total of the error signal. Therefore, a small steady state error accumulates into a large error value over time. This accumulated error signal is multiplied by an I gain factor and becomes the I output term of the PI controller.

IV. TUNING OF PI CONTROLLERS

Proportional-integral (PI) controllers have been introduced in process control industries. Hence various techniques using PI controllers to achieve certain performance index for system response are presented. The technique to be adapted for determining the proportional integral constants of the controller, called *Tuning,* depends upon the dynamic response of the plant.

In presenting the various tuning techniques we shall assume the basic control configuration wherein the controller input is the error between the desired output (command set point input) and the actual output. This error is manipulated by the controller (PI) to produce a command signal for the plant according to the relationship.

$$U(s) = K_p (1+1/\tau_i s). \quad (6)$$

Or in time domain

$$U(t) = K_p [e(t) + (1/\tau_i) \int edt] \quad (7)$$

where K_p = proportional gain

τ_i = integral time constant

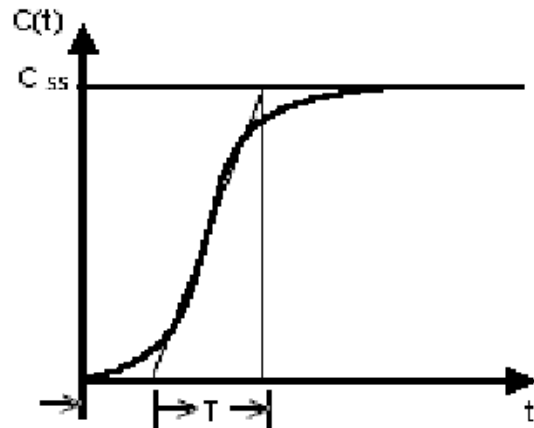If this response is *S*-shaped as in, Ziegler-Nichols tuning method is applicable.

Figure 3: S shaped response of the plant

Zeigler- Nichols Rules for tuning PI controllers:

First Rule: The *S*-shaped response is characterized by two constants, the dead time *L* and the time constant *T* as shown. These constants can be determined by drawing a tangent to the *S*-shaped curve at the inflection point and state value of the output. From the response of this nature the plant can be mathematically modeled as first order system with a time constant *T* and delay time *L* as shown in block diagram.

The gain *K* corresponds to the steady state value of the output C_{ss}. The value of K_p, T_i and T_d of the controllers can then be calculated as below:
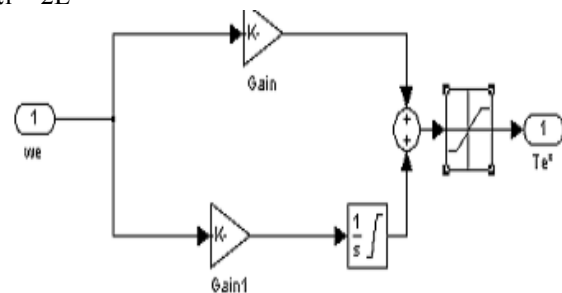
KP=1.2(T/L)

$\tau i = 2L$

Fig 4: Mathematical Model for PI controller

V. NEURAL NETWORKS BASED CONTROLLER

Neural networks can perform massively parallel operations. The exhibit fault tolerance since the information is distributed in the connections throughout the network[4]. By using neural PI controller the peak overshoot is reduced and the system reaches the steady state quickly when compared to a conventional PI controller.

Program for creating the Neural Network:

```
load n
k1=max(i');
k2=max(o');
P=i'/k1;
T=o'/k2;
n=157128;
net = newff(minmax(P),[5 1],{'tansig' 'purelin'});
net.trainParam.epochs = 200;
net = train(net,P,T);
Y = sim(net,P);
plot (P,T,P,Y,'o')
gensim(net,-1)
```
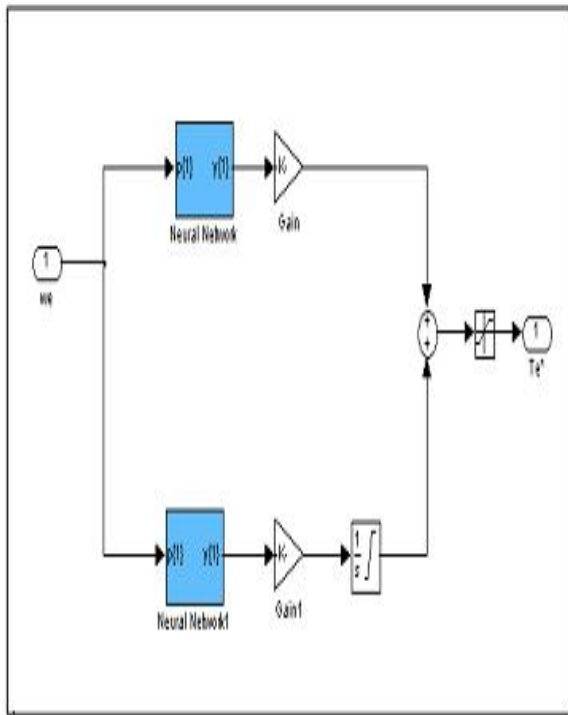

Fig 5: Neural Network based controller

VI. SIMULATION RESULTS

Specifications:

Kp=300	Ki=1000
Rr=9.295e-3ohm	Lrl=0.3027e-3H
Rs=14.85e-3ohm	Lsl=0.3027e-3H
Lm=10.46e-3H	P=8
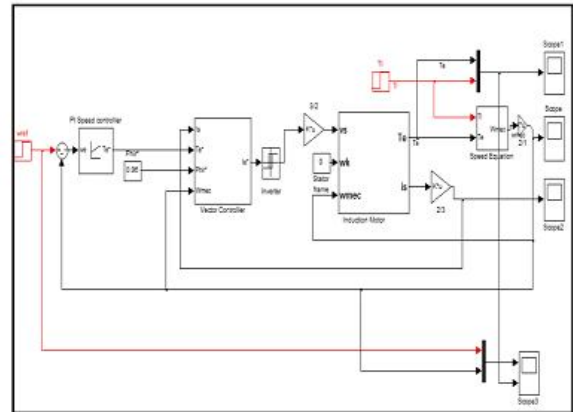
Fig 6: Simulation model of Induction Motor

The simulation of Field Oriented control of induction motor is done by using MATLAB-SIMULINK. The results for the following different cases are studied.

Case-1: No Load Condition
Case-2: Step Change in load
Case-3: Speed Reversal Command

The simulation results along with the relevant waveforms for on-road tested vehicle parameters are below:

Case-1: No Load Condition:
1. Torque Response
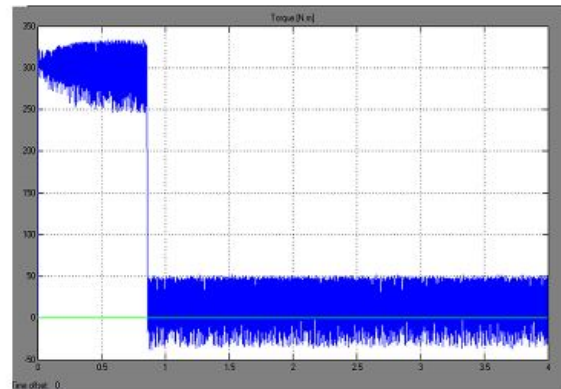
Figure 7: Torque (N-m) versus Time (Sec)

b. Speed Response
Reference Speed=150 rad/sec
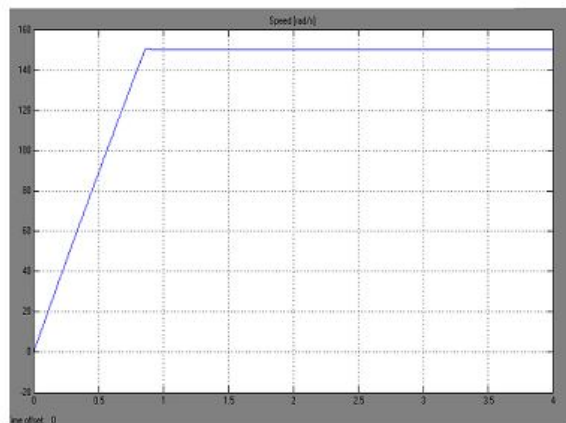
Figure 8: Speed (rpm) versus Time (Sec)

Case-2: Step Change in load
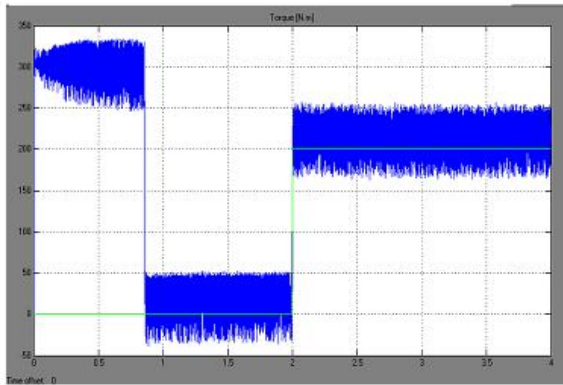A load torque of 200 N-M is applied at t = 2 sec

Figure 9: Torque (N-m) versus Time (sec)
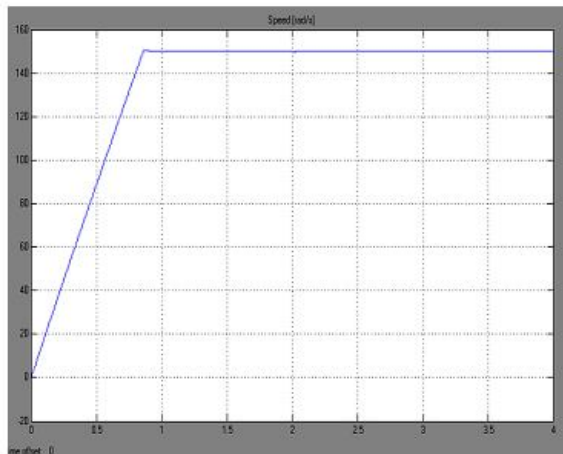
Speed Response
Reference Speed = 150 rad/sec

Figure10 Speed (rpm) versus Time (sec)

Case-3: Speed Reversal Command
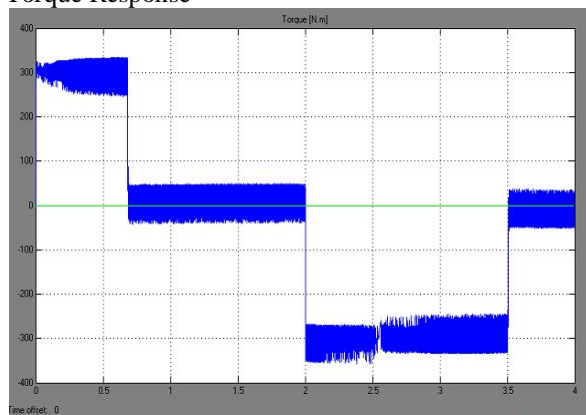Torque Response

Figure 11: Torque (N-m) versus Time (Sec)

Speed reversal command is given at t = 2 sec. i.e. Speed is changed from 150 rad/sec to -150 rad/sec at t = 2 sec.
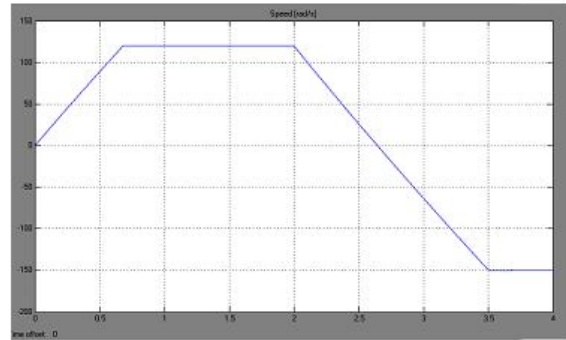

Figure 12: Speed (rpm) versus Time (Sec)

Speed and Torque characteristics of an Induction Motor **using a conventional PI controller:**
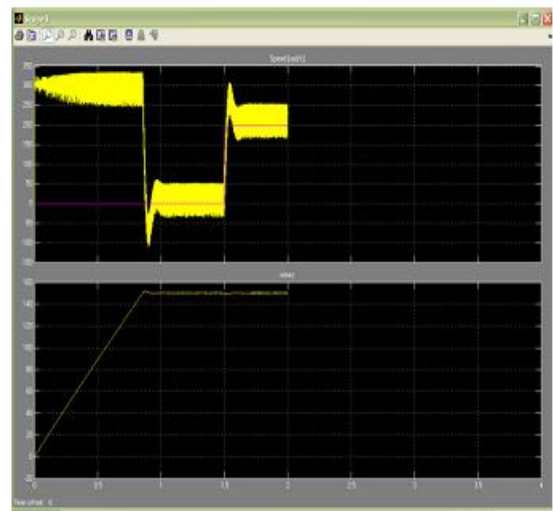
Figure 13: Torque (N-m) versus   Time (sec)

Speed and Torque characteristics of an Induction Motor using a conventional NN controller**:**
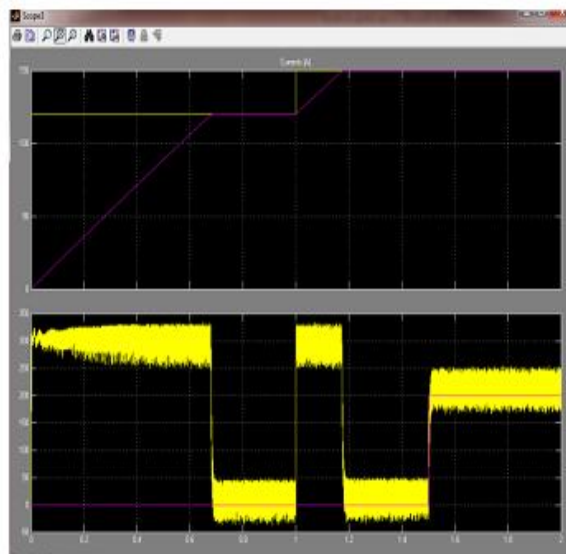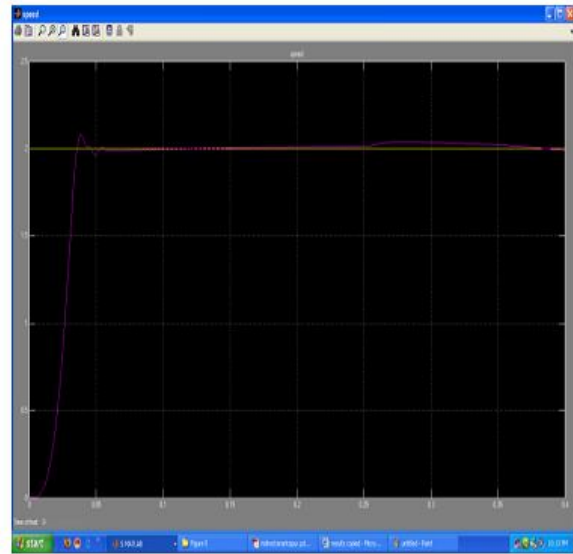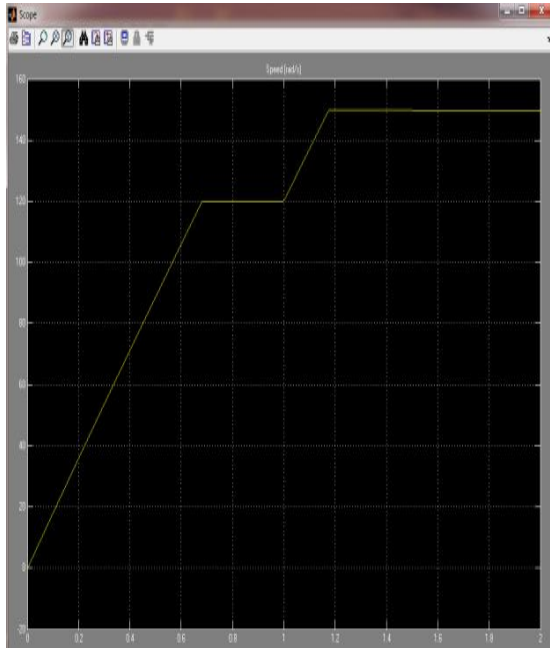
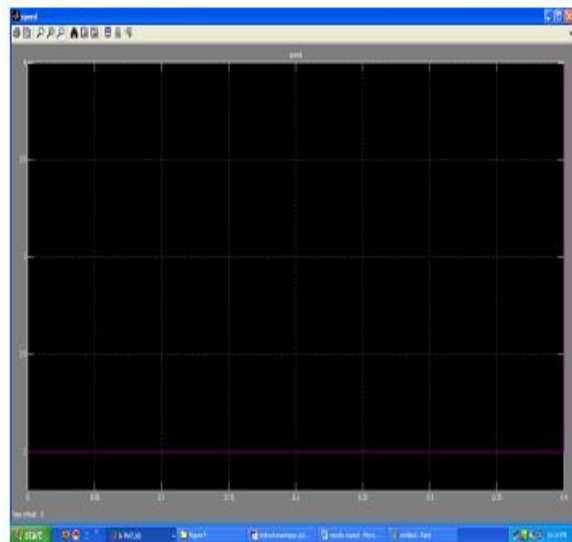Figure 15: Magnified speed with end effects

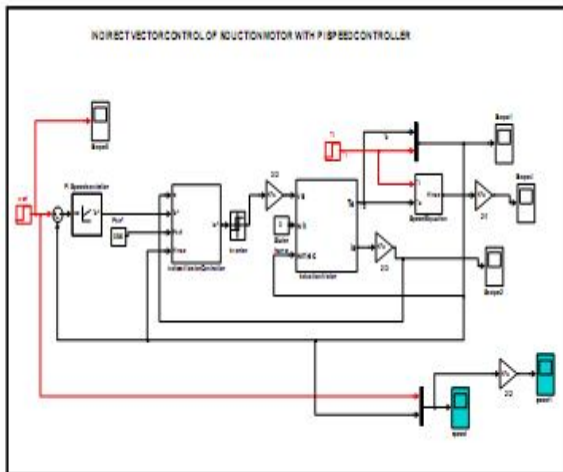**With and without end effects:**

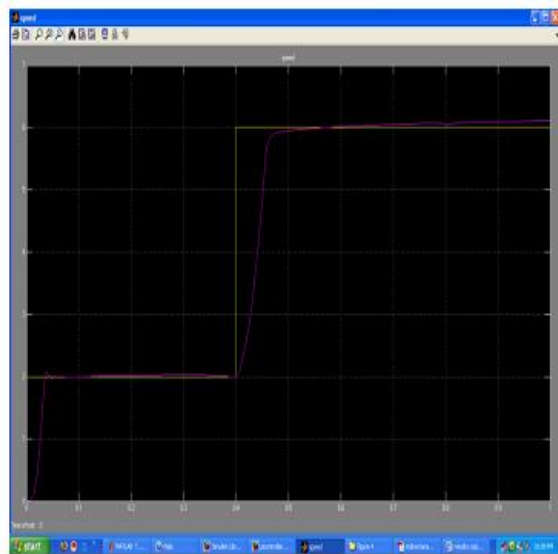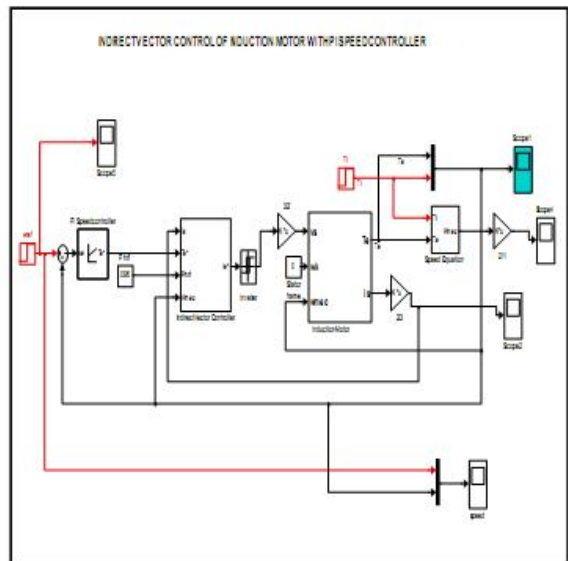Figure 16: Magnified speed without end effects

Figure 14: Speed (rpm) versus Time (Sec) With end effects
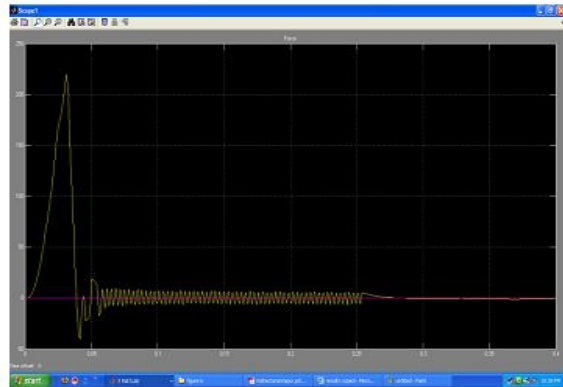
Figure 17: Magnified thrust with end effects

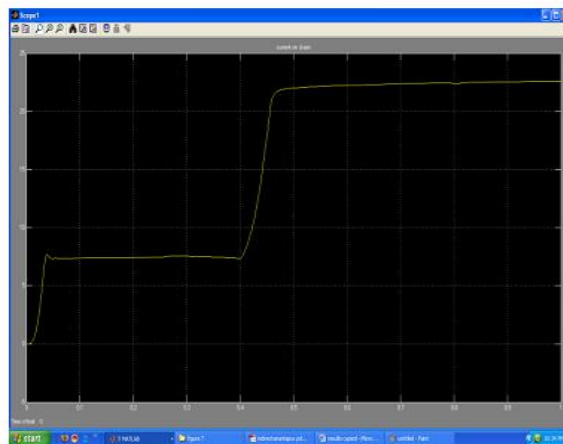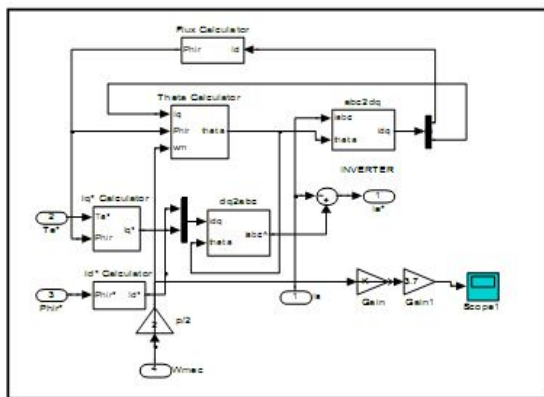**Figure 18: Magnified Thrust without end effects**

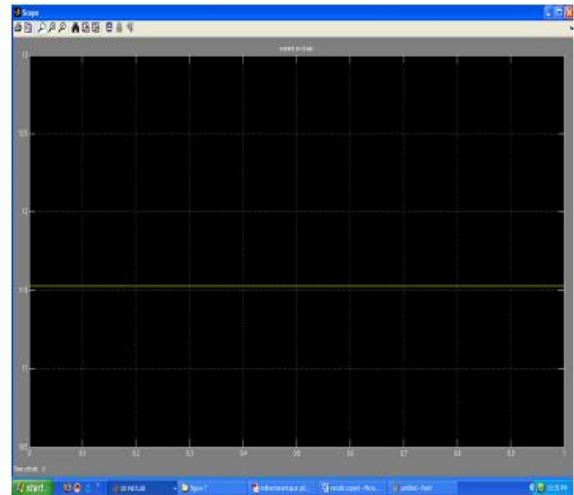**Figure 19: Current d-axis with end effects**

Figure 20: Current d-axis without end effects

VII. CONCLUSIONS

A control schemes applied to vector control of an induction motor drive was presented in this. The overall speed and flux control system was verified to be globally stable and robust to the variations of motor mechanical and electrical parameters variations. Simulation results obtained in MATLAB-SIMULINK were used to demonstrate the characteristics of the proposed method. It is shown that the proposed Neural Network controller has better tracking performance and robustness against parameters variations as compared with the conventional controller.

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