Neural Network Based Dynamic Simulation of Induction Motor Drive

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Abstract—With the improvement in the technology of Microprocessor and Power Electronics, Induction motor drives with digital control have become more popular. Artificial intelligent controller (AIC) could be the best candidate for Induction Motor control. Over the last two decades researchers have been working to apply AIC for induction motor drives. This is because that AIC possesses advantages as compared to the conventional PI, PID and their adaptive versions. The main advantages are that the designs of these controllers do not depend on accurate system mathematical model and their performances are robust. In recent years, scientists and researchers have acquired significant development on various sorts of control theories and methods. Among these control technologies, intelligent control methods, which are generally regarded as the aggregation of Fuzzy Logic Control, Neural Network Control, Genetic Algorithm, and Expert System, have exhibited particular superiorities. The artificial neural network controller introduced to the system for keeping the motor speed to be constant when the load varies. The speed control scheme of vector controlled induction motor drive involves decoupling of the speed and ref speed into torque and flux producing components. The performance of artificial neural network based controller's is compared with that of the conventional proportional integral controller. The dynamic modeling of Induction motor is done and the performance of the Induction motor drive has been analyzed for constant and variable loads. By using neuro controller the transient response of induction machine has been improved greatly and the dynamic response of the same has been made faster.

Keywords- ***Vector Control (VC), Direct, Dynamic Simulation, Artificial Intelligence (AI), PI Controller, Artificial Neural Network (ANN)***

I. INTRODUCTION

Induction motors are the most important workhorses in industry and they are manufactured in large numbers. About half of the electrical energy generated in a developed country is ultimately consumed by electric motors, of which over 90 % are induction motors. For a relatively long period, induction motors have mainly been deployed in constant-speed motor drives for general purpose applications. The rapid development of power electronic devices and converter technologies in the past few decades, however, has made possible efficient speed control by varying the supply frequency, giving rise to various forms of adjustable-speed induction motor drives. In about the same period, there were also advances in control methods and artificial intelligence (AI) techniques, including expert system, fuzzy logic, neural networks and genetic algorithm. Researchers soon realized that the performance of induction motor drives can be enhanced by adopting artificial-intelligence-based methods. Since the 1990s, AI-based induction motor drives have received greater attention. In recent years, scientists and researchers have acquired significant development on various sorts of control theories and methods. Among these control technologies, intelligent control methods, which are generally regarded as the aggregation of fuzzy logic control, neural network control, genetic algorithm, and expert system, have exhibited particular superiorities. Artificial Intelligent Controller (AIC) could be the best controller for Induction Motor control. Over the last two decades researchers have been working to apply AIC for induction motor drives [1-6]. This is because that AIC possesses advantages as compared to the conventional PI, PID and their adaptive versions. Mostly, it is often difficult to develop an accurate system mathematical model since the unknown and unavoidable parameter variations, and unknown load variation due to disturbances, saturation and variation temperature. High accuracy is not usually imperative for most of the induction motor drive, however high performance IM drive applications, a desirable control performance in both transient and steady states must be provided even when the parameters and load of the motor varying during the operation. Controllers with fixed parameters cannot provide these requirements unless unrealistically high gains are used. Thus, the conventional constant gain controller used in the variable speed induction motor drives become poor when the uncertainties of the drive such as load disturbance, mechanical parameter variations and unmodelled dynamics in practical applications. Therefore control strategy must be adaptive and robust. As a result several control strategies have been developed for induction motor drives with in last two decades. The Artificial Intelligence (AI) techniques, such as Expert System (ES), Fuzzy Logic (FL), Artificial Neural Network (ANN or NNW) and Genetic Algorithm (GA) have recently been applied widely in power electronics and motor drives. This paper presents the speed control scheme of vector controlled induction motor drive involves decoupling of the speed and ref speed into torque and flux producing components. Artificial

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Neural Network based control scheme is simulated. The performance of artificial neural network based controller's is compared with that of the conventional proportional integral controller. The dynamic modeling of Induction motor is done and the performance of the Induction motor drive has been analyzed for constant and variable loads[3-4].

II. DYNAMIC MODELING & SIMULATION OF INDUCTION MOTOR DRIVE

Dynamic behavior of induction motor can be expressed by voltage and torque which are time varying. The differential equations that belongs to dynamic analysis of induction motor are so sophisticated. Then with the change of variables, the complexity of these equations can be decreased through movement from poly phase winding to two phase winding (q-d). In other words, the stator and rotor variables like voltage, current and flux linkages of an induction machine are transferred to another reference model which remains stationary. The dynamic model of an induction motor is developed by using equations given in Appendix 'A'. The simulation model is constructed based on the equations as shown in fig. 1. The motor drive has balanced 3-phase voltages as the input, and the abc currents as the outputs. The complete Simulink model of the vector controlled induction motor drive with flux controller, vector controller, PI controller and PWM inverter is shown in fig. 2.

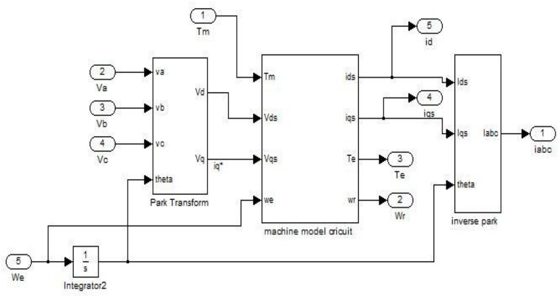

Figure 1 Induction Motor Model

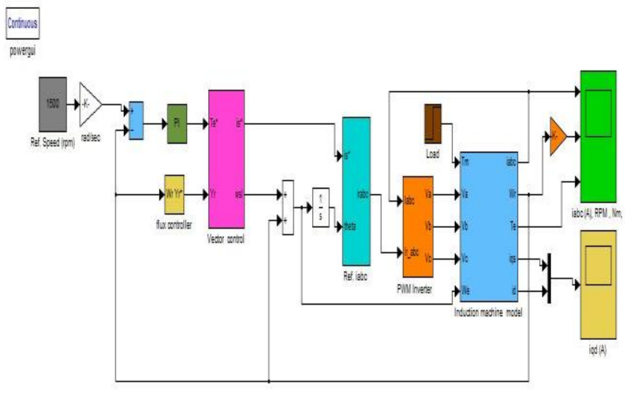

Figure 2 Induction motor with PI controller

III. NEURAL NETWORK CONTROLLER

The difficulties that arise in induction motor control are complex computations, model nonlinearity and uncertainties in machine parameters. Recently, intelligent techniques are introduced in order to overcome these difficulties. The definition of intelligent control from Astrom and McAvoy has been used widely: *'An intelligent control system has the ability to comprehend, reason, and learn about processes, disturbances and operating conditions in order to optimize the performance of the process under consideration'* Intelligent control techniques are generally classified as expert system control, fuzzy-logic control, neural-network control and genetic algorithm. Artificial neural networks are nonlinear information (signal) processing devices, which are built from interconnected elementary processing devices called neurons[4-5]. Artificial Neural Networks (ANN) are gross simplification of biological networks of neuron. The paradigm of neural network promises to be very important tool for studying the structure function relation of human brain. One of the most important features of Artificial Neural Networks (ANN) is their ability to learn and improve their operation using a neural network training data[7-8]. The basic element of an ANN is the neuron which has a summer and an activation function. The mathematical model of a neuron is given by:

$$y = \varphi \left(\sum_{i=1}^{N} w_i * x_i + b \right) \quad \text{...........(23)}$$

where (x_1, x_2… x_N) are the input signals of the neuron, (w1, w2,… wN) are their corresponding weights and b a bias parameter. Φ is a tangent sigmoid function and y is the output signal of the neuron. The neural network learns about its environment through an interactive process of adjustment applied to its synaptic weight and bias level. Nevertheless, it is possible that the learning algorithm did not produce any acceptable solution for all input–output association problems. The most popular supervised learning algorithm is back-propagation, which consists of a forward and backward action. In the forward step, the free parameters of the network are fixed, and the input signals are propagated throughout the network from the first layer to the last layer. In the forward step, we compute a mean square error.

$$E(k) = \frac{1}{N} \sum_{i=1}^{N} \left(d_i(k) - y_i(k) \right)^2 \quad \text{...........(24)}$$

where di is the desired response, yi is the actual output produced by the network in response to the input xi, k is the iteration number and N is the number of input-output training data. In the backward step , the error signal E(k) is propagated throughout the network in the backward direction in order to perform adjustments upon the free parameters of the network in order to decrease the error E(k) in a statistical sense as shown in Fig 3 and Fig.4. The weights associated with the output layer of the network are therefore updated using the following formula:

$$w_{ji}(k+1) = w_{ji}(k) - \eta \frac{\partial E(k)}{\partial w_{ji}(k)} \quad \text{....(25)}$$

The objective of this NNC is to develop a back propagation algorithm such that the output of the neural network speed observer can track the target one. Fig. 3 depicts the network structure of the NNC, which indicates that the neural network has three layered network structure. The first is formed with five neurons inputs Δ(ωANN(K+1), Δ(ωANN(K), ωANN, ωS(K-1), Δ(ωS(K-2). The second layer consists of five neurons. The lasted one contains one neuron to give the command variation Δ(ωS(K). The aim of the proposed NNC is to compute the command variation based on the future output variation Δ(ωANN(K+1).Hence, with this structure, we realize a predictive control with integrator. At time k, the neural network computes the command variation based on the output at time (k+1), while the later isn't defined at this time. In this case, we assume that ωANN(K+1) ≡ ωANN(K).The control law is deduced using the recurrent equation

ωS(K) = ωS(K-1) + GΔ(ωS(K).

It can be seen that the d axis and q axis voltage equations are coupled by the terms d E and q E . These terms are considered ads disturbances and are cancelled by using the proposed decoupling method. If the decoupling method is implemented, the flux components equations become

Φdr = G(s)vds

Φqr = G(s)vqs

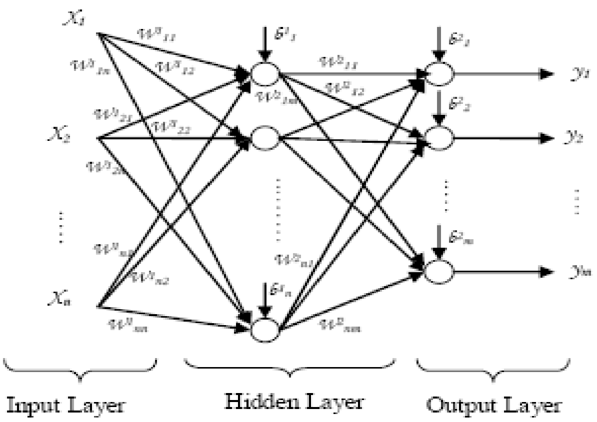

Fig.3 Structure of neural network

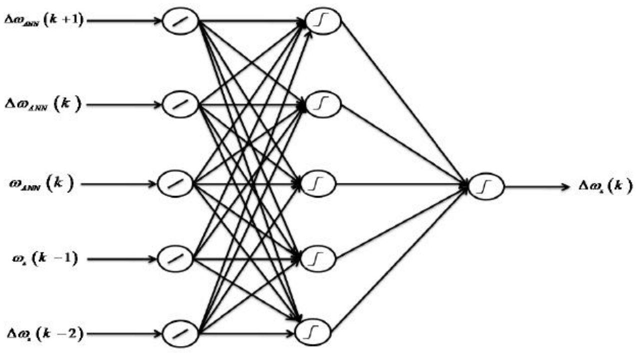

Fig. 4 Neural network speed controller

where w_{ji} is the weight connecting the j^{th} neuron of the output layer to the i^{th} neuron of the previous layer, η is the constant learning rate. The process of ANN learning can be accelerated by taking high values of η and consequently fast convergence but may cause oscillations in the network output, whereas low values will cause slow convergence as shown in flow chart Fig 5. Therefore, the value of η has to be chosen carefully to avoid instability[6-7].The proposed Neural network controller is shown in Fig. 6.

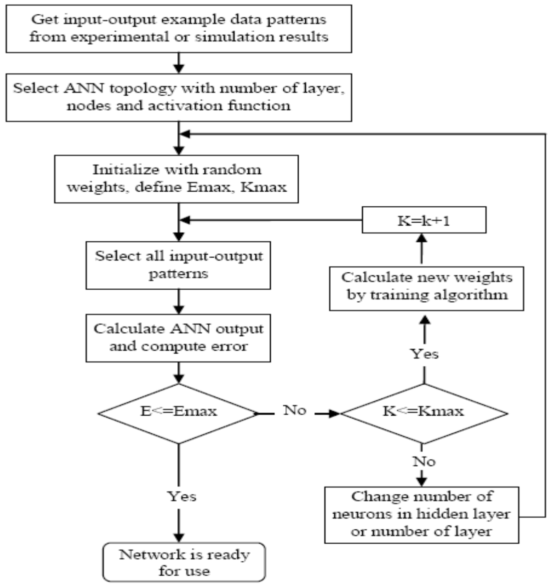

Fig.5 Flowchart for training back propagation networks

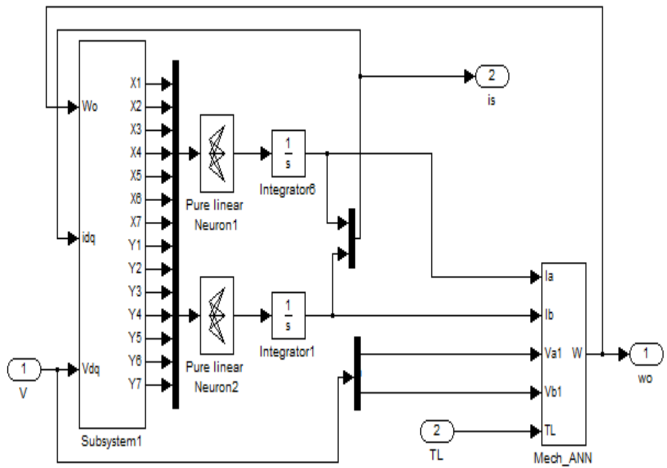

Fig. 6 Neural network controllers

IV. PERFORMANCE ASSESSMENT OF NEURAL NETWORK CONTROLLER BASED INDUCTION MOTOR DRIVES

A complete simulation model for vector controlled Induction motor drive incorporating PI and Neural network controller is developed. Vector control of Induction motor drive with Neural network controller is designed by adjusting the weights in order to get simulated results. The performance of the artificial intelligent based induction motor drive is investigated at different operating conditions. Parameters of the induction motor considered in this study are summarized in Appendix 'B'. The performance of the vector controlled induction motor with neural network is presented at constant load and variable load. The dynamic behaviors of the PI controller and with Neural Network controller are shown in Fig. 7, Fig.8, Fig. 9 and Fig. 10 at constant load and variable load conditions.

A. At constant load conditions

In case of rotor speed, a drive with PI controller has a peak overshoot, but in case of neural network controller it is eliminated as shown in Fig. 7(a) and Fig.7 (b). A trial and error method is used to tune the gain constants of a PI controller. Fig.8(a) shows the I_d and I_q currents of Induction motor drive, Fig. 8(b) shows Torque Characteristics of Induction motor drive, and it is observed that the characteristics are same with PI and neural based drive system at constant load. Although the PI controller is tuned to give an optimum response at this rated condition, the neural controller yields better performance in terms of faster response time and lower starting current.

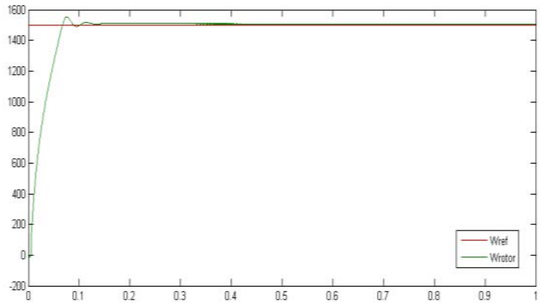

Fig. 7 (a) Rotor speed with PI controller

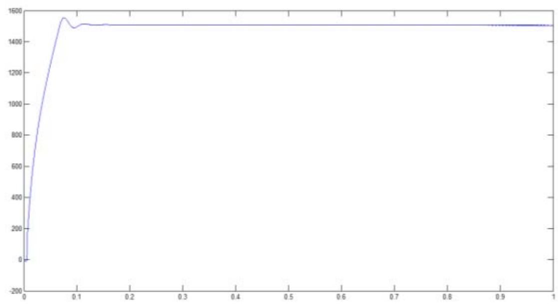

Fig. 7 (b) Rotor speed with neural network controller

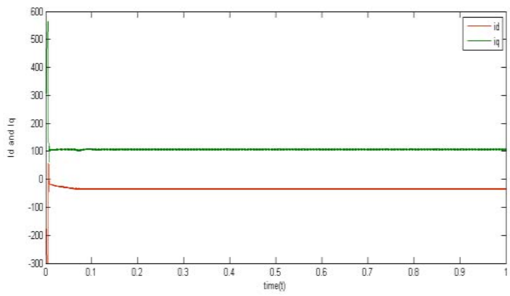

Fig. 8 (a) I_d and I_q currents of Induction motor drive

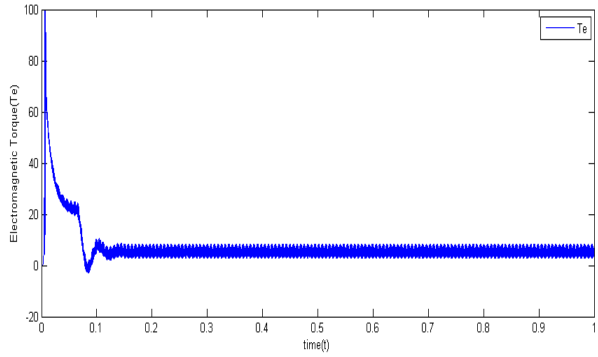

Fig. 8 (b) Torque Characteristics of Induction motor drive

B. At variable load conditions:

At variable load condition, induction motor drive with PI controller speed response has small peak at 0.4 sec, but in case of neural network speed response, it is quick and smooth which are given in Fig. 9(a) and Fig. 9(b), for step change in the load torque. The motor starts from standstill at load torque = 2 Nms and at t =0.4s, a sudden full load of 15 Nms is applied to the system. It is observed from Fig 10(a) and (b) the neural network performs better than PI controller. Since the time taken by the PI controller to achieve steady state is much higher than neuro-controller, the step change in load torque is applied at t = 1.25 sec. It is observed that the speed response is affected by the load condition as in case of PI controller. It is to be noted that the neuro controller gives better responses in terms of overshoot, steady-state error and fast response. These figures also show that the neuro -based drive system can handle the sudden increase in command speed quickly without overshoot, under- shoot, and steady-state error, whereas the PI-controller-based drive system has steady-state error and the response is not as fast as compared to the neuro controller.

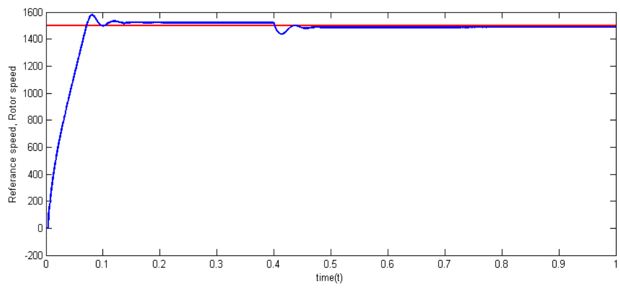

Figure 9 (a) Rotor speed with PI controller

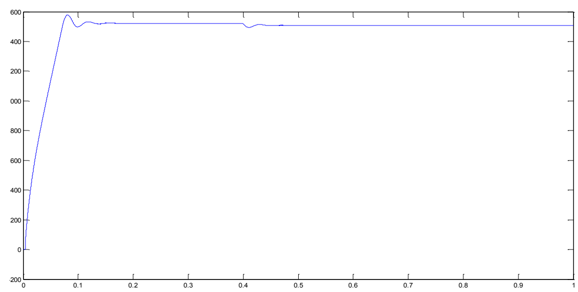

Figure 9(b) Rotor speed with neural network controller

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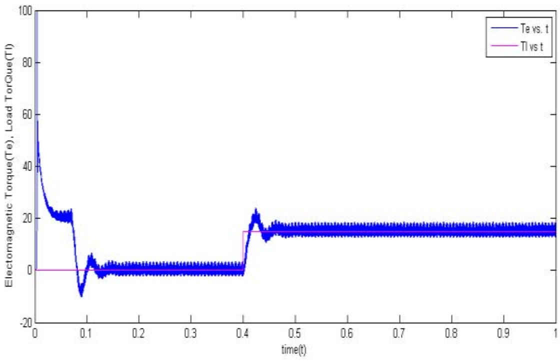

Fig 10(a) Torque characteristics with PI controller

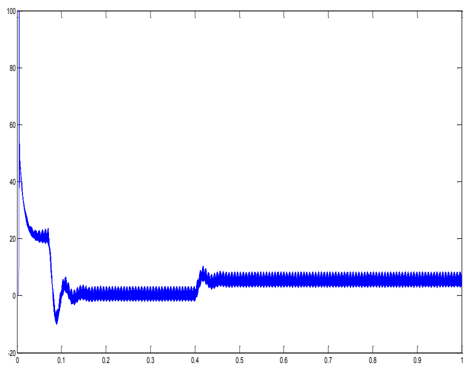

Figure 10 (b) Torque characteristics with Neural network controller

Table I and II present the performance comparison during steady state operation and transient operation in time domain analysis respectively.

TABLE I.
PERFORMANCE COMPARISON BETWEEN PI AND NEURAL CONTROLLERS DURING STEADY STATE OPERATION.

Control strategies	**Rise Time(s)**	**Time for speed regulation (s)**
Conventional PI	*0.24*	*0.25*
ANN	*0.08*	*0.04*

TABLE-II
PERFORMANCE COMPARISON BETWEEN PI AND NEURAL CONTROLLERS DURING TRANSIENT OPERATION

Control strategies	**Settling Time before changing the load (s)**	**Settling Time after Changing the load(s)**	**Overshoot**
Conventional PI	*0.58*	*0.2*	*Yes*
ANN	*0.09*	*0.02*	*No*

V. CONCLUSION

An Artificial intelligent based vector controlled induction motor has been presented in this paper. The vector control strategy is developed with Neural network controller. The conventional vector control of induction motor is compared with the proposed neural network based controllers, and from the results it is observed that the performance with neural network controller is better than PI controller. In steady state condition, the rise time and speed regulation with conventional controller is more than that of the ANN controller. During transient condition, the settling time before changing the load and after changing the load is less in case of ANN controller as compared to PI controller. It is observed that there is no overshoot in case of ANN controller. Thus, by using neuro controller the transient response of induction machine has been improved greatly and the dynamic response of the same has been made faster.

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Appendix 'A'
DYNAMIC MODEL OF INDUCTION MOTOR

$$v_{abc} = v_a + v_b e^{-j2\pi/3} + v_c e^{+j2\pi/3} \tag{1}$$

$$\tfrac{2}{3} v_{abc} e^{-j0} = v_{qs} - jv_{ds} \tag{2}$$

$$v_{ds} = r_s i_{ds} + \tfrac{d}{dt}\; L_{ls} i_{ds} + L_m i'_{dr} \; + L_m \tfrac{d}{dt} i_{ds} - \omega\varphi_{qs} \tag{3}$$

$$\varphi_{ds} = L_s i_{ds} + L_m i'_{dr} \tag{4}$$

$$\varphi'_{dr} = L_m i_{ds} + L_r i'_{dr} \tag{5}$$

$$L_s = L_{ls} + L_m \tag{6}$$

$$v_{ds} = r_s i_{ds} + \tfrac{d}{dt}\varphi_{ds} - \omega\varphi_{qs} \tag{7}$$

$$\varphi_{ds} = \int \; v_{ds} - r_s i_{ds} + \omega\varphi_{ds} \tag{8}$$

$$v'_{dr} = r'_r i'_{dr} + \tfrac{d}{dt}\varphi'_{dr} - \;\; \omega - \omega_r \;\; \varphi'_{qr} \tag{9}$$

$$\varphi'_{dr} = \int\!\left[v'_{dr} - r'_r i'_{dr} + \;\; \omega - \omega_r \;\; \varphi'_{qr} \right] \tag{10}$$

$$v_{qs} = r_s i_{qs} + \tfrac{d}{dt}\left[L_{ls} i_{qs} + L_m i'_{qr} \right] + \omega \;\; L_{ls} i_{ds} + L_m i'_{dr} \tag{11}$$

$$\varphi_{qs} = L_s i_{qs} + L_m i'_{qr} \tag{12}$$

$$\varphi'_{qr} = L_m i_{qs} + L_r i'_{qr} \tag{13}$$

$$v_{qs} = r_s i_{qs} + \tfrac{d}{dt}\varphi_{qs} + \omega\varphi_{ds} \tag{14}$$

$$\varphi_{qs} = \int \; v_{qs} - r_s i_{qs} - \omega\varphi_{qs} \tag{15}$$

$$v'_{qr} = r'_r i'_{qr} + \tfrac{d}{dt}\varphi'_{qr} + \;\; \omega - \omega_r \;\; \varphi'_{dr} \tag{16}$$

$$\varphi'_{qr} = \int\!\left[v'_{qr} - r'_r i'_{qr} - \;\; \omega - \omega_r \;\; \varphi'_{dr} \right] \tag{17}$$

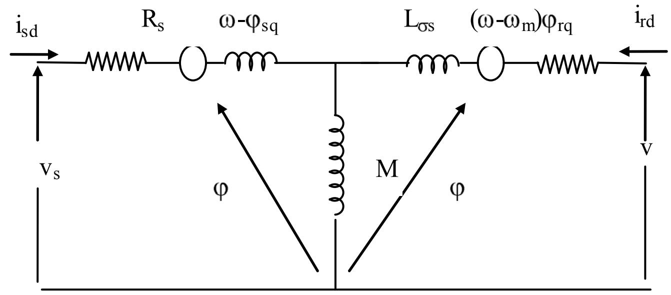
$$\begin{bmatrix} \varphi_{ds} \\ \varphi_{qs} \\ \varphi'_{dr} \\ \varphi'_{qr} \end{bmatrix} = \begin{bmatrix} L_s & 0 & L_m & 0 \\ 0 & L_s & 0 & L_m \\ L_m & 0 & L_r & 0 \\ 0 & L_m & 0 & L_r \end{bmatrix} \begin{bmatrix} i_{ds} \\ i_{qs} \\ i'_{dr} \\ i'_{qr} \end{bmatrix} \tag{18}$$

$$T_e = \tfrac{3}{2}\tfrac{P}{2}\left[\varphi'_{dr} i_{qs} - \varphi'_{qr} i_{ds} \right] \tag{19}$$

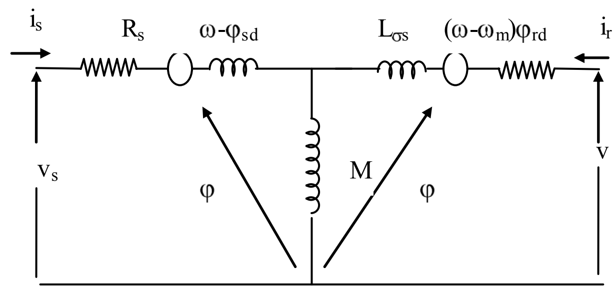
$$w_r = \tfrac{1}{Js+B} . T_e \tag{20}$$

$$\theta_r = \int w_r \tag{21}$$

$$T_e = \tfrac{3}{2}\tfrac{P}{2}\left[\varphi'_{dr} i_{qs} \right] \tag{22}$$



d-axis equivalent circuit of the induction motor



q-axis equivalent circuit of the induction motor

Appendix 'B'

The parameters of the induction motor are as follows:

p = 4	R_s = 2.2 Ohm	R_r = 0.9 Ohm	L_{ss} = 10	L_r = 2.0	L_m = 69.3
f = 50Hz	J = 0.031kg m^2	B = 0.012			
V_{dc} = 200V	Proportional gain = 2.0	Integral gain = 0.1240			