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MODEL REFERENCE ADAPTIVE SYSTEM FOR INDUCTION MOTOR DRIVES USING ANN CONTROLLER

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Abstract: The Model reference adaptive system are used to estimate the speed of an induction motor drive. Various functional parameters such as flux, back emf, reactive power etc. is used to estimate speed of an induction motor (IM) drive. Of these, reactive power (Q) based controllers perform well at low speeds and are inherently independent of stator resistance. However, such configuration fails to provide stability in the regenerative mode. The Artificial neural network controller based model reference adaptive system for induction motor drive control provides the system to be stable in all the four quadrants by reducing the dynamic instability .In this work stator current and stator flux are choosed as the functional parameters. A detailed MATLAB/SIMULINK based simulation is presented.
Index Terms: SQIM drive, MRAS, ANN, MPC

I. INTRODUCTION

Squirrel cage induction motor drives are widely used in industries because they are rugged and inexpensive. Vector control of induction motor drives can provide high dynamic performance. However, implementation of indirect vector control requires the rotor speed information. Use of a speed sensor for obtaining the rotor speed information degrades the reliability of the system especially in hostile environments. It also injects noise into the system. Moreover, it is difficult to mount sensors in certain applications. Thus, speed estimation from machine terminal quantities (i.e. voltages and currents) is preferred over speed sensing. Several speed sensorless schemes have been proposed in the references. These techniques are classified based on full-order and reduced order observers , Kalman filter, sliding modes, artificial neural networks (ANN), predictive control , saliency and signal injection , and model reference adaptive systems

Observer based methods use the complete or partial machine model equations to estimate the rotor speed. These methods need all the machine parameters. Observer based methods also suffer from instability problems at low speeds and regenerative mode of operation. More complicated methods are proposed to overcome instability and parameter dependency problems.

Artificial Neural Networks (ANN) based efficient speed control of an Induction Motor has been achieved as proposed in [2]. The ANN is properly trained to learn the dynamics of the Induction Motor. The Model Predictive Control (MPC) architecture is employed for system identification and the design of the Neural Network Control system. The Field Oriented Control system is implemented which allows for independent control of speed and torque and increases the robustness of the motor. Finally, the motor was given a toughest by sudden addition of load torque while it was in operation. The neural network controller however, demonstrated that it is worth the hype by rapid rejection of load disturbance and quick stabilization to its reference speed.

The challenges of achieving stability and good damping of a sensorless induction motor drive are much greater than for a sensored drive, as proposed in[3] , some frequently proposed flux and speed estimators-such as reduced- and full-order observers-are reviewed, along with their key static and dynamic properties as well as their parameter sensitivities. Three commonly occurring instability phenomena and their remedies are discussed, along with suitable analysis methods. Low-speed instabilities are most severe, and therefore, the stator resistance is the single most critical parameter. Methods for reducing the impact of this parameter are discussed.

II. DYNAMICAL MODEL

In the stationary reference frame (αβ-coordinates), the dynamic model of a 3-phase induction motor can be described as

$$\frac{d}{dt}\begin{bmatrix} i_s \\ \phi_r \end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} - j\rho\omega_r \\ a_{21} & a_{22} + j\omega_r \end{bmatrix}\begin{bmatrix} i_s \\ \phi_r \end{bmatrix} + \begin{bmatrix} b_s \\ 0 \end{bmatrix} v_s$$

where:

$$a_{11} = -\left(\frac{R_s}{\sigma L_s} - \frac{1-\sigma}{\sigma\tau_r}\right) \qquad a_{12} = \frac{L_m}{\sigma L_s L_r \tau_r}$$

$$a_{21} = \frac{L_m}{\tau_r} \qquad a_{22} = -\frac{1}{\tau_r}$$

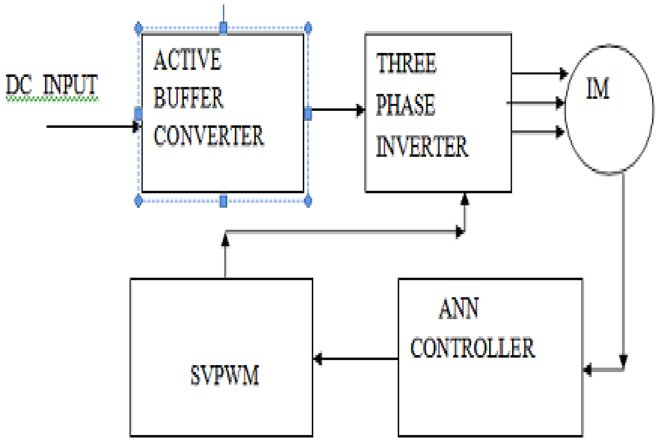
$$b_s = \frac{1}{\sigma L_s}$$

R_s , R_r : stator, rotor resistance per phase respectively
L_s , L_r : stator, rotor inductance per phase respectively
L_m : magnetizing inductance per phase
ω_r : rotor angular speed
τ_r : rotor time constant (= L_r / R_r)
ρ : $L_m / \sigma L_s L_r$
σ : leakage constant (= $1 - L_m^2 / L_s L_r$)

The input and state variables are as follows,
stator current : $i_s = i_{s\alpha} + j\, i_{s\beta}$
stator voltage : $v_s = v_{s\alpha} + j\, v_{s\beta}$
rotor flux : $\Phi_r = \Phi_{r\alpha} + j\, \Phi_{r\beta}$

The dynamic instability at lower speed can be improved by implementing artificial neural netwok controller based model reference adaptive system for indution motor drives.The system provides a good stability by operating in all the four quadrants.

III. BLOCK DIAGRAM FOR PROPOSED MODEL



IV. ACTIVE BUFFER CIRCUIT

There is a new circuit configuration and a control scheme for a single-phase current source inverter with a power decoupling circuit which is called as the active buffer. The proposed inverter achieves low-DC-input voltage ripple and also provides sinusoidal current that can achieve unity power factor, without large passive components in DC bus such as smoothing inductors and electrolytic capacitors, which are conventionally required in order to decouple the power pulsation caused by single-phase power source. In order to satisfy the requirements, many single phase circuits with a power decoupling circuit has been proposed, which can be classified as (i) passive power decoupling circuits with passive components and (ii) active decoupling circuits with semiconductor switches . One of the most popular power decoupling circuits is two stage converters, which compose of a boost chopper with a semiconductor switch and a voltage source inverter are generally used . However, the converter requires two large inductors (the boost inductor and the interconnected inductor) which inherently increasing the size of the inverter. In addition, a large electrolytic capacitor is necessary in order to compensate the power pulsation when the inverters are connected to the single-phase grid because the power is fluctuating at twice of the grid frequency. In a high temperature operating environment, the use of the electrolytic capacitor is not preferred in terms of the life time and the power density of the converter because the lifetime of electrolytic capacitor decreases due to frequent charge discharge operations and the long hours of high temperature operation .Here in this project the active buffer circuit acts as a boost converter.

V. ARTIFICIAL NEURAL NETWORK

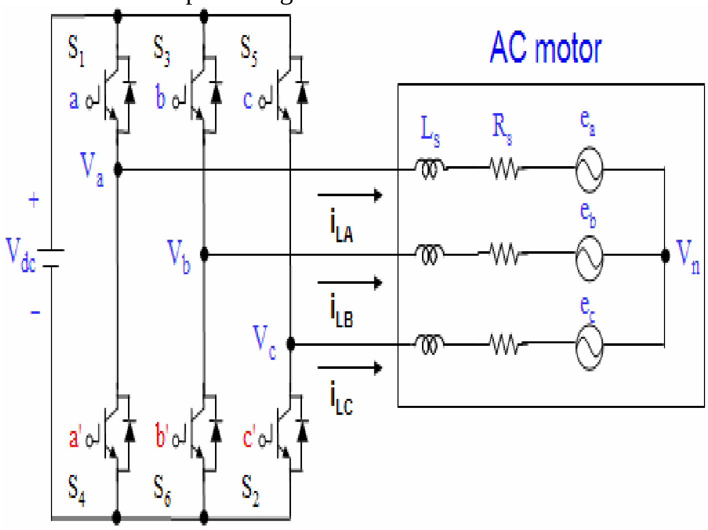
A neural network has the advantage of very fast implementation of an SVM algorithm, particularly when a dedicated application-specific IC chip is used instead of a digital signal processor (DSP). A three-level inverter has a large number of switching states compared to a two-level inverter and, therefore, the SVM algorithm to be implemented in a neural network is considerably more complex. In the proposed scheme, a three-layer feed forward neural network receives the command voltage and angle information at the input and generates symmetrical pulse width modulation waves for the three phases with the help of a single timer and simple logic circuits. The artificial-neural-network (ANN)-based modulator distributes switching states such that neutral-point voltage is balanced in an open-loop manner. The frequency and voltage can be varied from zero to full value in the whole under modulation range. A simulated DSP-based modulator generates the data which are used to train the network by a backpropagation algorithm in the MATLAB Neural Network Toolbox. The performance of an open-loop volts/Hz speed-controlled induction motor drive has been evaluated with the ANN-based modulator and compared with that of a conventional DSP-based modulator, and shows excellent performance. The modulator can be easily applied to a vector-controlled drive, and its performance can be extended to the over modulation region .A neural-network-based implementation of space-vector modulation (SVM) of a voltage-fed inverter has been proposed in this paper that fully covers the under modulation and over modulation regions linearly extending operation smoothly up to square wave. A neural network has the advantage of very fast implementation of an SVM algorithm that can increase the converter switching frequency, particularly when a dedicated application-specific integrated circuit chip is used in the modulator. The scheme has been fully implemented and extensively evaluated in a V/Hz-controlled 5 hp, 60 Hz, 230 V induction motor drive. The performances of the drive with artificial-neural-network-based SVM are excellent. The scheme can be easily extended to a vector-controlled drive.

Neural networks are showing promise for application in power electronics and motion control systems. So far, they have been applied for a few cases, mainly in the control of converters and drives, but their application in estimation is practically new. The purpose is to demonstrate that such a technology can be applied for estimation of feedback signals in an induction motor drive with some distinct advantages when compared to DSP based implementation. A feedforward neural network receives the machine terminal signals at the input and calculates flux, torque, and unit vectors (cos θe and sin θe) at the output which are then used in the control of a direct vector-controlled drive system. The three-layer network has been trained extensively by Neural Works Professional II/Plus program to emulate the DSP-based computational characteristics. The performance of the estimator is good and is comparable to that of DSP-based estimation. The system has been operated in the wide torque and speed regions independently with a DSP-based estimator and a neural network-based estimator, and are shown to have comparable performance. The neural network estimator has the advantages of faster execution speed, harmonic ripple immunity, and fault tolerance characteristics compared to DSP-based estimator. Furthermore, the use of ANN makes

the drive system robust, accurate and insensitive to parameter variations.
ANN proposed in this paper was trained with the target of rotor speed estimation in the lower rotor speed region (lower supply voltages frequencies). In this region, for observed IM operating modes, saturation of main magnetic flux is important. ANN is trained with mutual inductance estimated without error in an equivalent way as in references . The batch training is performed by using backpropagation algorithm described in [2]. For training process where chosen four reference rotor speed values: $\omega^* = 0{,}02$ [p.u.], $\omega^* = 0{,}03$ [p.u.], $\omega^* = 0{,}08$ [p.u.], $\omega^* = 0{,}12$ [p.u.]. These rotor speed reference values cover region of stator voltage supply frequencies from *1* [Hz] to *10* [Hz] (rotor speed region from $0{,}02\omega_n$ to $0{,}2\omega_n$, ω_n-nominal rotor speed value). For each of mentioned reference rotor speed values active step load and step unload was applied (Fig. 3.). In order to achieve rapider static torque-speed characteristic rotor flux has constant value $\Psi_r = 1{,}2\Psi_{rn}$. This value is set indirectly by *d* component of stator current i^*_{ds} .

VI. SPACE VECTOR PULSE WIDTH MODULATION

Inverters inherently have the property of controlling output frequency but the output voltage can't be varied. Usually to vary output voltage we have to vary supply voltage which is not always possible for this reason PWM techniques gained momentum. Basic aim of PWM technique is to control output voltage and harmonic reduction. Pulse-width modulation (PWM), or pulse duration modulation (PDM), is a commonly used technique for controlling power to inertial electrical devices, made practical by modern electronic power switches. Here we apply PWM techniques like Sinusoidal pulse width modulation (SPWM) and Space Vector Pulse width Modulation (SVPWM) to inverter and study its performance. In Sinusoidal Pulse width modulation (SPWM) we generate the gating signals by comparing a sinusoidal reference signal with a triangular carrier wave. In Space vector Modulation (SVPWM) we consider a rotating phased which is obtained by adding all the three voltages. Modulation is accomplished by switching state of an inverter. Space vector modulation is a PWM control algorithm for multi-phase AC generation, in which the reference signal is sampled regularly; after each sample, non-zero active switching vectors adjacent to the reference vector and one or more of the zero switching vectors are selected for the appropriate fraction of the sampling period in order to synthesize the reference signal as the average of the used vectors. The topology of a three-leg voltage source inverter is Because of the constraint that the input lines must never be shorted and the output current must always be continuous a voltage source inverter can assume only eight distinct topologies. Six out of these eight topologies produce a nonzero output voltage and are known as non-zero switching states and the remaining two topologies produce zero output voltage and are known as zero switching states. The SVPWM can be implemented by using wither sector selection algorithm or by using a carrier based space vector algorithm. The types of SVPWM implementations are: a) Sector selection based space vector modulation b) Reduced switching Space vector modulation c) Carrier based space vector modulation d) Reduced switching carrier based space vector pulse width modulation.
The circuit model of a typical three-phase voltage source PWM inverter is shown in Figure S1 to S6 are the six power switches that shape the output, which are controlled by the switching variables a, a′, b, b′, c and c′. When an upper transistor is switched on, i.e., when a, b or c is 1, the corresponding lower transistor is switched off, i.e., the corresponding a′, b′ or c′ is 0. Therefore, the on and off states of the upper transistors S1, S3 and S5 can be used to determine the output voltage.



VII. MODEL REFERENCE ADAPTIVE SYSTEM

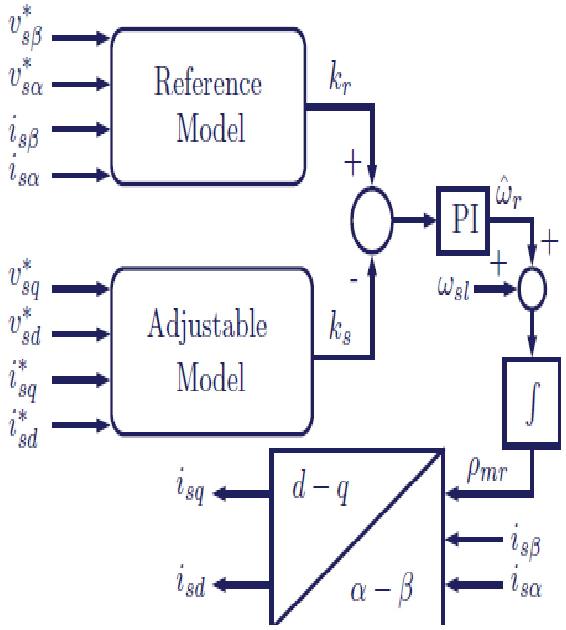
The basic structure of the proposed MRAS is presented in Fig.3.3.2, which mainly comprises of reference model, adjustable model and adaptation mechanism. Reference model is independent of the estimated quantity, whereas the adjustable model depends directly or indirectly on the same. The reference model computes *kr* using the stationary frame variables and hence does not require the information of rotor speed. The adjustable model on the other hand, computes *ks* with the quantities in the rotating reference frame and the rotating reference frame quantities are obtained from the stationary frame quantities using the rotor speed dependent vector rotator *ρmr* as shown in Figure below
The functional candidate 'k' can be instantaneous active power

P = _vs •_is

instantaneous reactive power

Q = _*vs* ×_*is* eqt

or fictitious quantities . The computation of these quantities in stationary and rotating reference frames is presented next to explore possible functional candidates to form the MRAS.



A new formulation of reactive power based model reference adaptive system is proposed which is stable in all the four quadrants of operation of the speed sensorless vector controlled induction motor drive. The proposed form of Q-MRAS is also free from integration and differentiation terms and independent of stator resistance. Estimation of flux and extra hardware/sensors are not required for its implementation. The drive works well at low speeds. A low cost implementation using FPGA is demonstrated in laboratory. Stability analysis, simulation, and experimental results confirm the advantages of the proposed speed estimator.

VIII. RELATION BETWEEN VOLTAGE AND TORQUE

A. SQIM Model

In three phase induction motors the emf induced by induction similar to that of transformer is given by

E or V= 4.44 Φ K.T.f

Where K is the winding constant, T is the number of turns per phase and f is frequency.

$$\Phi = V/4.44K\,T\,f$$

Controlling supply voltage: The torque produced by running three phase induction motor is given by

$$T \propto \frac{sE_2^2 R_2}{R_2^2 + (sX_2)^2}$$

In low slip region $(sX)^2$ is very small as compared to R_2 . So, it can be neglected. So torque becomes

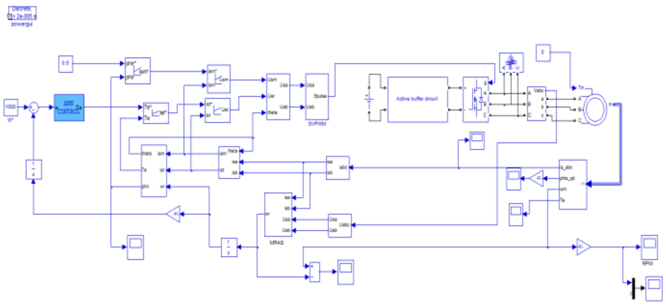
$$T \propto \frac{sE_2^2}{R_2}$$

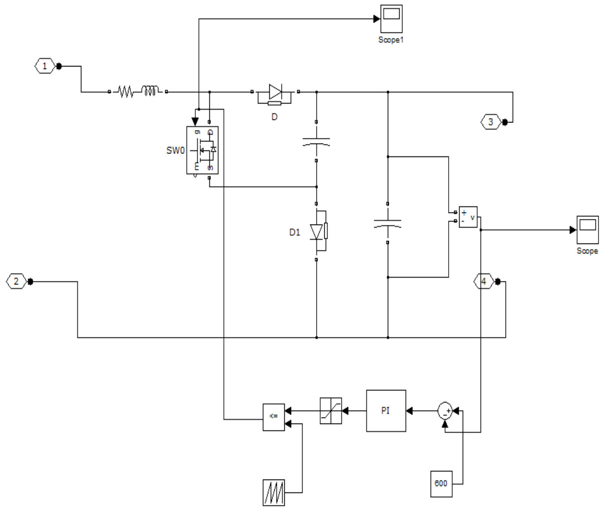
Since rotor resistance R_2 is constant so the equation of torque further reduces to

$$T \propto sE_2^2$$

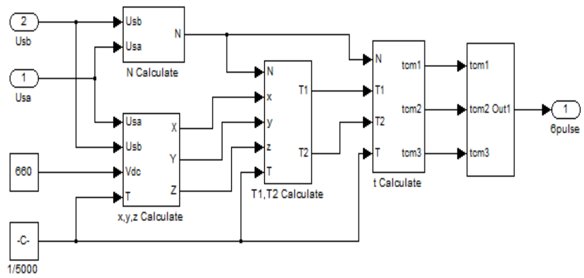
We know that rotor induced emf $E_2 \propto V$. So, $T \propto sV^2$.From the equation above it is clear that if we decrease supply voltage torque will also decrease.

IX. SIMULATION CIRCUITS WITH RESULTS

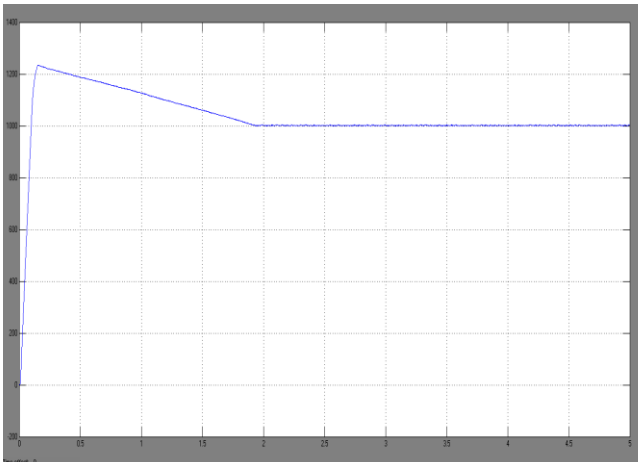




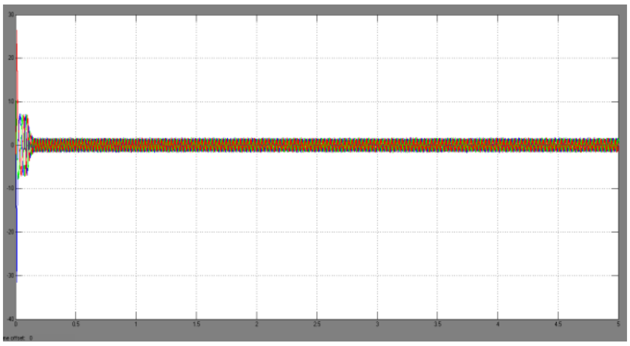
Active Buffer Circuit



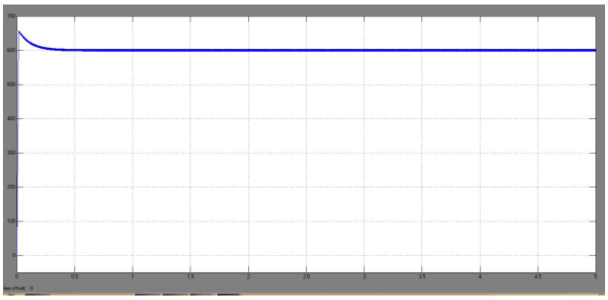
SPWM Model



Rotor speed waveform



Stator current waveform



Active buffer circuit

X. CONCLUSION

The model reference adaptive system technique is used here for sensorless speed estimation of an induction motor , by using the artificial neural network controllers. The implementation of this technique results in the improved dynamic performance of the machine. The drive can operate on all the four modes and instability problem is reduced .The model reference adaptive system provides a control strategy for non linear systems whose parameters measurements are quite complex. such kind of problems are avoided in this procedure and they provide best satisfactory performance. A detailed simulation using the matlab/simulink software is presented here in this project.

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