Novel Approaches in Sensorless Induction Motor Drive for Industrial Applications

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Abstract—In recent years, the use of sensorless induction motor drives is increasing in the fields ranging from industrial to household electrical applications. The major advantage of sensorless motor control technique include lower cost, high reliability, reduced hardware difficulty, noise free operation, and less maintenance requirements. To meet the current requirements of industrial applications more advanced sensorless control techniques are needed. For sensorless motor drives at low and zero-speed operation, inverter nonlinearities and motor parameter variation have significant impact on the stability of control system. Meanwhile, high observer's bandwidth is required in high-speed region. This paper introduces the state of art of recent progress in sensorless AC motor drives like Improved Q-MRAS, Virtual Current Sensor and Genetic Algorithm etc.

Index Terms — Sensorless, MRAS, Virtual Current sensor, Genetic Algorithm.

I. INTRODUCTION

In cutting-edge IM motor drive systems with high dynamic performance and efficiency, vector control strategy is mostly used, where accurate rotor position/speed is required. Normally, mechanical position/speed sensor with high resolution is necessary for excellent and better vector control, which increases the cost and complexity of the drive system. Therefore, the application of vector control system without mechanical position sensors [25], or known as sensorless speed control of IM motors has been increasing day by day in both industrial and household applications. Induction motor (IM) has been widely used in many industrial and household applications due to its simple construction, low cost, high reliability and easy maintenance. In recent years, for large quality control requirements the sensorless control methods are usually adapted in many industrial applications. This paper will introduce the novel approaches in position/speed sensorless control strategies adopted for Induction motors. The IM is presented in the first part. Firstly, conventional flux and speed estimation methods for IM are introduced. Then novel approaches for flux and speed estimation like Improved Q-MRAS, Virtual Current Sensor and Genetic Algorithm etc. are presented.

II. SENSORLESS CONTROL METHODS FOR IM

The block diagram of typical sensorless control of IM is shown in Fig 1. Sensor less control IM drive also known as vector control without any mechanical speed sensor in which the inherent coupling of motor is eliminated. The inverter generates switching pulses for the control of the IM [11, 30]. The analysis of induction motor is done with the two reaction theory in which with the help of inverter the currents and voltages are transformed into three phase to two phase also it translate from static reference frame to rotational frame and vice versa which decoupled with the IM. The voltage Vdc is the voltage which drives the inverter

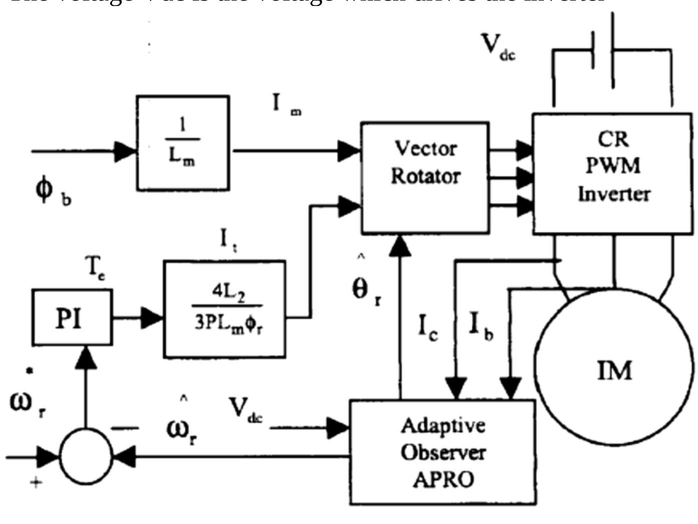

Figure 1: Block Diagram of Sensorless Control of Induction Motor Drive [30]

As in this scheme speed control is provided without using any mechanical sensor the flux and speed estimators are used to estimate the flux and speed respectively. These signals then compared with reference values and controlled by using the PI controller.

Speed and Flux sensorless estimation strategies.

In recent years, a many of researches have been done on speed and flux observer of IM sensorless drive system, mainly includes: Advanced Model Reference Adaptive System (MRAS) [1,19,21,24], Full Order Flux Observer

[3], Artificial Neural Estimator [7], Variable Frequency Injection Method [11], Fuzzy Logic Observer [8], Virtual Current Sensor [9], sliding mode observer [13],Extended Current Estimator [6]. Improved Speed Sensorless Vector Control Algorithm [12] and Genetic Algorithm [15] etc. According to the features of each method, the above can be divided into two groups.

1. Conventional Speed and Flux Estimation based on Observer.

In this Group Firstly, the mathematical model of IM is developed, and then the flux and speed of rotor is estimated. The most commonly used observers in Model Reference Adaptive System (MRAS) are Luenberger [44] and Kalman filter types [18]. The MRAS approach uses two models known as reference and adaptive model [1]. The fluxes achieved from both the models are equated to produce an error signal which is responsible for the motor speed estimation. If both models produce same flux then the accurate value of speed is estimated [26, 27].in these system dynamic equations of induction motor in stationary reference frame are used to obtain the outputs from both adaptive and reference model. Fig. 2 shows the de-qe dynamic model equivalent circuit of induction motor under synchronously rotating reference frame, if vqr = vdr = 0 and ωe=0 then it becomes stationary reference frame dynamic model.

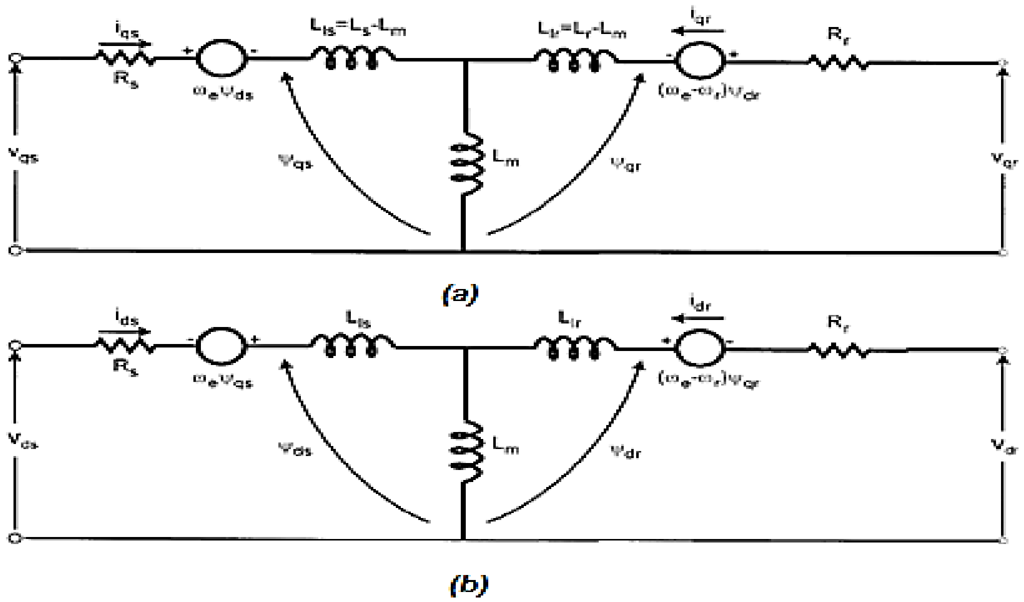

Figure 2: Dynamic d^e-q^e Equivalent Circuits of Machine (a) q^e-Axis Circuit (b) d^e-Axis Circuit [20]

The dynamic equations of the induction motor in any reference frame can be represented by using flux linkages as variables. This involves the reduction of a number of variables in the dynamic equations. Even when the voltages and currents are discontinuous the flux linkages are continuous [30]. Here the induction motor is represented in d-q model [16, 20] with the assumptions of Uniform air-gap, balanced rotor and stator windings with sinusoidal distributed mmfs, Inductance in rotor position is sinusoidal, Saturation and parameter changes are neglected and with these assumptions we get the following equations.

$$\psi_{ds} = \int (v_{ds} - R_s i_{ds})dt \qquad 1$$

$$\psi_{qs} = \int (v_{qs} - R_s i_{qs})dt \qquad 2$$

$$\psi_{dr} = \frac{-L_r \omega_r \psi_{qr} + L_m i_{ds} R_r}{R_r + sL_r} \qquad 3$$

$$\psi_{qr} = \frac{L_r \omega_r \psi_{dr} + L_m R_r i_{qs}}{R_r + sL_r} \qquad 4$$

$$i_{ds} = \frac{v_{ds}}{R_s + sL_s} - \left[\frac{\psi_{dr}.sL_m}{L_r.(R_s + sL_s)} \right] \qquad 5$$

$$i_{qs} = \frac{v_{qs}}{R_s + sL_s} - \left[\frac{\psi_{qr}.sL_m}{L_r.(R_s + sL_s)} \right] \qquad 6$$

By using the above 1 to 6 equations, the induction motor model can be developed in stator reference frame. In this control system the stator and rotor resistance varies largely with the variation in temperature and rotor side frequency which sometimes affects the estimation of the flux and leads to the inaccuracy of the speed estimation.

a. Conventional MRAS Approach

The conventional MRAS approach uses two models. The model in which the rotor speed ωr (the quantity to be estimated) is not involved called as the reference model and the model in which the rotor speed ωr (the quantity to be estimated) is involved considered as the adaptive or adjustable model. The output of the adaptive model is compared with that of the reference model, and the error is used to drive a suitable adaptive mechanism to estimate the rotor speed. The stability adaptive mechanism should be assured by the control system [29]. The reference model is formed by using following equations.

$$\frac{d}{dt}\psi_{dr} = \frac{L_r}{L_m}\left[v_{ds} - (R_s + \sigma\ SL_s)i_{ds}\right] \qquad 7$$

and

$$\frac{d}{dt}\psi_{qr} = \frac{L_r}{L_m}\left[v_{qs} - (R_s + \sigma\ SL_s)i_{qs}\right] \qquad 8$$

And the adaptive model can build by using

$$\frac{d}{dt}\psi_{dr} = \frac{L_m}{T_r}i_{ds} - \omega_r\psi_{qr} - \frac{1}{T_r}\psi_{dr} \qquad 9$$

And

$$\frac{d}{dt}\psi_{qr} = \frac{L_m}{T_r}i_{qs} - \omega_r\,\psi_{dr} - \frac{1}{T_r}\psi_{qr} \qquad 10$$

Where,

$$T_r = \frac{L_r}{R_r}$$

In this method, the rotor flux of the adaptive model is compared with that of the reference model. The rotor speed is estimated from the flux difference of the two models using adequate adaptive mechanism. However, the performance of this technique at low speed remains uncertain and the MRAS loses its efficiency [46]. To eliminate this disadvantage now a days Improved MRAS [12, 19] method is used instead of conventional MRAS method which will be discussed in the later part of the article.

b. Full-Order Adaptive State Observer

A full-order adaptive state observer is proposed [3, 30] in which the stator resistance and rotor flux are defined as state variables to construct the reference model, and a full-order flux observer is introduced to adjustable model. This method eliminates the drawbacks of the integral terms of the voltage model, ensures the accuracy of the reference model and reduces the parameter sensitivity while observing the rotor flux and speed. The stator current and rotor flux are considered as state equations as,

$$\frac{d}{dt}\,[i_s\ \Psi_r]^T = Ax+Bu \qquad 11$$

Where

$$A = \begin{pmatrix} -\frac{1}{T'_{sr}}I & \frac{Lm}{L'_r Lr}\left(\frac{1}{Tr}I - \omega r\,J\right) \\ \frac{Lm}{Tr}I & -\frac{1}{Tr}I + \omega r\,J \end{pmatrix},\ x = (i_{s\alpha}\ \ i_{s\beta}\ \ \Psi_{r\alpha}\ \ \Psi_{r\beta})^T,\ u = (u_{s\alpha}\ \ u_{s\beta})^T,\ B = \left(\frac{1}{L'_s}I\ \ 0\right)^T,\ J = \begin{pmatrix} 0 & -1 \\ 1 & 0 \end{pmatrix}$$

The output equation is defined as

$$\hat{i_s} = C\hat{x} \qquad 12$$

Where C= (I 0)

Also, an adjustable model can be constructed as follows

$$\left.\begin{aligned} \frac{d}{dt}\,[i_s\ \Psi_r]^T &= Ax+Bu \\ \hat{i_s} &= C\hat{x} \end{aligned}\right\} \qquad 13$$

Where $\hat{x}$ is the state estimation value, and $\hat{is}$ is the output current state vector of the stator. When the initial state of the adjustable model and the reference model is same then, $\hat{x}$ =x. But, most of the times initial states are falsely set and not same every time. Even if the matrix of the two systems is exactly the same, the initial state is not necessarily the same. At this point, $\hat{x}$ is not equal to x. If x-$\hat{x}$ is not equal 0, then the output state vector, y - $\hat{y}$ is also not equal to 0. By using equation (13) the basic structure of full-order flux observer can be constructed as shown in figure 3.

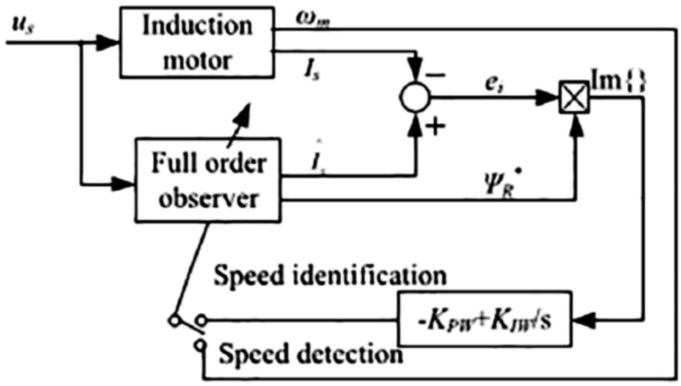

Figure 3. The basic structure of full-order flux observer [3]

Since this method is a model-based method, it cannot be applied to get stable operation for a long time when the stator current frequency is zero.

c. Sliding Mode Observer

A sliding mode observer for rotor flux observation was presented in [3, 13]. In recent years use of sensorless induction motor drives rapidly increasing. But sensorless induction motor drives are very sensitive to the stator and rotor resistances they changes with temperature and skin effects, it is clear that when these parameters varies, decoupling between the flux and torque components of stator currents is lost and therefore the effective performance of the machine weakens. However, when a very high accuracy is desired, to improve the performance of speed estimation low speeds, this paper [13] proposes a method for both rotor speed identification with stator and rotor resistance estimation in sensorless induction motor drives based on sliding mode observer.

Sliding-mode observer control techniques are based on the theory of systems with variable structure in which the gain corrector term of the observer contains the discontinuous function. A sliding-mode observer is written in the form,

$$\left.\begin{aligned} \xi &= f(\xi,u)+\Lambda \mathrm{sign}(y-\hat{y}) \\ \hat{y} &= h(\xi) \end{aligned}\right\} \quad \textbf{\textit{14}}$$

With

$\hat{x}$: Estimated state, L: Matrix Gain of the observer, f (.): Nonlinear function of state evolution, h (.): Nonlinear output function, y and$\hat{y}$: Outputs measured and estimated.

This method consists of stabilizing the error dynamics of the states to be estimated, which amounts to determine a slip surface on which the error of the estimate of the output is zero. Establish the slip conditions (calculation of the observer's gains for which all the trajectories of the system move Towards the sliding surface (attractiveness) and remain there (invariance). The observer is only a copy of the original system to which one adds the control gains with the terms of commutation. The sliding surfaces are defined by

$$S = \begin{bmatrix} S1 \\ S2 \end{bmatrix} = \begin{bmatrix} \widehat{is\alpha} - is\alpha \\ \widehat{is\beta} - is\beta \end{bmatrix}$$

But, based on the sliding mode observer, it was difficult to avoid the unstable problem at low speed, and the speed cannot be observed at the zero frequency. In addition, the system has a weak robustness to the motor parameters because the motor parameters were used in both flux and rotor speed estimation.

d. Rotor Speed Observer with Extended Current Estimator

For an efficient sensorless control method with vector-control technique the Rotor Speed Observer with Extended Current Estimator [4, 6] is proposed for the induction motor (IM) drive systems. The proposed technique depends on the indirect rotor-field orientation control scheme (IRFOC).

Most of the sensorless control techniques are significantly affected by the observation of the speed estimation procedure [18]. So the useful new algorithm for estimating the rotor speed of the machine is proposed along with that a method to estimate the rotor currents is also suggested. The implemented rotor-speed observer is based on the concept of IRFOC method and the phase-axis relationships of induction motor. The model is developed in the MATLAB/Simulink software to ensure the ability of the proposed sensorless speed-control system. The robustness of the proposed method is investigated under parameter uncertainty issue. Also, complete experimental results are achieved. The entire obtained results confirm the soundness of the proposed observer for sensorless speed control capability. The obtained results also confirm the effectiveness of the suggested sensorless control system-based IRFOC for speed-control drive systems of induction motor. Additionally, the results assure that the proposed speed observer is effectively robust in case of any parameter changes.

2. Novel Speed and Flux sensorless estimation strategies.

In the conventional MRAS method without a speed variable the flux linkages of the voltage model is used as the reference model. While the current model of the flux linkage including speed is used as the adjustable model. Meanwhile in this MRAS method, the precision Influences the accuracy of the speed estimation because this method is based on the voltage model and flux linkage which normally involves parameters related to the stator résistance [28]. This impact could be further weakened by the variations in resistance during the motor operation. Meanwhile, included pure integrator the voltage model pointed towards the accumulation of error and zero drift.

This will affect the speed estimation precision in the low-speed operating situation. To overcome this disadvantage of the conventional MRAS method, in recent year's research works have been mainly focuses on the selection of a suitable reference and adjustable models.

a. Improved Q- MRAS Approach.

In [23, 24, and 35] the instantaneous air gap reactive power was proposed to replace the back-EMF. The stator resistance parameters are removed from the reference model, which can remove its effect over the system speed estimation. However, the reference model still depends on the derivative operation on stator current and because of that this method becomes very sensitive to the noise of the entire system. To resolve this problem of speed estimation based on air gap reactive power, a new method was proposed in [17] where the air gap reactive power was replaced with the reactive power obtained from the induction machine. This method also successfully removes the differential term of the stator current. Also, the complete MRAS system does not have the parameters of stator resistance and the pure integrator, which helps improve the performance of the motor speed estimation considerably but the adjustable model include motor parameters like the flux leakage coefficient, inductance etc. This may have a negative impact on the speed estimation. Also, this method not able to solve the problem of stability of the control system.

A novel speed estimation scheme based on instantaneous reactive power (Q) based on model reference adaptive system (Q-MRAS) is proposed in [21] where the reactive power in the static coordinate system is used as the reference model, which does not cover information about the speed. However, the reactive power in the rotating coordinate system contains the rotational speed information used as the adjustable model. The basic structure of the proposed improved MRAS is illustrated in Figure 4.

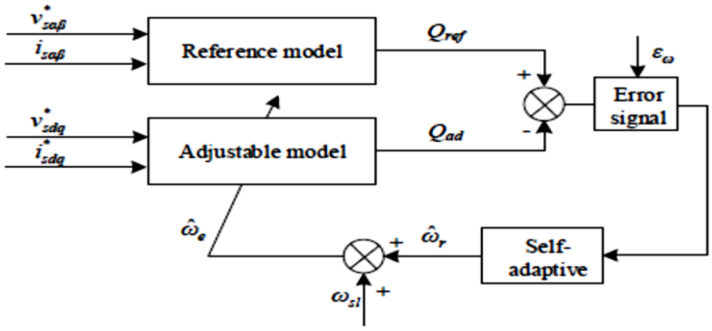

Figure 4. The structure of speed estimation based on the improved Q-MRAS [21]

Equation (15) is used to construct the reference and adaptive model

$$\left.\begin{aligned} Q_{ref} &= (i_{s\alpha} + \mathrm{j}i_{s\beta}) \times (v_{s\alpha} + \mathrm{j}v_{s\beta}) = v_{s\beta}i_{s\alpha} - v_{s\alpha}i_{s\beta} \\ Q_{ad} &= v_{sq}i_{sd} - v_{sd}i_{sq} \end{aligned}\right\} \quad (15)$$

In order to confirm the reliability and accuracy of the estimation system, the adaptation law design of the improved Q-MRAS system in figure 4 wants to ensure the stability of the closed loop system.

According to the simulation results the performance of induction motor like speed estimation at zero load, zero to full load, at speed mutation, and speed estimation in the low speed condition is more accurate and stable in improved Q-MRAS method than Conventional MRAS method. Table1. shows the comparison between improved Q-MRAS method and Conventional MRAS method under various load conditions.

Table 1: comparison between Improved Q-MRAS method and Conventional MRAS method [21]

Experimental Condition	Conventional MRAS	Improved Q-MRAS
Speed Estimation at zero speed condition	Lagging to the actual speed signals with delay of almost 0.02 sec	Tracks the actual speed signals with no delay
Speed Estimation from zero to full load	Greater lag and regulation time is very long which is almost 0.03 sec.	Tracks the actual speed signals without delay
Speed Estimation in the condition of speed mutation	Has poor tracking performance at the start of mutation process	Has good tracking performance at the start of mutation process
Speed Estimation in the low speed region	Low accuracy having the fluctuations in the actual speed of about ±40%	High accuracy with fluctuations in the actual speed of about ±10%
Speed Estimation at zero load condition	Error fluctuations between ±3 to 4%	Error controlled between ±0.5%

b. Virtual Current Sensor

Vector control of an induction motor requires information to be provided to the control system about state variables such as hard to measure stator and rotor fluxes or electromagnetic torque as well as the measurement of the voltage in the intermediate circuit of the voltage-source inverter (VSI), angular velocity, and phase currents [14,22]. The most popular methods for the estimation of difficult to measure state variables are algorithmic methods [32, 33], whose accuracy is mostly dependent on the correct identification of parameters of the IM equivalent circuit and the accuracy of the phase current measurement. Therefore, it is required that information on the actual values of phase currents are provided not only to the control system itself [31], but also to the flux estimation module during drive operation.

In systems where safety and reliability are more important than cost there speed, voltage and current sensors are also used in the electric drives to ensure safe driving of the vehicle. But, due to the limited reliability of these devices, some solution is requiring that will allow for the safe braking of the motor in the occurrence of a sensor failure. Introduction of software redundancy in the form of virtual sensors based on state variable estimators developed on the basis of the mathematical model of the motor may be the possible solution [33, 47]. A vector control method of induction motor always operates on the actual information about the stator currents [45]. So, in the occurrence of a failure of the current sensors, it is necessary to replace them with virtual current sensor (VCS). The algorithm of VCS presents in [9], uses a rotor flux estimator model, and thus speed measurement is required to implement it. This method is devoted to fault tolerant systems, where as a result of damage to current sensors, it is necessary to switch to scalar control. The proposed VCS allow further, continuous operation of the direct rotor field oriented control (DRFOC) of the induction motor drive. The stator current estimator has been presented in the form of equations to enable its practical implementation on a microprocessor system.

The algorithm for estimating three phase currents only uses the measurement of the angular velocity ωm and direct voltage udc in the VSI intermediate circuit. To obtain the estimated value of the stator current vector components, the rotor flux should be determined, whose components resulting from the well-known current model of the rotor flux vector were described in (α–β) coordinates using the symmetric Euler (SE) discretization method [43]. The final equations of the stator current estimator in the (α–β) system are obtained as

$$i^{e}_{s\alpha}(k+1) = i^{e}_{s\alpha}(k)+\frac{1}{\sigma is}\left(u_{s\alpha}(k)-r_s i^{e}_{s\alpha}(k)-\frac{Im}{Ir}\left(\frac{rr}{Ir}\left(I_m i^{e}_{s\alpha}(k)-\Psi^{i}_{r\alpha}(k)\right)-\omega_m(k)\,\Psi^{i}_{r\beta}(k)\right)\right)\frac{TS}{TN} \qquad \textbf{16}$$

$$i^{e}_{s\beta}(k+1) = i^{e}_{s\beta}(k)+\frac{1}{\sigma is}\left(u_{s\beta}(k)-r_s i^{e}_{s\beta}(k)-\frac{Im}{Ir}\left(\frac{rr}{Ir}\left(I_m i^{e}_{s\beta}(k)-\Psi^{i}_{r\beta}(k)\right)-\omega_m(k)\,\Psi^{i}_{r\alpha}(k+1)\right)\right)\frac{TS}{TN}$$

From the above equations block diagram of the proposed algorithm can presented as shown in figure 5.

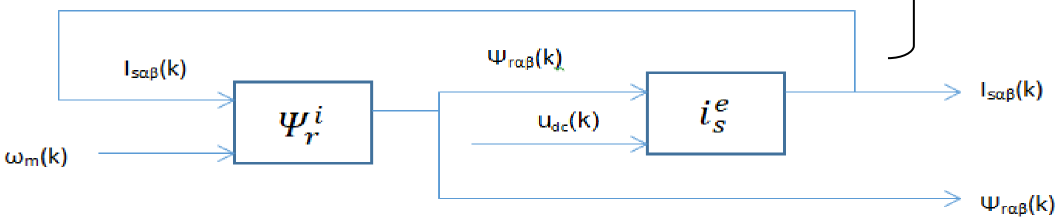

Figure 5. Block diagram of the stator current estimation based on the measurement of angular velocity [9]

Under the various cases the stator current estimation quality were tested [9] and for each of the case the quality of the estimation was estimated on the basis of the average modules of the difference between the estimated and measured current in each motor phase. Since the current value was different for the adopted operating condition, this module was divided by the average value of the phase currents to normalize the estimation error and this average error was calculated over the ten measured periods of the stator current. The test results are presented in table 2.

Table 2. Quality Indicators of the Stator Current Estimation [9].

Test Case	Rated Speed Zero Load	Rated Speed 25 % Load	Rated Speed 50 % Load	Rated Speed 75 % Load	Rated Speed And Load Torque	25 % Speed At Rated Load	50 % Speed At Rated Load	75 % Speed At Rated Load
Average Error ei (%)	7.998	6.726	4.472	3.282	5.501	4.134	3.021	3.491

As can be seen from table 2, the current value in the real system was estimated with high accuracy. The algorithm worked better while the system was loaded.

c. Genetic Algorithm PID (GA-PID) Controller

The online Genetic Algorithm PID (GA-PID) speed controller is suggested [15] instead of classical PID controller. Constant parameters are not available in online GA-PID controller and [34, 38], their values adjust to new conditions and circumstances in a variable control system. Modifying and adjusting these constants confirms that the PID controller works well and helps to obtain the optimum speed response. The genetic algorithm receives the input variables as the speed error ω, the electric current which it will determine the best values of KP, Ki, Kd and sends it to the PID controller. Figure 6 shows the Speed controller using GA [50].

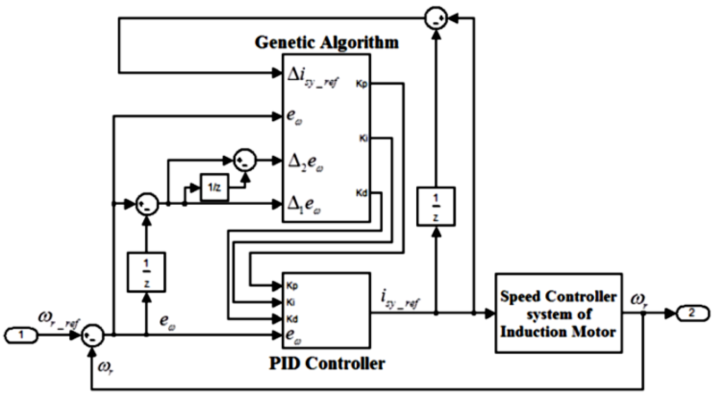

Figure 6. Speed controller using genetic algorithm [15]

The experimental results showing in table 3. Give the performance analysis between classical PID controller and GA-PID speed controller.

Table 3. Control quality parameters at load torque of 5 Nm and 7Nm [15]

Quality Parameter	**Load 5 Nm**		**Load 7 Nm**	
	GA Speed Controller	**PID Speed Controller**	**GA Speed Controller**	**PID Speed Controller**
Rise Time (s)	0.097	0.18	0.097	0.19
Setting Time (s)	0.1	0.2	0.1	0.21
Overshoot (%)	0.5	1	0.5	1
Steady state error (rpm)	0.1	1.5	0.1	2

The online tuned PID controller uses the genetic algorithm to replace the classical PID controller for the induction motor drive. It improves the performance of the induction motor speed response. The efficient MRAS speed observer is used to make the sensorless speed control, more cost effective, and more reliable [10, 50]

d. Artificial Neural Network (ANN) with Fuzzy logic.

To control nonlinear devices in present time, the Artificial Neural Network (ANN) [7, 36, and 42] becomes an effective tool. This paper proposes the use of ANN instead of DSP for the estimation of the motor parameters in order to decrease the complexity related with and the impact of Electromagnetic Interference (EMI). Also, it introduces the PI-NN controller which is based on ANN. The systems simulations for both DSP and ANN are depicted.

To improve the overall performance of the device, performance of nonlinearity became improved by using Neural Network Controller (NNC). A neural network is a sensible device which can be learned the use of real present inputs and outputs, the process can be executed in real-time or off-time operation. [40]

It has four input and output neurons, along with 7 hidden layers are calculated and trained to satisfy the required performance of the estimator. Generally a huge wide range of input and output records of various operating conditions are used to train the neural network, but in this paper [7] a unique unit step signal with rising and fall edges was used to train the network, which offers a top-notch overall performance in various speed situations.

In this paper new tools and concepts for controlling techniques are presented based on adaptive PID controller combined with ANN. Back Propagation (BP) neural network has the self-learning ability and can be tuned automatically to modify the PID parameters. Figure 7. shows the block diagram of the PID controller based on the discrete representation

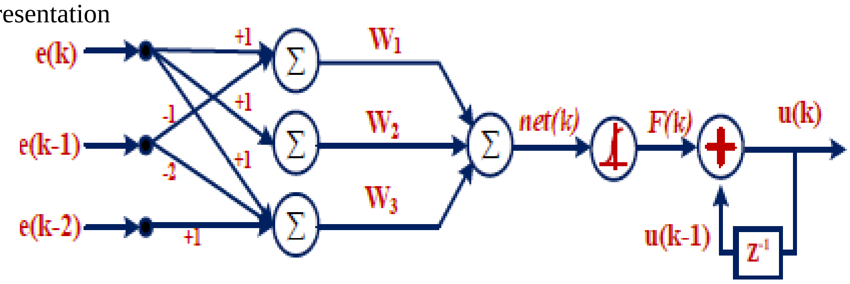

Figure 7. Block diagram of the PID controller based on the discrete representation [7]

The proposed adaptive controller law based on neural community method is as the following:

$$net(k) = W_1[e(k)-e(k-1)]+W_2 e(k)+W_3[e(k)-2e(k-1)+e(k-2)]$$

17

The main difficulty of this proposed method is that, it needs to use optimization technique to restrict parameters into local optima to achieve the required performance of PID-NN Controller. Sensorless speed estimation of three-phase induction motor based on MRAS and Fuzzy logic controller [8, 39, and 41] is presented which tracks the actual motor speed with very small error.

A solution based on the theory of the fuzzy logic is developed in [48, 49] to eliminate the problem related with variation of the rotor resistance which causes an error in the Estimation of the rotor speed. This method permits the estimation of rotor resistance and re injects it in the control loop in order to assure the decoupling between the torque and flux transients.

Conclusion.

The conventional MRAS and sliding mode control both methods are having problem of unstable operation at low speed and speed cannot be observed at the zero frequency. This difficulty can be resolved using improved Q-MRAS method also the tracking performance of the improved algorithm is better at the low-speed condition and the switching state condition.

Virtual current estimator not only ensures the safe operation of the drive, but also allows for continued control with the vector method, even in a structure using information about the stator currents in feedback loops. The developed VCS have better accuracy compare to the extended current estimators when the IM works with the load torque.

The use of classical PID controllers and observer in the methods like full order observer, Sliding mode control, IRFOC and other conventional observer increases hardware complexity of drive and reduces its reliability but The use of genetic algorithm based speed controller (GA-PID) and Artificial Neural Network (ANN) based observer for parameter estimation reduces the hardware complexity and increases reliability of the drive also the speed response of the induction motor has many advantages with the GA-PID controller over the classic PID speed controller.

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