

Self-Tuning PID Controller with Genetic Algorithm Based Sliding Mode MRAS for Induction Motor Drive

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Abstract:- Modern industrial processes are becoming more and more automatized and complex. Therefore, their monitoring and diagnosis systems must be continuously improved. A great majority of today's industrial applications use induction motors (IMs) to ensure rotational movement, however, usually their speeds are still measured by sensors. A speed observer can be applied in order to decrease the amount of cables and increase reliability by avoiding the use of a measurement device. When an encoder is already present in the industrial process, the sensorless technique can also be used to design a speed sensor fault tolerant drive system.

The speed of IM can be estimated using various techniques and the number of proposed methods is already high. One of the existing solutions, which can be distinguished, is the use of the sliding mode (SM) technique. It is practically always concluded to be the most advantageous in all comparisons. One of the disadvantages is the chattering problem, which arises due to the sign function usage and the necessity to apply a low pass filter. Therefore, many different solutions have been applied to reduce this problem. However, this problem is still not recognized in the case of the SM solutions.

The paper presents a Self Tuned PID with Genetic Algorithm (GA) for sensorless induction motor drives. The proposed Self Tuned PID with sliding mode estimationalgorithm is a Model Reference Adaptive System (MRAS) type estimator. Its reference model is the induction motor, while both the stator current and rotor flux estimators create the adaptive system. The estimator uses a sliding mode technique in order to ensure robustness and simple implementation. The algorithm is based on the equivalent signal technique which allows to significantly decreasing chattering, while simultaneously retaining the properties of the sliding mode estimator. Additionally, the estimator is extended with an auxiliary variable which allows improving the stability of the estimation in regenerating mode operation. The proposed estimator is verified using MATLAB simulation tests.

keywords: induction motor drives, MRAS, online parameter estimation, rotor flux observer, GA.

I. INTRODUCTION

Control of motor is required in both industrial and domestic applications ranging from transportation systems, rolling mills, textile mills in industries to washing machines, fans and pumps in household applications. In such applications motor drives whose speed can be adjusted or varied over a wide range of speeds are of much importance and form an integral part of automation. These types of drives are usually termed as variable speed motor drives or adjustable motor drives. The efficiency of the system or the process can be increased by using these variable speed drives in place of constant speed drives whose speed cannot be adjusted. Hence, these variable speed drives are mostly employed in industrial applications[1].

2 Estimation of Speed

It is desirable to avoid the use of speed sensors from the standpoints of cost, size of the drive, noise immunity and reliability. So the development of shaft sensorless adjustable speed drive has become an important research topic. Many speed estimation algorithms and sensorless control schemes [22] have been developed during the past few years. The speed information required in the proposed control technique is estimated by the algorithm described in this section. The speed of the motor is estimated by estimating the synchronous speed and subtracting the command slip speed. The synchronous speed is estimated using the stator flux components, because of its higher accuracy compared to estimation based on rotor flux components.

The rotor speed of an induction motor is expressed in terms of synchronous and slip (angular) frequencies is as follows:

$$\omega_r = (\omega_e - \omega_{sl})/P \quad (1)$$

he estimation of rotor speed is accomplished by an estimation of either synchronous, or slip frequency, with the other being known. In the proposed speed estimation

scheme, the synchronous frequency is estimated and slip frequency is assumed as command. So the estimated rotor speed of the sensorless drive is obtained from the above equation as: Where,

The estimated synchronous frequency is derived based on the rotor flux model, or the stator flux model. The principles of both the methods are briefly explained below.

$$\theta_{\psi_r} = \tan^{-1} \left(\frac{\psi_{\beta r}}{\psi_{\alpha r}} \right) \tag{2}$$

If $\psi_{\beta r}$ and $\psi_{\alpha r}$ are the two components of the rotor flux vector in the stationary (α - β) reference frame as shown in Fig. 2.1 (a), the electrical angle of the rotor flux vector is defined as:

From the basic equation of induction motor in stationary (α - β) reference frame, the stator and rotor flux linkages are given by

$$\left. \begin{aligned} \psi_{\alpha s} &= \int_0^t (v_{\alpha s} - R_s i_{\alpha s}) dt \\ \psi_{\beta s} &= \int_0^t (v_{\beta s} - R_s i_{\beta s}) dt \end{aligned} \right\}$$

$$\left. \begin{aligned} \psi_{\alpha r} &= \frac{L_r}{L_m} (\psi_{\alpha s} - \sigma L_s i_{\alpha s}) \\ \psi_{\beta r} &= \frac{L_r}{L_m} (\psi_{\beta s} - \sigma L_s i_{\beta s}) \end{aligned} \right\}$$

equation (3) and equation.(4)

Equation(3) shows that the stator flux depends on the stator resistance and measured stator voltages and currents. Equation (4) shows that the rotor flux depends on the estimated stator flux and requires the knowledge of the inductances of the machine, especially the stator leakage inductance (σL_s). Usually the stator resistance can be measured fairly accurately. Hence stator flux can be estimated more accurately compared to the rotor flux. Therefore the estimated stator flux can be used to derive the synchronous frequency.

The block diagram of the described speed estimation algorithm with the sensorless speed control scheme is shown in fig 2.1

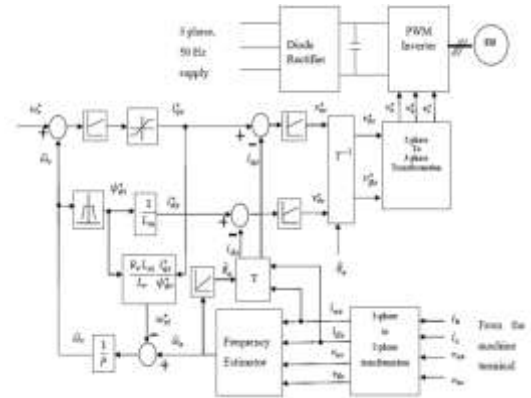


Fig 2.1 Induction motor drive system with sensorless speed control scheme

3. MRAS SYSTEM

In this section a brief survey of different control techniques for induction motor drive is presented. As in this research the main focus is on the control of induction motor using model reference adaptive system (MRAS), the different types of MRAS schemes and their draw backs are also analyzed. In the above discussed estimation schemes either open loop or closed loop speed and flux linkage estimators were utilized. It was also discussed that the accuracy of the closed loop estimators is better than the open loop estimators. In this section a closed loop speed estimation scheme using the Model Reference Adaptive System (MRAS) is described.

Tamai et al. in 1987 described one speed estimation scheme based on MRAS [34]. In 1992 C. Schauder presented an alternative MRAS technique which was less complex and more effective than the earlier one [35]. Usually in MRAS technique some state variables such as rotor flux linkage components or back emf components or reactive power components of the induction motor that are obtained by using measured terminal quantities are estimated in a reference model. Then these quantities are compared with state variables estimated by using an adaptive model. The difference hence obtained between these variables known as error is tuned by an adaptation mechanism which outputs the estimated value of the rotor speed and adjusts the adaptive model until the error obtained is minimized thereby giving the satisfactory performance of the drive.

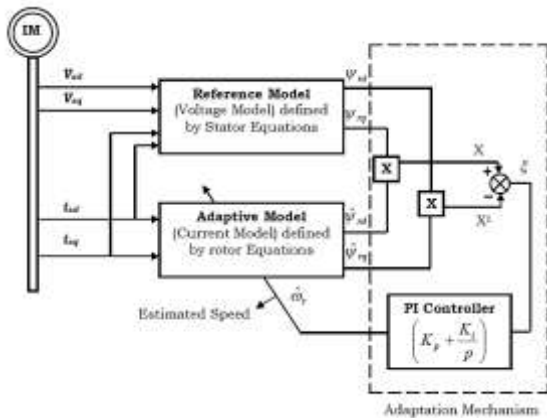


Fig. 2.2 Block diagram of speed estimation using MRAS

The above equations do not contain rotor speed and therefore does not get affected by rotor speed and hence it is taken as reference model. These equations can be written in matrix format as

$$\begin{bmatrix} p\psi_{rd} \\ p\psi_{rq} \end{bmatrix} = \frac{L_r}{L_m} \begin{bmatrix} v_{sd} \\ v_{sq} \end{bmatrix} - \begin{bmatrix} R_s + \sigma L_s p & 0 \\ 0 & R_s + L_s p \end{bmatrix} * \begin{bmatrix} i_{sd} \\ i_{sq} \end{bmatrix} \quad (5)$$

The current model consisting of rotor is obtained and is given in equations

$$\xi = X - X^1 = \hat{\psi}_{rd} \psi_{rq} - \hat{\psi}_{rq} \psi_{rd} \quad (6)$$

$$\sigma = 1 - \frac{L_m^2}{L_s L_r} \text{ is leakage coefficient.}$$

The current model given in equations (6) consists of rotor speed and hence gets affected by it. Therefore this model is known as adaptive model or adjustable model. The reference model and the adaptive model are used to estimate the rotor flux linkages. The angular difference of the outputs of the two estimators known as error

is given as in equation

$$\xi = X - X^1 = \hat{\psi}_{rd} \psi_{rq} - \hat{\psi}_{rq} \psi_{rd} \quad (7)$$

This is used as speed tuning signal that is given as input to adaptation mechanism, which forms the main part of the MRAS scheme. The adaptation mechanism conventionally utilizes a PI controller. When the error between the two models is not zero then the adaptation mechanism tunes the rotor speed. In other words when the error between the rotor flux linkages ($X - X^1$) is not zero, the PI controller tunes the rotor speed. The rotor speed identification algorithm is actuated by error signal generated when the error is not zero, making the error converge to zero. The estimated speed by using MRAS scheme is given as

$$\hat{\omega}_r = \left(K_p + \frac{K_i}{p} \right) \xi$$

where K_p and K_i are proportional and integral gain constants respectively.

4. Sliding Mode Observer

SMO with observer feedback in the form of sign of the stator current estimation error. To identify Speed, Various adaptation mechanism can be used such as Integration of vector product of the rotor flux and sign of the stator current for attaining low frequency signal (LFS) from sign function. Which is value of vector product of the rotor flux and the stator current error. SMO's with open loop equation to estimate the speed based on back emf value (or) slip speed expression. Which are strongly dependent on the motor parameters and based on derivative of the rotor flux vector components.

5. Genetic algorithms

Genetic algorithms (GAs) are stochastic global search and optimization methods that mimic the metaphor of natural biological evolution and which are developed based on the Darwinian theory of "survival of fittest". GA have found numerous applications in a number of problem domains where a randomized local search of the parameter space is applicable. Some examples of such applications are various pattern detection and recognition problems training the weights of neural networks and signal enhancement. Simple GA has three basic operators: selection, crossover and mutation. A GA starts iteration with an initial

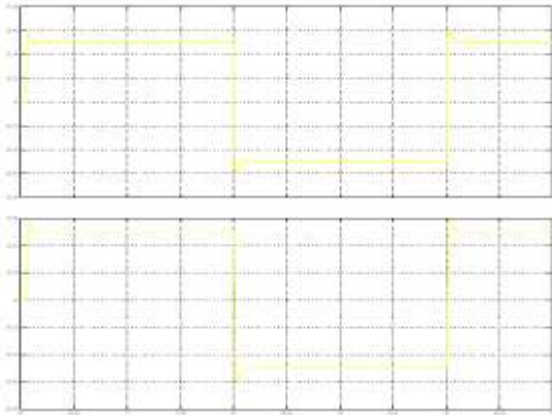
population. Each member in this population is evaluated and assigned a fitness value. In the selection procedure, some selection criterion is to select a certain number of strings, namely parents, from this population according to their fitness values. Strings with higher fitness values have more opportunities to be selected for reproduction in next step. Next, in crossover procedure, selected strings from old population are randomly paired to mate. For binary coding, a cross-site is determined according to some law, and the paired strings exchange all characters following the cross-site. Crossover usually results in two new strings, namely, two children that are expected to combine the best characters of their parents. Mutation simply changes one bit 0 to 1 and vice versa, at a position determined by some rules. Mutation is simple but still important in evolution because it increases the diversity of the population members and enables the optimization to get out of local optima. After mutation, a new generation is created, and thus becomes the parents for next generation. This process is iterated until convergence is achieved or a near optimal. Gas operates on a population (a number of potential solutions). The population at time t is represented by the time-dependent variable $P(t)$, with the initial population of random estimates being $P(0)$.

```
Begin
t=0
Initialize P (t)
Evaluate P(t) (fitness)
while not finished do
begin
t=t+1
select P(t) from P(t-1)
alter (cross and mutation)
P(t)
evaluate P(t) (fitness)
end
en
begin
t=0
initialize P(t)
evaluate P(t) (fitness)
while not finished do
begin
t=t+1
select P(t) from P(t-1)
alter (cross and mutation)
P(t)
evaluate P(t) (fitness)
end
en
begin
t=0
```

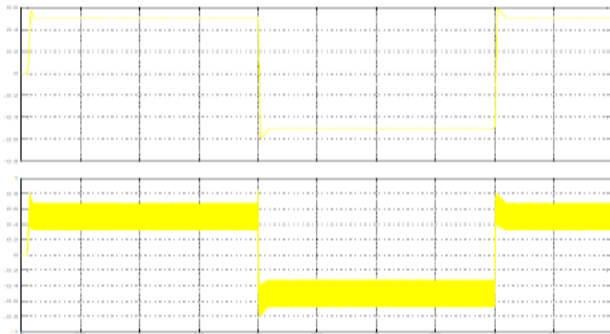
```
initialize P(t)
evaluate P(t) (fitness)
while not finished do
begin
t=t+1
select P(t) from P(t-1)
alter (cross and mutation)
P(t)
evaluate P(t) (fitness)
end
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initialize P(t)
evaluate P(t) (fitness)
while not finished do
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select P(t) from P(t-1)
alter (cross and mutation)
P(t)
evaluate P(t) (fitness)
end
en
```

6. SIMULATION AND RESULTS:

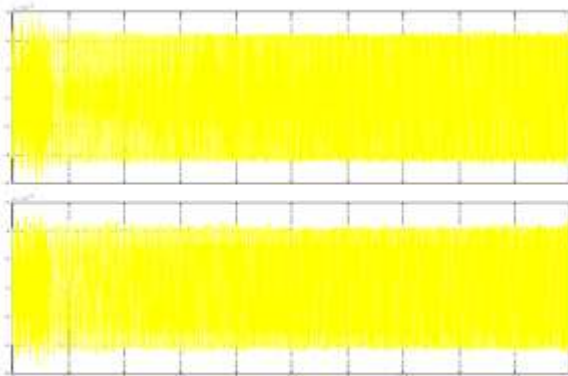
1. Performance of the proposed EqSM-MRAS estimator with auxiliary variable in the case of rapid speed reversal for Real and estimated Speed



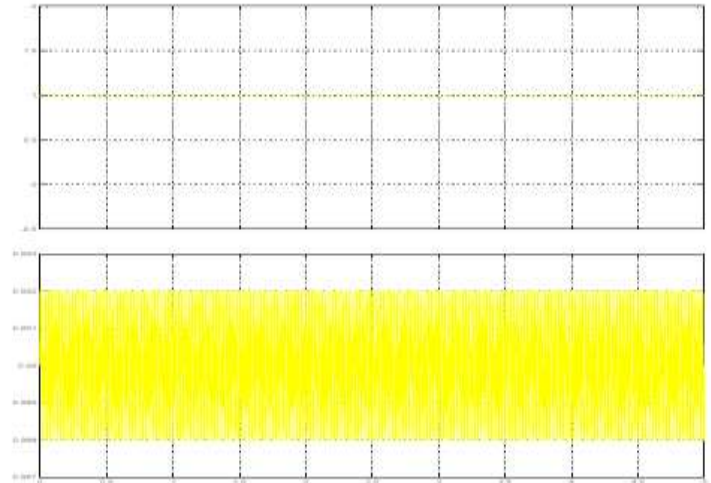
2. Performance of the proposed EqSM-MRAS estimator with auxiliary variable in the case of rapid speed reversal for high frequency signal and its filtered form



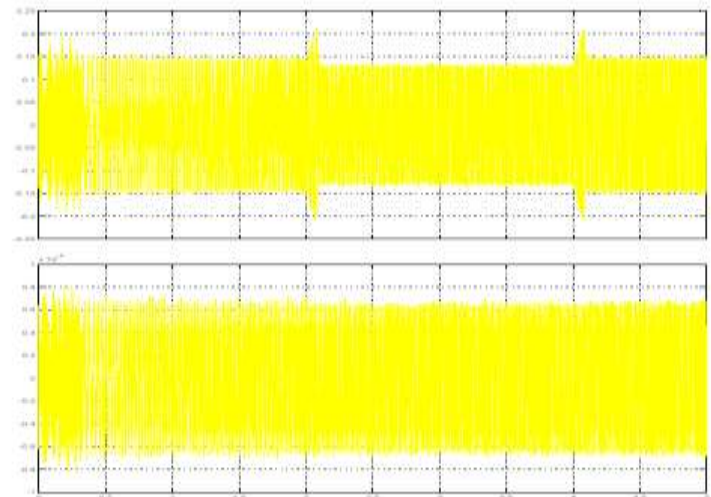
3. Performance of the proposed EqSM-MRAS estimator with auxiliary variable in the case of rapid speed reversal for auxiliary variable, estimated and filtered



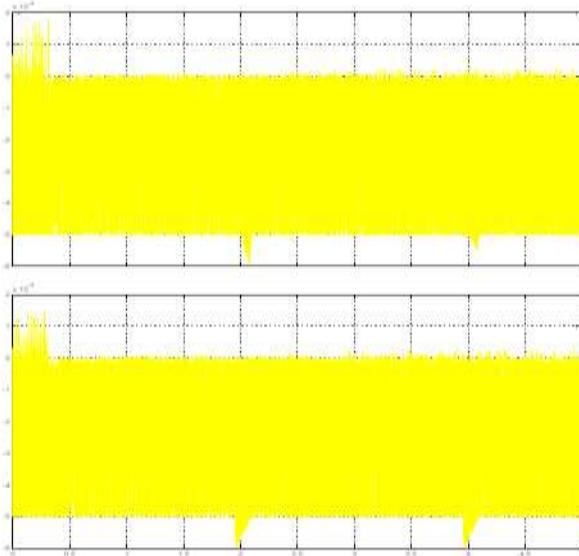
4. Performance of the proposed EqSM-MRAS estimator with auxiliary variable in the case of rapid speed reversal for Estimated and real amplitudes of rotor flux



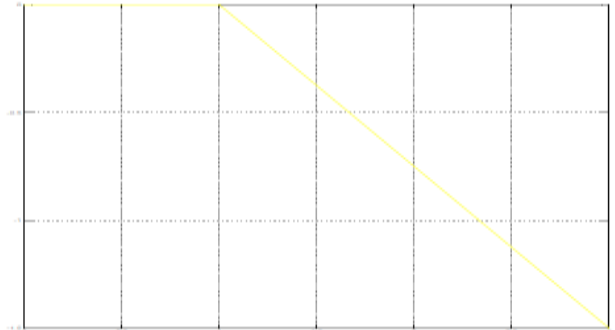
5. Performance of the proposed EqSM-MRAS estimator with auxiliary variable in the case of rapid speed reversal for switching functions



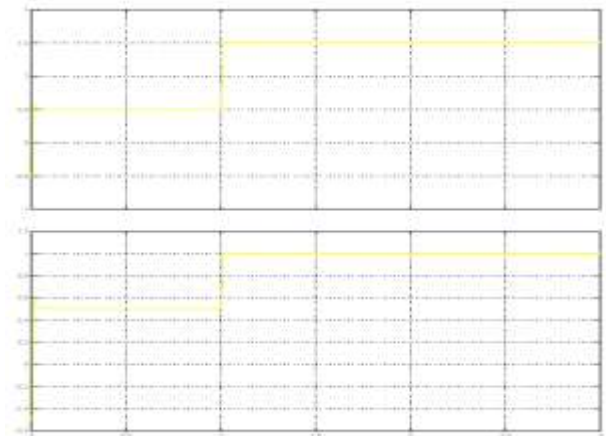
6. Performance of the proposed EqSM-MRAS estimator with auxiliary variable in the case of rapid speed reversal for stator current vector components estimation errors



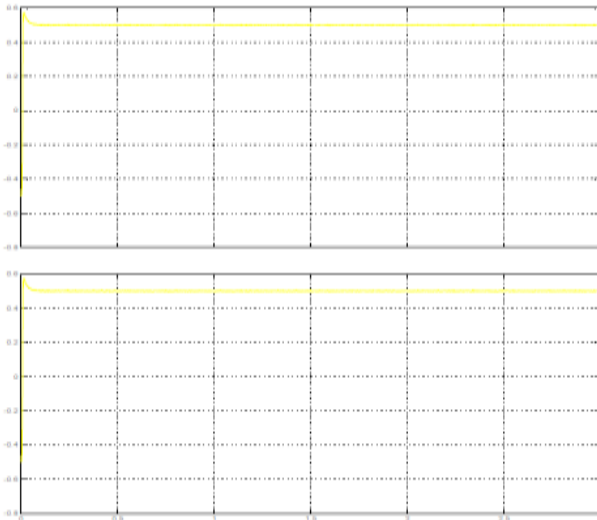
8. Estimation of stability in regenerating mode with auxiliary variable



9. Estimation of stability in regenerating mode without auxiliary variable



7. Estimation of stability in regenerating mode



10. Estimated flux in rotor parameters variation

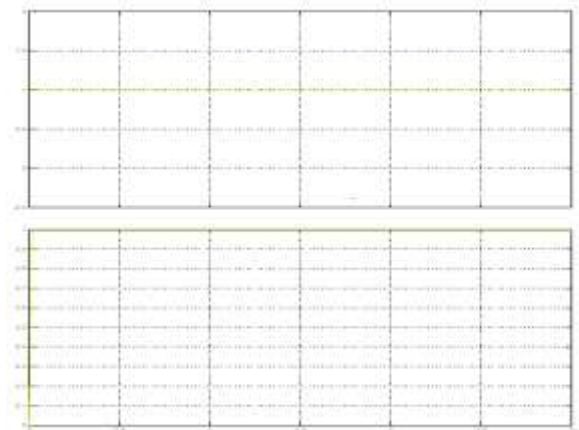


Fig.11 Characteristic curves of speed wrt time using PI and PID controller with GA

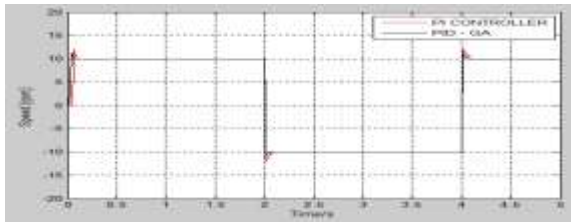


Fig.12 Characteristic curves of Torque wrt time using PI and PID controller with GA

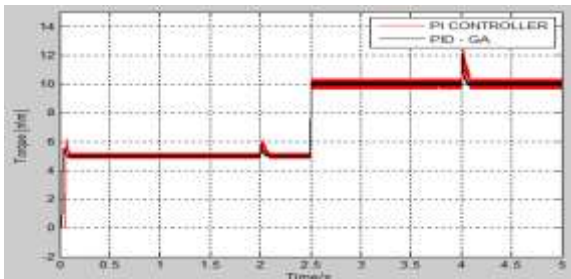


Fig.13 Estimated speed With filter

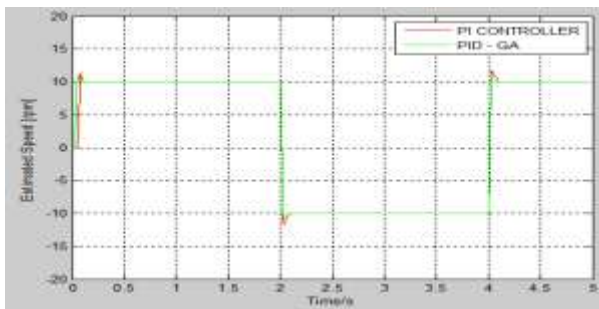
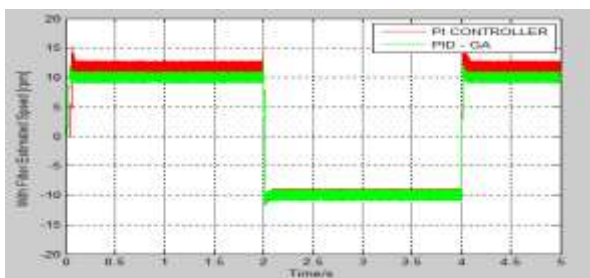


fig.14 Estimated speed without filter



V, CONCLUSION

This paper proposed a parameter estimation scheme for IFOC of IMs. In this scheme, the errors in the phase and in the magnitude of the current model rotor flux, from that given by the designed observers, are input to the adaptive mechanisms respectively to estimate both the rotor resistance and the mutual high-order TSMO providing the state variable, the back-EMF, and a first-order sliding mode

observer estimating the rotor flux itself. As demonstrated by simulation, the rotor flux coming out of the observers is highly robust to the mismatch of the rotor resistance and/or of the mutual inductance, which allows it to be used as a reference in the ANFIS MRAS-based estimations of these two parameters: the rotor resistance and the mutual inductance. Although there is coupling between the estimation of the resistance and that of the inductance, their actual values can still be obtained robustly over time. If a decoupling method can be found and integrated into the parameter estimation scheme in future investigation, the converging process would be expedited and the estimating performance would be improved further.

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