

# **CHAPTER THREE**

## **SPEED SENSORLESS ESTIMATION TECHNIQUES**

### **3.1 Introduction**

In recent years, the vector control theory has been receiving much attention because of the better steady and dynamic performance over conventional control methods in controlling motors torque and speed. High performance vector controlled induction motor drives require speed or position information for its operation. Generally speed or position sensors provide this information. However, these mechanical sensors are costly and fragile. Therefore there has been great tendency in developing a high performance induction motor drive that does not require a speed or position sensor for its operation. One of the more recent developments in the control of induction motor drives is the elimination of the speed sensor mounted on the motor shaft. This technology is usually referred to as sensorless control where the motor speed is estimated rather than measured. Estimated speed instead of the measured one essentially reduces the cost and the complexity of the drive system. However, the induction motor drive will still usually need current and perhaps voltage sensors to achieve the control task [3-9].

This chapter provides a comprehensive review of different estimation strategies employed for speed sensorless control of induction motor drives with particular focus given to model reference adaptive system techniques. The final section is concerned with modelling of rotor flux model reference adaptive system observer for speed sensorless induction motor drives.

## **3.2 Types of Estimation Methods**

Estimation can be defined as the determination of parameters or state variables for any system, according to a performance level and based in the measurements taken from the process. Estimation of unmeasurable state variables is commonly called observation. A computer program (or device) that estimates or observes the states is called a state-observer or simply an observer. If the state-observer observes all state variables of the system, regardless of whether some state variables are available for direct measurement, it is called a full-order state-observer. An observer that estimates fewer than the dimension of the state-vector is called reduced-order state-observer or simply a reduced-order observer. Basically, there are two forms (groups) of the implementation of an observer [5, 6]. The first one is the open loop observer which does not have the feedback correction and the other one is the closed loop observer which make use of the feedback correction to improve the estimation accuracy. The open loop calculation method is simple to implement but prone to error because of high dependency on the machine parameters. The closed loop group observers for state estimation are much more versatile in terms of performance such as the Luenberger observers, Kalman filter observers, and model reference adaptive system estimators. Each of these state estimation schemes differs from each other in terms of equations and structure used but they share the same objective to provide the state information and to improve the performance of the system. Out of various state estimation techniques, model reference adaptive system schemes are the most popular strategies employed due to their relative simplicity and low computational effort [10, 11].

## **3.3 Model Reference Adaptive System**

Adaptive control may be defined in many ways. A possible definition of adaptive control is a system that adapts itself to changes in the process. Another definition, that is often used but probably too vague to be useful, is a

system which is designed from an adaptive point of view. A more useful one is “a system that consists of a primary feedback that takes care of process signal variations and a secondary feedback that deals with process state changes. In this definition, the primary feedback is used as in non-adaptive control, and the secondary feedback makes the system adaptive. From this definition it is clear that process state variations give rise to adaptation of the system. The aim of reacting to state changes is to attempt to maintain a high system performance, even if the process states are unknown or varying. In the literature there exist several adaptive control techniques.

Model reference adaptive system is one of the most popular adaptive control method used in induction motor control applications for tracking and observing system parameters and states. The model reference adaptive system approach uses two models. The model that does not involve the quantity to be estimated is considered as the reference model or the voltage model. The model that has the quantity to be estimated involved is considered as the adaptive model or adjustable model or current model. The output of the adaptive model is compared with that of the reference model, and the difference (error) is used to drive a suitable adaptive mechanism whose output is the quantity to be estimated. This is used to adjust the adaptive model. This process continues till the error between two outputs tends to zero. The adaptive mechanism can be a proportional-integral controller, as used in this thesis, or any other tool such as neural networks, fuzzy logic control, or some other options. The adaptive mechanism should be designed to assure the stability of the control system. A successful model reference adaptive system design can yield the desired values with less computational error [10, 11]. Different approaches have been developed using model reference adaptive system, such as back e.m.f based model reference adaptive system, Reactive Power based Model Reference Adaptive System (RP-MRAS) and Rotor Flux based Model Reference Adaptive System (RF-MRAS). However, rotor flux

based model reference adaptive system is the most popularly used conventional speed estimation scheme for sensorless induction motor drives [12-15]. In the following a basic description of these schemes will be discussed with particular focus given to rotor flux based model reference adaptive system technique.

### **3.3.1 Rotor flux based MRAS**

The rotor flux based model reference adaptive system estimator was initially proposed by Schauder in 1989 as an improvement to the drawbacks incurred in the open loop estimator. In the rotor flux based model reference adaptive system speed estimator, the state variable used is the rotor flux. This scheme suffers from motor parameter sensitivity and flux pure integration which may cause DC drift and initial condition problems [10-15].

### **3.3.2 Back electromotive force based MRAS**

In this type of model reference adaptive system estimator, back electromotive force is used as output variables from reference and adaptive model rather than the rotor flux. The main advantage of this type of estimator is that no integration is used in reference model. Disadvantage is that voltage derivation must be computed, and behavior of back electromotive force based model reference adaptive system is nonlinear. Moreover, back electromotive force quantities vanish at low and zero speed. That causes problems with tuning system [10-15].

### **3.3.3 Reactive power based MRAS**

In this type of model reference adaptive system estimator, reactive power is used as output variables from reference and adaptive model rather than the rotor flux. The main advantage of this type of estimator is that no integration is used in reference model. However, this scheme exhibits an unstable nature at some operating conditions. Moreover, reactive power quantities vanish at low and zero speed [10-15].

### 3.4 RF-MRAS Modelling for Speed Estimation

The design of rotor flux based model reference adaptive system estimator for speed estimation of induction motor drive requires the definition of two models having similar outputs. One model, termed the reference model, should be independent of the rotor speed while the other the adaptive model is speed dependent. The schematic representation of rotor flux based model reference adaptive system is shown in Figure 3.1 [10-15].

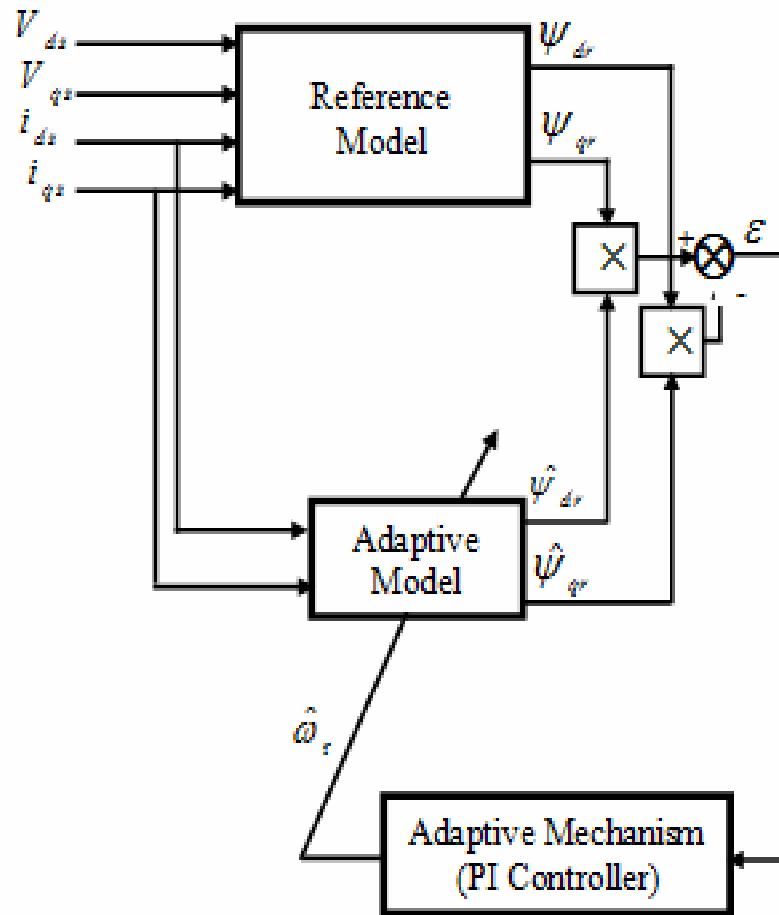


Figure 3.1: Block diagram of RF-MRAS

The reference model, usually expressed by the voltage model, represents the stator equation. It generates the reference value of the rotor flux components in the stationary reference frame from the monitored stator voltage and current components. The reference rotor flux components obtained from the reference model are given by [10-15]:

$$\begin{aligned}\frac{\psi_{dr}}{dt} &= \frac{L_r}{L_m} (v_{ds} - R_s i_{ds} - \sigma L_s \frac{di_{ds}}{dt}) \\ \frac{\psi_{qr}}{dt} &= \frac{L_r}{L_m} (v_{qs} - R_s i_{qs} - \sigma L_s \frac{di_{qs}}{dt})\end{aligned}\tag{3.1}$$

The adjustable model usually represented by the current model, describes the rotor equation where the rotor flux components are expressed in terms of stator current components and the rotor speed. The rotor flux components obtained from the adaptive model are given by [10-15]:

$$\begin{aligned}\frac{\hat{\psi}_{dr}}{dt} &= \frac{L_m}{T_r} i_{ds} - \frac{1}{T_r} \hat{\psi}_{dr} - \hat{\omega}_r \hat{\psi}_{qr} \\ \frac{\hat{\psi}_{qr}}{dt} &= \frac{L_m}{T_r} i_{qs} - \frac{1}{T_r} \hat{\psi}_{qr} - \hat{\omega}_r \hat{\psi}_{dr}\end{aligned}\tag{3.2}$$

Finally, the adaptation scheme generates the value of the estimated speed to be used in such a way as to minimize the error between the reference and estimated fluxes. In the rotor flux based model reference adaptive system estimator scheme, this is performed by defining a speed tuning signal ( $\varepsilon$ ) as the cross product between reference and adaptive model output vectors which can be written as [10-15]:

$$\varepsilon = \psi_{qr} \hat{\psi}_{dr} - \psi_{dr} \hat{\psi}_{qr}\tag{3.3}$$

This speed tuning signal is minimized by a PI controller which generates the estimated value of rotor speed as shown in Figure 3.1. Estimated rotor speed can be expressed as [10-15].

$$\hat{\omega}_r = (K_p + \frac{K_i}{p}) \varepsilon\tag{3.4}$$

Where  $k_p$  and  $k_i$  are the proportional and integral constants respectively of PI controller. The symbol “^” denotes the quantities estimated by the adaptive

model. The Figure 3.2 presents a general scheme of the structure applied in this thesis in order to estimate the speed of the induction motor [10-15].

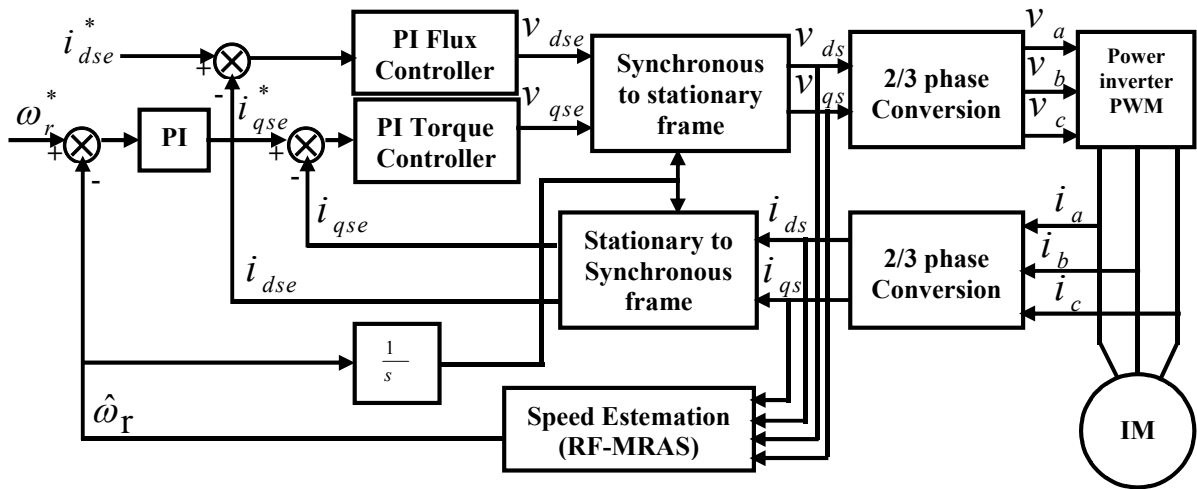


Figure 3.2: Speed sensorless block diagram of indirect vector controlled induction motor with RF-MRAS