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# A Review of Sensorless Control Methods for Induction Motor Drives

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## ABSTRACT

*Induction motors have become popular in the home appliance and industry due to their advantages over other motors. These motors require drives for control. The use of sensorless drive for induction motors is expanding due to its advantages. The advantages of sensorless motor drives include increased reliability, reduced hardware complexity, lower cost ,better noise immunity, and less maintenance requirements. With the advancement of industry and the development of modern industry, more efficient and advanced methods are required for sensorless control of induction motors. In this paper, sensorless control methods for induction motors are introduced and their operation and performance in different modes are investigated. The advantages and superiority of each method over other methods are examined and the simulation forms of the new model reference adaptive system (MRAS) and Classical rotor flux MRAS speed observer methods are given and these two methods are compared with other methods.*

**KEYWORDS:** Induction motor drives, Sensorless control, High speed operation, Model reference adaptive system

## 1. INTRODUCTION

In induction motor drive systems with high dynamic performance, space vector control is mostly used, where accurate rotor position and speed is needed. To do this requires an accurate mechanical position sensor and the complexity of the system and reduce its reliability. Therefore, the study is performed on the drive of induction motors to remove the sensors. In this paper, flow and velocity estimation methods for induction motor (IM) are first introduced and Kalman filter methods and model reference adaptive system (MRAS) (MRAS) are investigated. The advantages and disadvantages of these methods over each are carefully considered. In addition, field damping control methods have been investigated. At last, special current loop control methods are discussed. .Rotor speed estimation method using MRAS is proposed to improve the performance of a sensorless vector control in the very low and zero speed regions. In the classical MRAS method, the rotor flux of the adaptive model is compared with that of the reference model. The rotor speed is estimated from the fluxes 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, but in the new MRAS method, two differences are used at the same time.

The first difference is between the rotor fluxes and the second difference is between the electromagnetic torques. The adaptive mechanism used in this new structure contains two parallel loops having Proportional-integral controller and low-pass filter.

The first and the second loops are used to adjust the rotor flux and electromagnetic torque. To ensure good performance, a robust vector control using sliding mode control is proposed. Simulation and experimental results show the effectiveness of the proposed speed estimation method at low and zero speed regions, and good robustness with respect to parameter variations, measurement errors, and noise is obtained.

## 2.SENSORLESS CONTROL METHODS FOR IM [1]

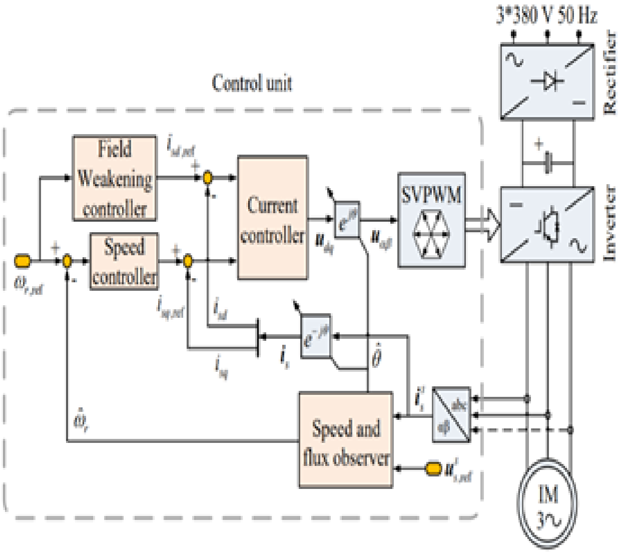

Fig.1. Block diagram of typical IM vector control system.

Figure.1 shows a block diagram of a vector motor control system of a typical IM.

The control system includes:

1- control unit
2-rectifier
3-inverter unit
4- squirrel-cage IM

Vector-oriented control of the rotor flux is applied as the main control strategy. The dual closed-loop structure is used, including current inner loop and speed outer loop. The flux and speed observer is used to estimate the motor speed and rotor flux angle. The three-phase alternating current is rectified to the DC direct current and then the direct current is reversed to the three-phase alternating current to drive the IM. This section focuses on the process of vector control-based for IM drives.

### A. Flux and Speed Estimation

the advantages of the sensorless drive system include: low cost driving system, less integrated parts of the system, small size, high reliability, and convenient maintenance. The disadvantages mainly include low load. A review of sensorless control methods for AC motor drives, low speed accuracy and low speed range generation instability.

General methods for flux and the speed observer of a sensorless system for induction motors are:

1-High frequency signal injection method
2-Low frequency signal injection method
3-Full order flux observer
4-Model reference adaptive system
5- Reduced order observer
6- sliding mode observer
7- neural network
8- Kalman filter

According to the characteristics of each method, the above can be divided into two categories:

### I. Signal injection-based flux and speed observer:

By injecting signal, this kind of method uses rotor slot harmonic, saturated, and the leakage inductance to extract the rotor position information. It can guarantee the stability of IM operation at zero stator current frequency. There are two methods for injecting a high frequency signal. In the first method after injection, the sampling the stator current, the low frequency component is extracted as the current feedback loop and the high frequency response component is extracted to obtain the rotor position.

the second kind of current injection method is to extract the high frequency component command voltage to calculate rotor position information. This method can be unlike the previous method guarantee a high bandwidth for speed loop, but it need complex signal processing method to overcome the effect of inverter nonlinear error. The high frequency signal injected based method can guarantee the sensorless IM running steadily under 150% rated load at zero speed or even zero current frequency. However due to the weak rotor anisotropy, the IM needs to be specially designed to extract the correct rotor position from the feedback current information, so this kind of method highly depends on the motor design.

There is a low frequency current signal injected based vector control method for sensorless IM control which a low frequency, current signal is injected into the device then the rotor position can be extracted from the current back EMF. Compared with high frequency signal injection based method, low frequency signal injection based method can guarantee the motor 150% output of the rated torque for a long time at zero speed and zero frequency without obvious anisotropy of magnetic field. The injected signal amplitude is larger than that of injected high frequency signal, and the torque ripple is more obvious. At the same time, the motor need to be special designed, so the low frequency signal injection based method has not yet widely used.

All methods above can guarantee stable operation of sensorless IM control system for a long time at zero frequency and zero speed. But this kind of methods for IM need obvious anisotropy of magnetic field, strongly rely on the motor design,and some problems such as torque ripple and noise make it hard to be widely used in industry.

## II. IM model-based flux and speed observer:

The mathematical model of the induction motor is considered first, then the rotor flux and rotor speed is estimated.

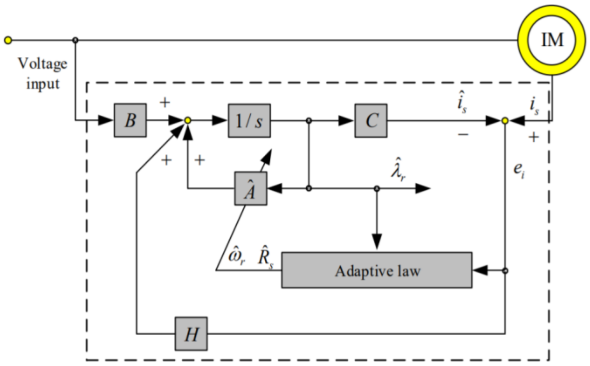

Fig.2. Block diagram of full order observer

Figure.2 shows the block diagram of full order flux observer. There is an observer equation that can be used to unify all the current observer into a form. This method could effectively take advantage of the voltage model in high speed and the current model in low speed to avoid the drawbacks of voltage model and current model and improve the flux observation accuracy, realize the smooth transition of the voltage model and current model. However, there was no attention on low speed generation and observer parameters robustness of sensorless IM. In addition, since this method was a model-based method, it cannot be carried on stable operation for a long time when the stator current frequency is zero. A sliding mode observer for rotor flux observation was presented where in the motor voltage equations and current equation were used to build up the full order sliding mode observer. The observer does not include the rotation speed variable, so the observer is not affected by the estimated speed error with strong robustness.

Based on MRAS system, replaced the traditional proportional-integral (PI) modulator by sliding mode adaptive method to estimate the speed. The improved speed adaptive law had strong anti-interference ability. Therefore, 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. Then the Kalman filter method was presented. Kalman Filter is a special type of observer that provides filtering of noises in measurement if covariance of the noises is known [2].

Then the extended Kalman filter (EKF) was introduced. The EKF offers a transient response as well as a better steady state. However, the level of accuracy is very high at higher speeds where noise can be accurately detected. EKF can also eliminate static error and compensate for any time-limited changes in load torque. In EKF, the rotor speed acts as a mode as well as a parameter. Due to the high complexity, computing time is long and difficult to apply in real time, especially faster speed changes. Despite its high complexity, EKF performs online estimation in a very short period of time.

Firstly, a flux observer and a robust coefficient are designed to optimize the Kalman filter, which makes the system more immune to the variation of motor parameters.Then, a speed estimation adaptive law is designed according to the least square principle. Kalman filter-based speed and flux observation have strong robustness to motor parameters because the error of the motor parameters was considered at the beginning.

In conclusion, strongly relying on motor design, the signal injection-based method has not been widely used yet. The researches on sensorless vector control method for IM mainly focus on stable operation at zero speed and zero frequency to improve the control performance and enlarge the sensorless vector control of IM in the field of industrial applications.

The MRAS approach uses two models. [3]

The model that does not involve the quantity to be estimated (the rotor speed) is considered as the reference model. The model that has the quantity to be estimated involved is considered as the adaptive model (or adjustable model). The outputs obtained with the two models are compared, and the difference is used to derive a suitable adaptive mechanism whose output is the quantity to be estimated (rotor speed in our case). The adaptive mechanism should be designed to ensure the stability of the controlled system.

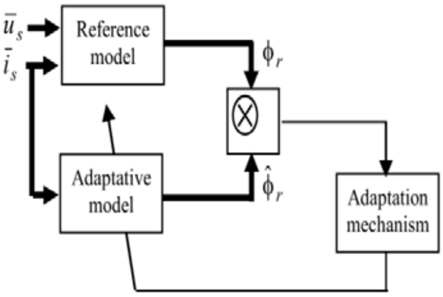

Fig. 3. Classical rotor flux MRAS speed observer.

However, the main problem of the classical MRAS observer is its poor estimation at low speeds. That is why we present a new MRAS speed observer . In the new MRAS method, two differences are used on the same time. The first is between rotor fluxes, and the second is between electromagnetic torques.

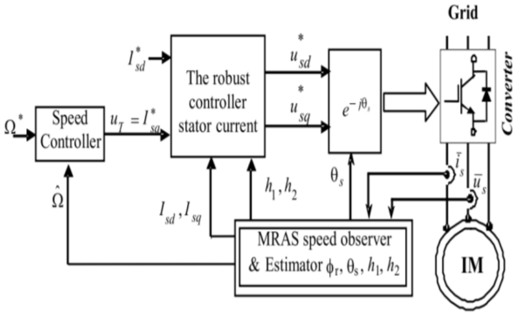

Fig.4. Block diagram of sensorless field-oriented control system.

Based on the same principle, a variation in the estimated torque results in a variation of the estimated speed until the estimated torque becomes equal to the electromagnetic torque.

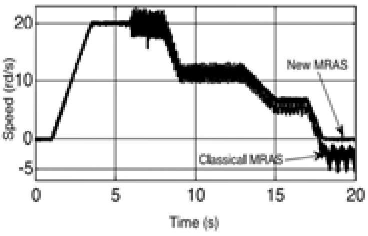

Fig. 5. Classical MRAS observer: Reference, actual, and estimated speed for load torque and Rs variations.

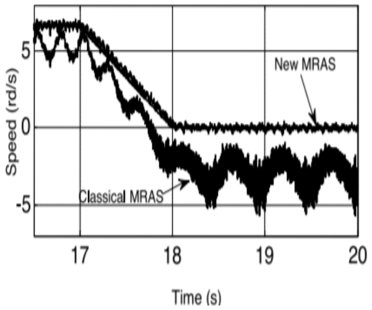

Fig. 6. Classical MRAS observer: Zoom of Reference, actual, and estimated [5]

The neural network-based model reference controller(NNMRC) consists of two neural networks, namely, the neural network identifier and the neural network controller. The identifier is a three-layer neural network that uses a back-propagation algorithm to identify the motor model. The second network is also a three-layer that uses a backpropagation algorithm to control the induction motor speed to track a reference stable second order system.

This scheme is applied for both scalar and field-oriented control of induction motor. Figure 7 shows the block diagram of the proposed NNMRC.

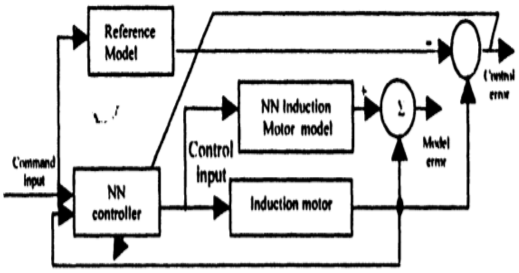

Fig 7 block diagram of the proposed model refrence neural

Structure of the neural network identifier for field-oriented control of induction motor is selected to have four input neurons (direct and quadrature stator voltages and direct and quadrature stator currents) and one output neuron (motor speed) and thirty hidden neurons with pure linear and sigmoid activation functions at the hidden and the output layers respectively.

The field-oriented neural network identifier takes 20,000 iterations to learn the dynamics of a training set of data (obtained from the motor) with sum of square error equal $10^{-6}$.

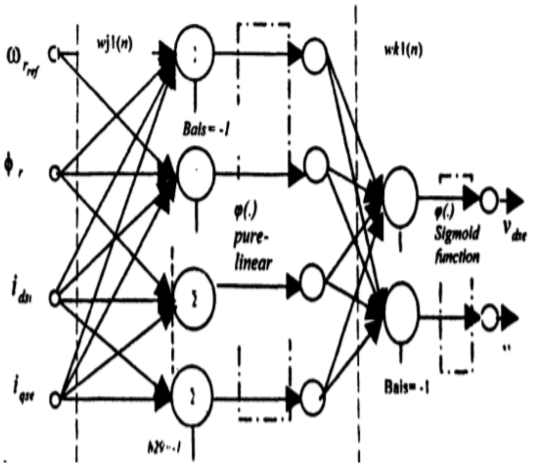

Fig .8 stracture of the neural network controller for field oriented control

### B. Field-Weakening Control Strategy

for high-speed driving requirements, it is necessary to carry out in-depth analysis and research on the field-weakening control strategy of IM. When the IM runs above the base speed, inverter output voltage will not be able to offset the motor back electromotive force (EMF). At this point,we need to reduce the back EMF by reducing motor magnetic field, so that the motor could have a further acceleration ability.At the same time, in order to ensure that the motor has a quick start-stop capability, it is expected to have the maximum torque output capability during the filed-weakening acceleration.

A large number of field-weakening control methods are proposed, and the starting points are consistent, namely the reasonable distribution of excitation current and torque current in field-weakening region to obtain the maximum torque output capacity. The main methods can be divided into two categories:

1- the method of open-loop calculation of the motor model

2- the method based on the voltage limit closed-loop regulation

### C. Current Loop Control Strategy

In the double closed-loop vector control system of IM, the current loop acts as the inner loop of the control system which plays a key role in the overall system performance. [1]

The fast response current loop not only speeds up the current convergence but also guarantees the bandwidth enhancement of the speed loop, which is of great significance for applications such as CNC machine tools and high-speed drilling machines that require high dynamic performance. To this end, theacademic community has proposed a variety of current loop control strategies as follows:

(1) Hysteresis control

(2) PI control in the stationary frame

(3) PI control in the synchronous rotating frame

(4) Predictive control

## 3. CONCLUSIONS

This paper introduced the state-of-art of recent progress in position/speed sensorless control and presented the position/speed sensorless control strategies for IM. For sensorless IM drives at low- and zero-speed operation,inverter nonlinearity and motor parameter deviation due to loads have the most significant impact on the stability of control system. This paper gives several approaches to solve these problems for robust low-speed sensorless IM control. In addition, to achieve maximum torque capacity in high-speed region, a robust field-weakening control strategy which can regulate the field current and the clamp of torque current is presented.

In The two methods introduced for high frequency signal injection in this paper, the second method, unlike the first method, guarantees high bandwidth for the speed loop, but requires a complex signal processing method to overcome the inverter error of the inverter.

The high frequency signal injection method can ensure that the sensorless IM operates continuously under 150% of the rated load at zero speed or even zero current frequency.However, due to the poor anisotropy of the rotor, the IM must be specially designed to extract the correct position of the rotor from the feedback flow information, so this type of method depends very much on the design of the motor.Low frequency current signal based vector control method Compared to high frequency signal based method, low frequency signal injection method can deliver motor output of 150% of rated torque for a long time at zero speed and zero frequency without obvious field anisotropy Guarantee magnetism.

Flow and velocity observation based on Kalman filter has high strength compared to motor parameters because the error of motor parameters was initially considered and The extended Kalman filter (EKF) offers a transient response as well as a better steady state. However, the level of accuracy is very high at higher speeds where noise can be accurately detected. The main problem with the classic MRAS observer is its poor estimation at low speeds. This problem has been solved in the new MRAS speed observer.

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