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A Review of Methods for Controlling Induction Electric Actuators

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Abstracr

Electic motors are controlled according to different aspects depending on the specific applications they have in different systems. Start-up, speed control, position control and braking are the control aspects of an electric motor, for which a control method is considered depending on the intended application. A three-phase induction motor is essentially a constant speed motor. However, due to changes the mechanical load, changes in rotor rotation speed are inevitable. Therefore, it is somewhat difficult to control its speed. Induction motor speed control is accomplished at the cost of reduced efficiency and low power factor. In this paper, all methods of speed control of induction motors are examined in detail. By examining conventional methods, their advantages and disadvantages are reviewed.

Keywoeds: Induction motor, frequency control, Speed control

1. INTRODUCTION

Nowaday, induction motors provide a significant percentage of the mechanical driving force of industries [1]. The reason for this is the low price comparison to the production capacity of this type of motor compared to other common motors such as dc or synchronous motors. Other advantages of induction motors compared to dc or synchronous motors are their smooth operation and low service life, as well as their low service and maintenance requirements [2]. Induction motors are preferably three-phase and are in fact a significant percentage of the motors used in the three-phase industry. However, a significant number of induction motors are still built in single-phase and are used in areas that are not accessible to the three-phase network.

Nevertheless a three-phase induction motor is essentially a constant speed motor [3], and its speed control has several problems. In adittion, by controlling the induction motor speed, reducing productivity and power factor is inevitable. Moreover today, with the advancement of electronic power technologies and control systems, numerous and advanced methods have been introduced for optimal control and proper operation of electric machines [4]. As a result, in recent decades, there have been great changes in the industry, and it has brought many benefits to people's lives. In this paper, the speed control methods of induction motors, as well as the advantages and disadvantages of each method are examined.

2. INDUCTION MOTOR SPPEED

Before discussing the speed control of a three-phase induction motor, the formula of Speed- torque of the induction motor should be considered, because speed control methods depend on these formulas.

The formula for synchronous speed is as follows:

$$N_s = \frac{120f}{P} \quad (1)$$

Where f is the frequency and P is the number of poles. The speed of the induction motor is expressed as follows:

$$N = N_s(1 - s) \quad (2)$$

Where, N is the speed of the induction motor rotor, Ns is the synchronous speed and S is the slip. Engine output torque is also equal to:

$$T = \frac{3}{2\pi N_s} X \frac{sE_2^2 R_2}{R_2^2 + (sX_2)^2} \quad (3)$$

When the engine slips so much that the engine stops, s is equal to 1. In this case, the torque is equal to:

$$T = \frac{3}{2\pi N_s} X \frac{E_2^2 R_2}{R_2^2 + X_2^2} \quad (4)$$

Where E_2 is the amount of electrical driving force (EMF) of the rotor, Ns is the synchronous velocity, R_2 is the rotor resistance and X_2 is the inductive reactance of the rotor.

3. Methods of Controlling the Speed of Induction Motors

Induction motor speed can be done through both stator and rotor.

3.1 Methods of controlling the speed of induction motors with stator

The speed of the stator can be controlled by the following methods:

- •V / f control or frequency control
- •Power supply voltage control
- •Change the number of stator poles
- •Add rheostat to stator circuit

3.1.1 V / f control or frequency control

When a three-phase power supply feeds the induction motor, a rotating magnetic field is generated that rotates at a synchronous speed: Fig.1 shows the induction machine torque-speed curves.

$$N_s = \frac{120f}{P} \quad (5)$$

In a three-phase induction motor, the inductive driving force, similar to that of a transformer, is expressed by the following relation:

$$V = 4.44\emptyset K.T.f \quad (6)$$

Or

$$\emptyset = \frac{V}{4.44KTf} \quad (7)$$

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

Now if we change the frequency, the synchronous speed changes. However, as the frequency decreases, the flux increases, and this change in the amount of flux causes the rotor and stator cores to saturate, which in turn increases the idle current of the motor. Therefore, it is necessary to keep the $\emptyset$ constant. In this case, we have to change the voltage along with changing the frequency. Thus, if we reduce the frequency, the flux increases, Furthermore if we reduce the voltage at the same time, the flux decreases, and thus the flux does not change and remains constant. As a result, we have to keep the V / f ratio constant. That's why this method is called V / f. To control the speed of the three-phase induction motor by the V / f method, we must change the voltage and frequency of the supply. This can be done easily and using a set of converters and inverters [5]. Figure 2 show the diagram of basic IPM synchronous motor drive using stationary current regulators. Asterisks designate commanded values.

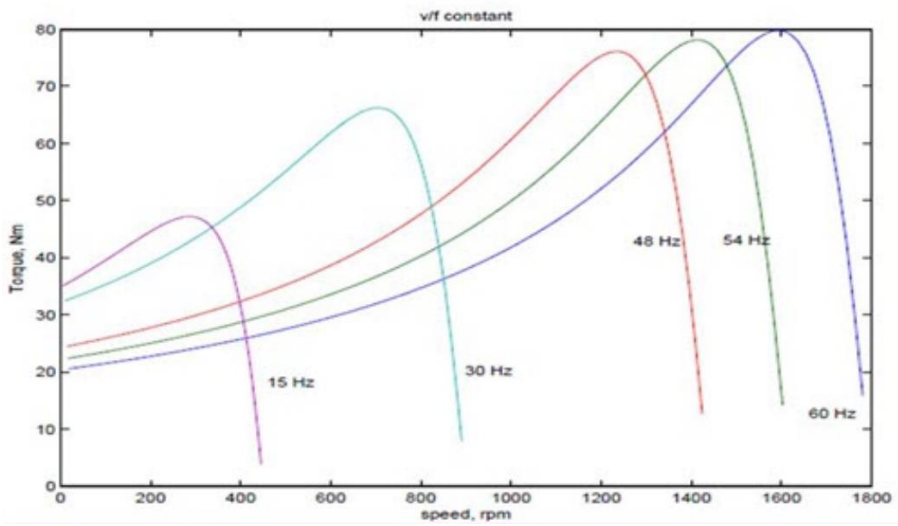

Fig.1 .The induction machine torque-speed curve

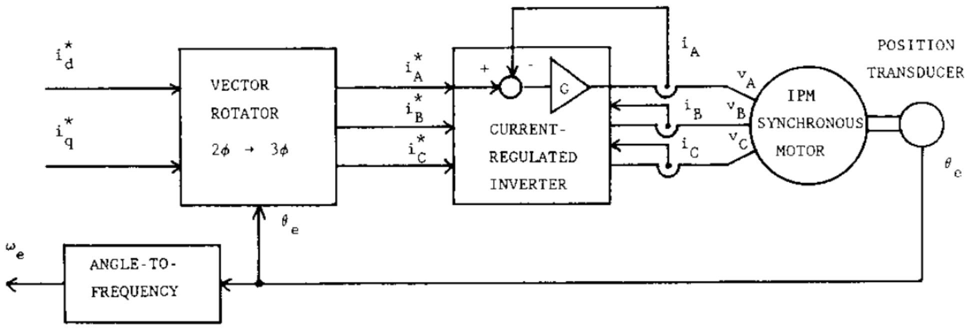

Fig.2 . Diagram of basic IPM synchronous motor drive using stationary current regulators.

3.1.2 Power supply voltage control

The speed control of a three-phase induction motor is achieved by changing the voltage control of the power supply (stator voltage) until the required torque of the load is generated at the desired speed. The torque generated by the induction motor is directly proportional to the square of the supply voltage and the current proportional to the voltage. The output torque of a three-phase induction motor is as follows:

$$T \propto \frac{sE_2^2R_2}{R_2^2+(sX_2)^2} \qquad (8)$$

In the low slip region, the expression sX_2 is very small compared to R_2. So we can ignore it and write the torque as follows:

$$T \propto \frac{sE_2^2}{R_2} \qquad (9)$$

Since the resistance R_2 of the rotor is constant, the torque equation can be written as follows:

$$T \propto sE_2^2 \qquad (10)$$

We know that $E_2 \propto V$, therefore $T \propto sV_2$.
It is clear from the latter equation that if we reduce the supply voltage, the torque will also decrease. But to feed the same load, we have to keep the torque constant. In this case, we can only increase the slip, and if we do, the engine will run at a slower speed. This method of speed control is rarely used, because a small change in speed requires a large reduction in voltage, and as a result, the current drawn by the motor increases and causes it to heat up [6]. Fig 3 shows the speed control of three phase induction motors by changing the supply voltage.

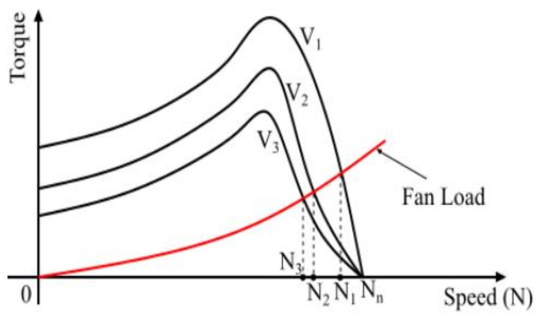

Fig. 3. The speed control of three phase induction motors by changing the supply voltage

3.1.3 Change the number of stator poles

The number of poles of the machine can be changed with changes in coil connections. The number of poles can be changed in a ratio of two to one. However, as the number of poles increases, the rotation speed of the rotor decreases accordingly. Fig. 4. Shows the speed control of three phase induction motors by changing the number of stator poles [7].

The number of stator poles can be changed in two ways.

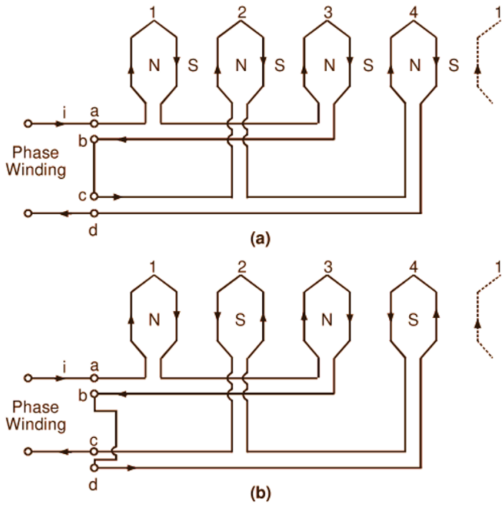

Fig. 4. The speed control of three phase induction motors by changing the number of stator poles

3.1.3.1 Multiple stator winding method

In this method, there are two separate windings in the stator. The two coils are electrically insulated from each other and are made for two different poles. Using a switching arrangement, the source feeds only one of the coils at a time, making speed control possible. One of the disadvantages of this method is the impossibility of soft speed control and that it has a high cost and low productivity, because it uses two windings. This speed control method can only be applied to the squirrel cage motor.

3.1.3.2 Pole amplitude modulation (PAM) method

In this method, the original sinusoidal magnetic drive (mmf) wave is modulated with another sinusoidal mmf wave, which has a different number of poles [8]. Suppose $f_1(\theta)$ is the main mmf wave of the induction motor that we must control its speed. Consider $f_2(\theta)$ as the modulation mmf wave.

Also, P_1 is the number of induction motor poles and P_2 is the number of modulation wave poles. We have the following relationships:

$$f_1(\theta) = F_1 \sin\frac{P_1\theta}{2} \qquad (11)$$

$$f_2(\theta) = F_2 \sin\frac{P_2\theta}{2} \qquad (12)$$

After modulation, the mmf wave will be as follows:

$$F_r(\theta) = F_1F_2 \sin\frac{P_1\theta}{2}\sin\frac{P_2\theta}{2} \qquad (13)$$

We get help from the following formula:

$$2\sin A \sin B = \cos\frac{A-B}{2} - \cos\frac{A+B}{2} \qquad (14)$$

As a result, we have:

$$F_r(\theta) = F_1F_2\frac{\cos\frac{(P_1-P_2)\theta}{2} - \cos\frac{(P_1+P_2)\theta}{2}}{2} \qquad (15)$$

Therefore, the mmf shape has two different polar values $P_{11} = P_1 - P_2$ and $P_{12} = P_1 + P_2$. As a result, by changing the number of poles, we can easily change the engine speed.

3.1.4 Add rheostat to stator circuit

In this method, a rheostat is added to the stator circuit, resulting in a voltage drop. As we know, the $T \propto sV_{22}$ relationship is established in a three-phase induction motor. Therefore, if we reduce the source voltage, the torque also decreases. But to feed the same load once, the torque must remain constant, and this is only possible if we increase the slip. Increased slip also reduces speed [9]. Fig. 5 shows the speed control of three phase induction motors by add rheostat to stator circuit.

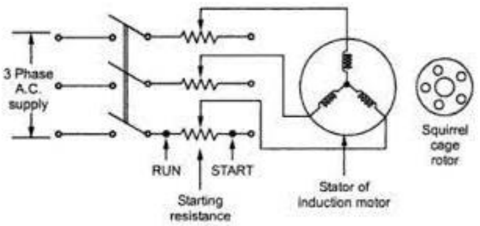

Fig. 5. The speed control of three phase induction motors by add rheostat to stator circuit

Now, we look at the speed control methods on the rotor side.

3.2. Methods of controlling the speed of induction motors with rotor

The speed control of the three-phase induction motor from the rotor side can also be done by the following methods:

- •Add external resistance to the rotor
- •Cascade control method
- •Injection of electric driving force of slip frequency towards the rotor

3.2.1. Add external resistance to the rotor

In this method, external resistance is added to the rotor. The torque equation of a three-phase induction motor is as follows:

$$T \propto \frac{sE_2^2R_2}{R_2^2+(sX_2)^2} \quad (16)$$

The three-phase induction motor operates in the low-slip region. In this region, $(sX)^2$ is very small relative to R_2 and can be ignored. E_2 is also constant. The torque equation after simplification will be as follows:

$$T \propto \frac{s}{R_2} \quad (17)$$

Suppose Ns_1 is the synchronous speed of the main motor, Ns_2 is the synchronous speed of the auxiliary motor, P_1 is the number of poles of the main motor, P_2 is the number of poles of the auxiliary motor, F is the source frequency, F_1 is the induction emf frequency of the main motor rotor and N is the set speed of the two motors. Slide S_1 main engine is equal to:

Now if we increase the resistance R_2 of the rotor, the torque decreases. But to feed the same load, we have to keep it constant. Therefore, we increase the slip, as a result of which, the speed decreases. As a result, by adding external resistance to the rotor circuit, the speed of the three-phase induction motor can be reduced. The main advantage of this method is that by adding resistance to the rotor circuit, the starting torque increases [10]. Morever this method also has disadvantages, which include:

Speed higher than the nominal value is not possible.

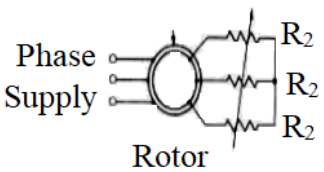

Fig. 6. adding resistances to rotor circuit

Large changes in speed require large resistances, and if a large amount of resistance is added to the circuit, it will cause large losses and thus reduce efficiency.

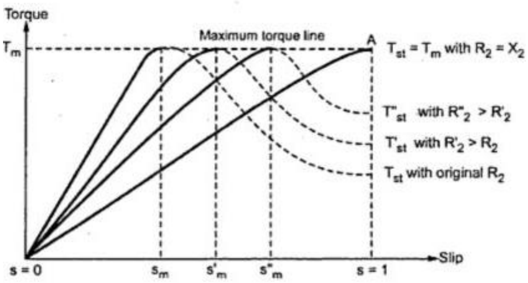

Fig. 7. The speed control of three phase induction motors by add resistances to rotor circuit

Existence of resistance causes more losses.

This method cannot be applied to squirrel cage motors.

3.2.2. Cascade control method

In this method, two three-phase induction motors are connected to a common shaft, and for this reason, this method is called cascade control. One is the main engine and the other is the auxiliary. A three-phase source is applied to the main motor stator, while the auxiliary motor slip frequency is determined by the main motor slip ring [11].

Suppose Ns_1 is the synchronous speed of the main motor, Ns_2 is the synchronous speed of the auxiliary motor, P_1 is the number of poles of the main motor, P_1 is the number of poles of the auxiliary motor, F is the source frequency, F_1 is the induction emf frequency of the main motor rotor and N is the set speed of the two motors. Slide S_1 main engine is equal to:

$$S_1 = \frac{N_{S1}-N}{N_{S1}} \quad (18)$$

$$F_1 = S_1 F \quad (19)$$

The auxiliary motor is fed at the same frequency as the main motor. That's mean:

$$F_1 = F_2 \quad (20)$$

$$N_{S2} = \frac{120F_2}{P_2} = \frac{120F_1}{P_2} \quad (21)$$

$$N_{S2} = \frac{120S_1F}{P_2} \quad (22)$$

We now place the value

$$N_{S2} = \frac{N_{S1}-N}{N_{S1}} \quad (23)$$

in the recent formula. Therefore, we have:

$$N_{S2} = \frac{120F(N_{S1}-N)}{P_2N_{S1}} \quad (24)$$

In idle mode, the speed of the auxiliary motor is equal to the synchronous speed, ie $N = N_{S2}$:

$$N = \frac{120F(N_{S1}-N)}{P_2N_{S1}} \quad (25)$$

With a few simple mathematical operations on the latter equation, the value of N can be obtained:

$$N = \frac{120F}{P_1-P_2} \quad (26)$$

This cascading combination of two motors will have a new speed with the number of poles $(P_1 + P_2)$. In this method, the torque of the main motor and the auxiliary motor is in the same direction, and this type of cascade connection is called retractable. There is another type of cascade connection in which the torque produced by the main motor is opposite to the direction of the auxiliary motor torque. This type of cascade connection is called subtraction. In this case, the velocity corresponds to the number of poles $P_1 - P_2$. In this method of controlling the speed of three-phase induction motors, four different speeds are obtained:

When only the main engine is running, the speed is equal to:

$$N_{S1} = \frac{120F}{P_1} \quad (27)$$

When only the auxiliary motor is running, the speed is equal to

$$N_{S2} = \frac{120F}{P_2} \quad (28)$$

When the connection of two motors is in a collapsible cascade, the set speed is equal to

$$N = \frac{120F}{(P_1+P_2)} \quad (29)$$

When the connection of two motors is cascading, the set speed is equal to

$$N = \frac{120F}{(P_1-P_2)} \quad (30)$$

Fig 8. shows the speed control of three phase induction motors by cascade control method.

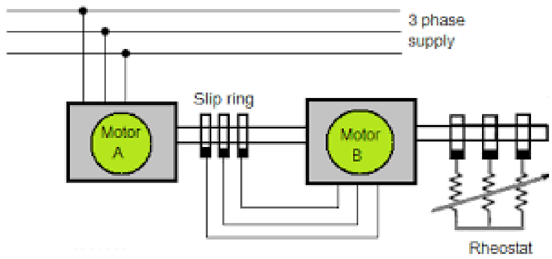

Fig. 8. The speed control of three phase induction motors by cascade control method

3.2.3. Injection of electric driving force of slip frequency towards the rotor

When the speed of a three-phase induction motor is controlled by adding resistance to the rotor circuit, a portion of the power, called the slip power, is lost by the formula RI^2. Therefore, the efficiency of the three-phase induction motor is reduced in this method [12]. These slip losses can be compensated for and overall efficiency improved. This method is called slip power recovery and by connecting an external emf source, the slip frequency in the circuit is done.

The injected electrical driving force can counteract or aid the rotor induced emf. If it opposes the induced emf of the rotor, the total resistance of the rotor increases and consequently the speed decreases. If the injected emf contributes to the induced emf of the rotor, the total resistance of the rotor decreases and the speed increases.

The main advantage of this speed control method is that a wide range of different speeds (above the nominal value and below it) can be controlled. Fig 9. Shows the speed control vector diagram of induction motors by injection of electric driving force of slip frequency towards the rotor

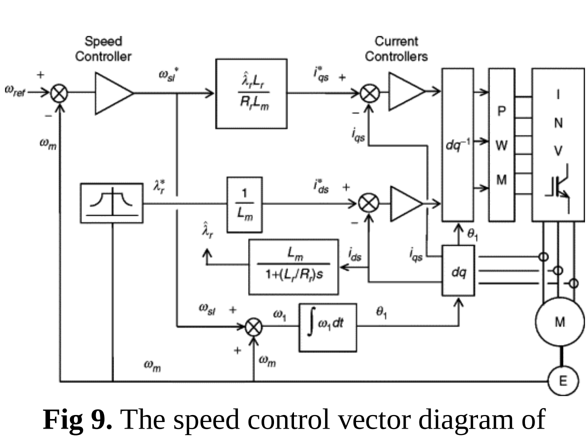

Fig 9. The speed control vector diagram of induction motors by injection of electric driving force of slip frequency towards the rotor

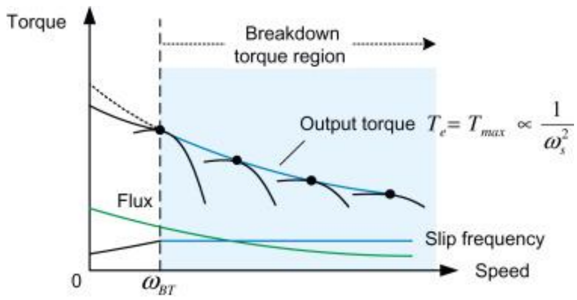

Fig. 10. The speed control of three phase induction motors by injection of electric driving force of slip frequency towards the rotor

4. Conclusion

This paper provides an review of speed and torque control of induction motors. The induction motor is one of the most widely used electrical actuators in the industry due to its simple structure and very low maintenance costs, it can be said that speed and torque control are an integral part of induction motors and must be carefully Examined. speed and torque control is so important for sensitive industrial loads, the engine speed and torque must be constantly monitored. In addition, in some cases, the speed and torque must be compared separately depending on the situation. In this article, an review of induction motor and speed and torque control methods and the advantages and disadvantages of control methods were discussed.

Refrences

[1] P. K. Ghosha, P. K. Sadhua, R. Basakb, and A. Sanyal, "Energy efficient design of three phase induction motor by water cycle algorithm, Ain Shams Engineering Journal Vol. 11, No 4, Pages 1139-1147, 2020,

[2] O. Dobzhanskyi, E. Amiri, and Rupert Gouws, "Comparison analysis of electric motors with two degrees of mechanical freedom: PM synchronous motor vs induction motor" International Young Scientists Forum on Applied Physics and Engineering Conference (YSF), indexed in IEEE, 2016

[3] T. Latif, and I. Husain, "Design and analysis of an induction motor for an enhanced constant

power region with electronic pole changing" IEEE International Electric Machines & Drives Conference (IEMDC), 2021

[4] H.K. Sarkar, and H.K. Nigam "Technological advancements in medium and high voltage motors" World Pumps Scince Direct Journal Vol. 3, No. 439, Pages 24-27, 2003

[5] Jin-Woo Lee, "Novel Current Control Assisted V/F Control Method for High Speed Induction Motor Drives" 10th International Conferance IEEE, 2019.

[6] Tian, Xiuhe Wang; Daohan Wang, Wenliang Zhao, and Chang Li, "A Novel Line-Start Permanent Magnet Synchronous Motor with 6/8 Pole Changing Stator Winding" IEEE Transactions on Energy Conversion Vol. 33 No. 3, 2018.

[7] A. Derdiyok, "Speed-sensorless control of induction motor using a continuous control approach of sliding-mode and flux observer," IEEE Transactions on Industrial Vol. 52, No. 4, 2005.

[8] A. Moraveji, A. Siadatan, E. Afjei, M. Rafiee, and E. Zarei Ali Abadi, "DSP sensorless controller of Switched Reluctance Motor-Generator approaching to AM modulation" 2012 4th International Conference on Intelligent and Advanced Systems (ICIAS2012) indexed in IEEE, 2012.

[9] Marouane Rayyam, Malika Zazi, Youssef Hajji, and Ihssane Chtouki, "Stator and rotor faults detection in Induction Motor (IM) using the Extended Kaman Filter (EKF)" International Conference on Electrical and Information Technologies (ICEIT), indexed in IEEE, 2016.

[10] M. Ikeda, and T. Hiyama, "Simulation Studies of the Transients of Squirrel-Cage Induction Motors" IEEE Transactions on Energy Conversion, Vol. 22, No. 2, 2007.

[11] Naga Surya Prakash Musunuru;Srinivas Srirama, "Cascaded Predictive Control of a Single Power Supply-Driven Four-Level Open-End Winding Induction Motor Drive Without Weighting Factors" IEEE Journal of Emerging and Selected Topics in Power Electronics, Vol. 9, No. 3, 2021.

[12] Tong Wang, Jin Huang, Ming Ye, Jiahao Chen, Wubin Kong, Min Kang, and Mingfei Yu, "An EMF Observer for PMSM Sensorless Drives Adaptive to Stator Resistance and Rotor Flux Linkage" IEEE Journal of Emerging and Selected Topics in Power Electronics, Vol. 7,No. 3, 2019.