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Optimization of Induction Motor Efficiency Based on Online Parameter Estimation

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***Abstract*—The induction motor (IM), especially the squirrel-cage type, is widely used in electrical drives and is most frequently used in high performance drive applications. Control schemes of such drives require accurate values of motor parameters but the stator and rotor resistance vary due to motor temperature variation. The problems of estimating the parameters and states of a motor have been attacked from a variety of different perspectives. Since the resistance varies linearly with the temperature this paper presents an easy method to calculate the dynamic winding resistance by online detecting the winding temperature so that the motor efficiency is optimized.**

Keywords— Induction motor, online parameter identification, Field oriented control

I. INTRODUCTION

There has been a growing global concern over energy consumption and high energy efficiency has become one of the most important factors in development of the products that consume electrical energy. The utility of induction motors are more than 50% of the total electric energy generated worldwide. A small improvement in efficiency would significantly save the total electric energy. Hence, it is important to optimize the efficiency of motor drive systems if significant energy savings are to be obtained[2]. The induction motor (IM), the squirrel-cage type, is widely used in high performance drive applications.

Field oriented (or vector) control is the most popular ac machine control method that is widely used in high performance industrial applications of electric drives. However, the control effect of all kinds of indirect vector control method deeply depends on whether the motor parameters are accurate or not but the stator and rotor resistance vary due to motor temperature variation[1]. The problems of estimating the parameters and states of a motor have been attacked from a variety of different perspectives. A variety of on-line and off-line methods have been proposed for determining the speed of an induction motor rotor. Since any vector controlled induction motor drive is inverter fed, numerous tests based on an inverter supply have been developed in recent past for determination of the required parameter values. Such methods are further on called “offline parameter identification methods[3].” In addition, numerous possibilities exist nowadays to update the parameter values during the drive operation. The techniques that enable parameter adaptation during the drive operation are further on termed “online parameter estimation methods.”

This paper presents design and implements a voltage source inverter type space vector pulse width modulation (SVPWM) for controlling the stator voltage of IM. The basic block diagram is as shown in fig.1.

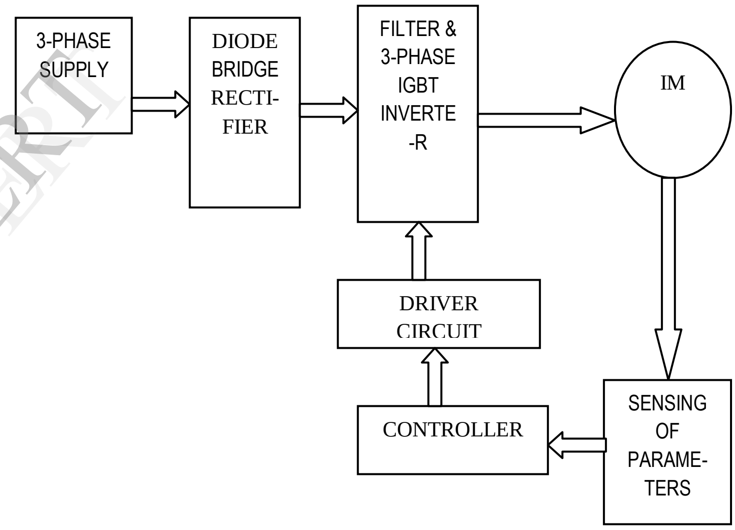

Fig. 1 Basic block diagram

One of the main drawback with IM representation is the unavailability of parameter values to construct accurate models. This is one of the reasons motors are not usually explicitly represented in system studies[5]. The issue of IM parameter estimation has been addressed by several researchers. In many of these cases high accuracy is required in the parameter determination, when the problem is viewed from the machine point of view. Hence, good online parameter identification methods are necessary. Therefore, this paper presents a method, which is accurate, simple and realization is easy[1].

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II. PARAMETERS OF IM UNDER TRANSIENT CONDITIONS

The equivalent circuit of IM is as shown in fig.2, which represents the physical model of motor[4]. The parameters are leakage reactance x_1, leakage resistance R_s, rotor leakage resistance and reactance R_r and jx_2, excitation reactance x_m and equivalent load resistance $R_r(1-s)/s$.

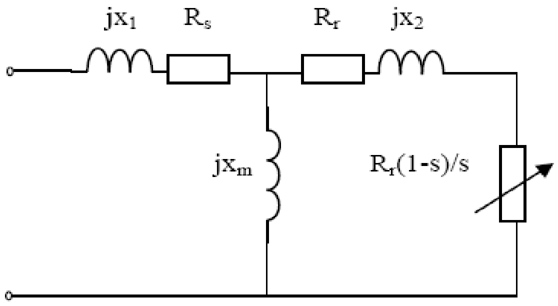

Fig. 2 Equivalent circuit of IM

T-1 type steady state equivalent circuit is as shown in fig. 3 is used for vector control is obtained from the equivalent circuit shown in fig 2.

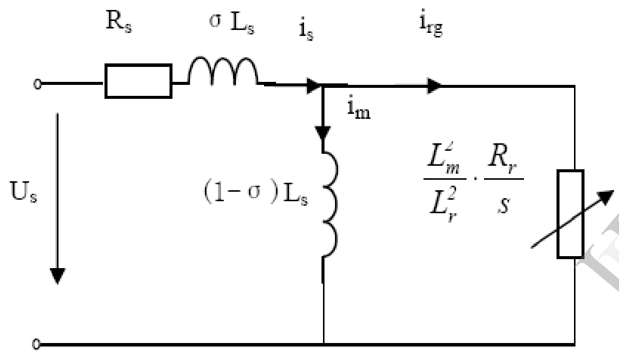

Fig. 3 T-1 equivalent circuit of IM

From fig. 3 the stator and rotor voltage is given by the matrix:

$$\begin{bmatrix} U_s \\ 0 \end{bmatrix} = \begin{bmatrix} R_s + L_s p & -\frac{L_m^2}{L_r} p \\ -\frac{L_m^2}{L_r} p & \frac{L_m^2}{L_r^2} R + \frac{L_m^2}{L_r} p \end{bmatrix} \begin{bmatrix} i_s \\ i_{rg} \end{bmatrix} \tag{1}$$

From (1), the stator voltage equation is

$$U_s = (R_s + L_s p) i_s - \frac{L_m^2}{L_r} p i_{rg} \tag{2}$$

And $i_s = i_m + i_{rg}$, therefore equation (1) becomes,

$$U_s(s) = \left(R_s + L_s p - \frac{L_m^2}{L_r} p\right) i_s + \frac{L_m^2}{L_r} p i_m \tag{3}$$

In vector control, stator current is regarded as the given quantity and is expressed as:

$$I_s(s) = \frac{\sqrt{2} I_s}{s - j\omega_{sl}} \tag{4}$$

The Laplace transformation of equation (4) is:

$$I_s(s) = \frac{\sqrt{2} I_s}{s - j\omega_{sl}} \tag{5}$$

The rotor voltage equation is:

$$-\frac{L_m^2}{L_r} p i_s + \left(\frac{L_m^2}{L_r^2} R + \frac{L_m^2}{L_r} p\right) i_{rg} \tag{6}$$

We know that $i_s = i_m + i_{rg}$, therefore equation (6) can be written as,

$$(R_r + L_r p) i_m = R_r i_s \tag{7}$$

The Laplace transformation of equation (7) is obtained as

$$I_m(s) = \frac{R_r}{R_r + L_r s} I_s(s) + \frac{L_r}{R_r + L_r s} i_m(0) \tag{8}$$

and solved to find the eigen value which is given by,

$$\lambda = -\frac{R_r}{L_r} = -\frac{1}{T_r} \tag{9}$$

From equations (5) and (9), equation (8) can be written as,

$$I_m(s) = \frac{\sqrt{2}\frac{R_r}{L_r}}{(s-\lambda)(s-j\omega_{sl})} I_s(s) + \frac{L_r}{s-\lambda} i_m(0) \tag{10}$$

The Laplace Inverse transformation of equation (4) is:

$$i_m(t) = \frac{\sqrt{2} R_r}{R_r + j\omega_{sl} L_r} I_s e^{j\omega_{sl} t} + \left(i_m(0) - \frac{\sqrt{2} R_r}{R_r + j\omega_{sl} L_r} I_s\right) e^{\lambda t} \tag{11}$$

In equation (11), the first term of the right side is steady-state quantity; the second term is transient quantity. In vector control, when the reference coordinate system is correctly orientated in rotator flux, there is no transient current in rotator loop. Under this condition the current i_m and torque is given by:

$$i_m = \frac{\frac{L_m^2}{L_m^2} R_r}{\frac{L_m^2}{L_m^2} R_r + j\omega_{sl}(1-\sigma) L_s} i_s \tag{12}$$

Where, $\sigma = 1 - \frac{L_m^2}{L_s L_r}$ is the magnetic flux leakage coefficient

$$T_e = 2 p_n \frac{L_m^2 \omega_{sl}}{(R_r^2 + \omega_{sl}^2 L_r^2)} I_s^2 \tag{13}$$

If the motor parameters are not identified correctly, the reference coordinate system will not be oriented in rotor flux. Hence the transient current is not zero, which is obtained from equation (11) as:

$$i_m'(t) = \frac{\sqrt{2} R_r'}{R_r' + j\omega_{sl} L_r'} I_s e^{j\omega_{sl} t} + \sqrt{2} \Delta i_0 e^{\lambda' t} \tag{14}$$

And torque is given by

$$T_e' = 2p_n \frac{L_m'^2 \omega_{sl}}{(R_r'^2+\omega_{sl}^2 L_r'^2)} I_s^2 + 2p_n \frac{L_m'^2}{L_r'} I_s \Delta i_0 \sin(\omega_{sl} t - \Delta\phi) e^{\frac{R_r'}{L_r'}t} \qquad (15)$$

Where $\Delta\phi$ is the phase angle of Δi_0, lagging rotor current vector and the time constant is $\frac{L_r'}{R_r'}$. Therefore when impedance parameters of motor are varied, the ideal dynamic control will not be realized if the control parameters are not modified.

III. PRINCIPLE OF PARAMETER IDENTIFICATION

The resistance of conductors often changes with temperature. Since the motor windings are usually made of copper, the stator and rotor winding resistance changes with the temperature. The linear relation between the resistance and temperature is given by

$$R = R_0[1+\propto (T - T_0)] \qquad (17)$$

Where, $\propto$ is called the temperature coefficient of resistance, T_0 is a fixed reference temperature (usually room temperature), R_0 is the resistance at temperature T_0, and T is the varying temperature. The value of $\propto$ varies for different materials . Therefore by measuring the winding temperature, the stator and rotor winding can be identified online. Thus improving the accuracy and performance of the motor.

IV. SIMULATION RESULTS

The simulation work is carried out for the motor ratings as listed below in table I.

TABLE I

PARAMETERS	VALUES
Power	5hp
Frequency	50Hz
Voltage	400V
Stator resistance	1.3ohms
Rotor resistance	1.5ohms
Pole pairs	2
Mutual inductance	0.2037H
Inertia	0. 002kg.m^2
Friction factor	0.005752N.m.s

The SVPWM method is implemented to see the simulation results of stator voltages and currents as shown in fig 4, Torque and speed of the motor is as shown in fig 5.

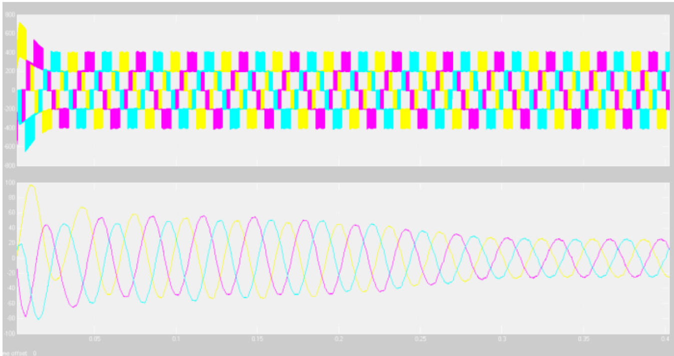

Fig. 4 Stator voltages and currents

Fig. 4 shows the inverter output waveforms to the motor. We can see a six stepped voltage waveform which contains less harmonics. In fig. 6 the rotor speed and torque remains constant after a few oscillations at the starting.

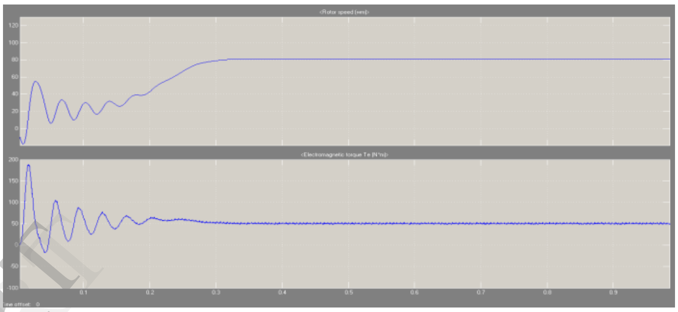

Fig. 5 Torque and speed

V. HARDWARE IMPLEMENTATION

The system structure for parameter estimation is as shown in fig 6.

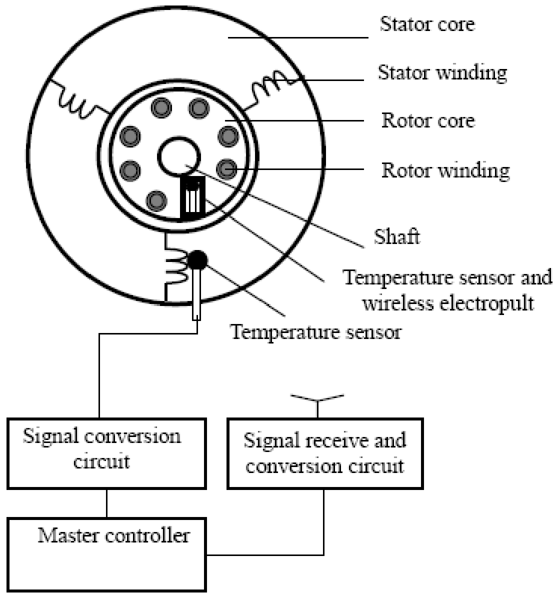

Fig 6. System structure for parameter estimation using temperature sensors

The temperature sensors for the rotor and stator windings is placed in rotor and the stator slots respectively. Wireless sensor is used for the rotor because it is a rotating element. The temperature sensed is sent to the signal conversion circuit and then to the master controller where the received signal is converted to resistance by the linear relationship as mentioned in equation (17). Depending on the calculated resistance values the controller can modify the induction motor parameters.

In order to detect temperatures of the rotator, it needs to be designed that rotate temperature detection and wireless transmitter, as well as wireless signal receiver circuit. Temperature detection sensor is PT100 platinum resistance; the signal transmitter circuit is TLC548 of TI Company; signal processor and transmitter circuit is composed of MC68HC608FF2. By this circuit, the stator temperature is detected real-time, and then is converted into wireless signal transmitted to receiver circuit of stator. The wireless receiver circuit of rotor is composed of MC33594; signal process controller is P89LPC930. The temperature signal of rotator is received by this circuit. Then, after being analyzed and processed, it is transferred to the main controller. And the stator Temperature circuit is easy to design. The sensor is PT100 platinum resistance; signal transmitter circuit is composed of resistance voltage divided circuit and AD module. Temperature signal is transmitted to main controller by AD module.

V. CONCLUSION

As the motor parameters are changing, the motor performance deteriorates because the vector control largely depends on the motor parameters. Hence this paper presents a novel method of online parameter identification of IM and been implemented based on the linear relationship between the resistance and temperature. With this method the values of stator and rotor winding resistances were found to be same as that of the measured value. Therefore the efficiency is optimized with novel parameter identification method. Hence this method is highly accurate, simple to design, less calculation and easy to realize. Therefore this method can be implemented in various applications.

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