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Estimation of Rotor Resistance in Sensorless Field Oriented Controlled InductionMotor Drive

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***Abstract*- In a sensorless vector control of induction motor drive the motor parameters have a strong influence on the performance of the drive. Variation of a rotor resistance impares performance of the drive system. It is very essential to estimate correct value of rotor resistance to ensure expected performace of drive system. No-load test, locked rotor test anddc test are the conventional methods for the parameter estimation.In real time system, no load test and locked rotor test have many limitations. The concepts of no-load test andlocked test can be modified under Field Oriented Control(FOC) of induction motor drive. An advanced locked rotor test is presented in this paper for the accurate estimation of rotor resistance without any additional hardware requirement.The presented method has been simulated for three different standared rating three phase inductionmotors, i.e. 10 hp, 100hp and420hp.**

Keywords - Field orientedcontrol(FOC), rotor resistance estimation, advanced locked rotor test

I. INTRODUCTION

Induction motors are the most widely used electrical motors in industrial as well as domestic applications. Superior control of induction motor must be necessary forbettrerperformance[1].Vector control is the most popular ac machine control method in high performance drive applications because it imparts control characteristics similar to a separately excited dc motor. Nowadays, sensorless vector control is increasingly becoming popular in induction motor drive. Performance of vector controlled induction motor drive strongly depends on the accurate estimation of motor parameters. The required parameters are stator resistance(R_s), rotor resistance(R_r), stator leakage inductance(L_{ls}),rotor leakage inductance(L_{lr}) andmagnetizing inductance(L_m).

Over the past decades, many parameter estimation methods have been studied and analyzed in detail. Conventionally, these parameters are estimated by no load test, lockedrotor test and dc test.But in many industrial applications, it is very difficult to perform these tests because the machine is usually coupled to the mechanical load. Also, it is impossible to lockthe rotor in real time applications. The estimated rotor resistance from locked rotor test at rated frequency is inaccurate on account of skin effect [2].Among all parameters (R_s,L_{ls},R_r,L_r,L_m), rotor resistance has a strong influence on the estimation of speed of sensorless vector controlled induction motor drive.An algorithm for the rotor resistance (R_r) estimation under the speed transient state without signal injection with only the stator current measurement is proposed in [3]. Though most of the vector control drives are based on the slip frequency type vector control technique (or indirect control)which is strongly influenced by the rotor resistance variation as$R_r$is used for the speed estimation. It is known that the simultaneous estimation of the rotor speed and R_r is very critical. It is difficult to estimate them simultaneously under the steady state conditionin the slip frequency type vector control[3].To overcome the above problem, there are several algorithms for the R_r estimation in the sensorlessspeed control technique [4], [6]. This paper presents advanced locked rotor test to estimate the correct value of rotor resistance.

II. SENSORLESS FOC OF INDUCTION MOTOR

A. Model of induction machine

The dynamic D-Q model of induction machineshown in Fig. 1 is the per phase equivalent circuit for the d^s-q^s equivalent circuits with counter emf[4].

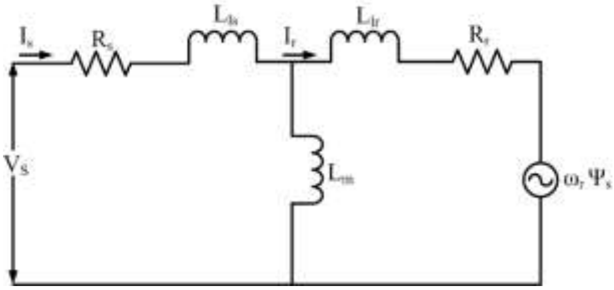

Fig. 1Per phase equivalent circuit of Induction Motor

R_s,R_r,L_{ls},L_{lr},L_m can be derived from the conventional tests,i.e. dc test,no-load test and locked rotor test. The currents and voltages can be represented in this dynamic model as follows.

$$\left|\hat{V}_s\right| = \sqrt{V_{ds}^2 + V_{qs}^2} \qquad \_\_(1)$$

$$\left|\hat{\psi}_r\right| = \sqrt{\psi_{qr}^{s\ 2} + \psi_{dr}^{s\ 2}} \qquad \_\_(2)$$

$$\begin{bmatrix} \hat{V}_s \\ 0 \end{bmatrix} = \begin{bmatrix} R_s + p(L_{ls} + L_m) & p\,L_m \\ (p - j\omega_m)L_m & R_r + (p - j\omega_m)(L_m + L_{lr}) \end{bmatrix} \begin{bmatrix} \hat{i}_s \\ \hat{i}_r \end{bmatrix} \qquad \_\_(3)$$

where p = d/dt is the differential operator

ω_m is the electrical speed of the rotor

$$\hat{V}_s = v_{qs} - j\,v_{ds}$$

$$\hat{i}_s = i_{qs}^s - j\,i_{ds}^s$$

$$\hat{i}_r = i_{qr}^s - j\,i_{dr}^s$$

B. Sensorless FOC

The schematic block diagram of sensorless FOC with PWM inverter is shown in Fig. 2. The vectorcontrolled induction motors require speed or position sensors. However, these sensors bring several disadvantages from the standpoint of drive cost, reliability, size and noise immunity. The precise control of torque and speed without using position and speed sensors is achieved using sensorlessFOC IM drives[5].

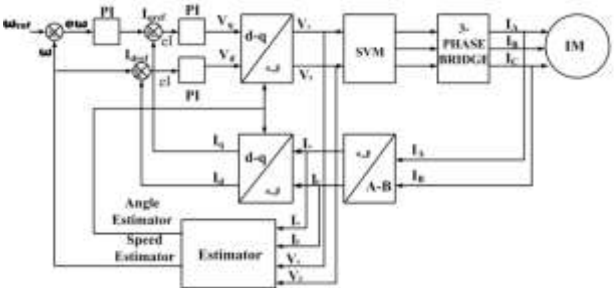

Fig. 2 Block diagram of sensorless FOC

The schematic block diagram is formed using following modules.

(1)Induction motor
(2) 3-Φ bridge rectifier,inverter
(3) Clarke forward transformation block
(4) Park inverse and forward transformation block
(5) Angle and speed estimator block
(6) PI controller block
(7) Fielding weakening block
(8) SVM block

The decoupling block comprises of set of blocks:Clarke and Park transformation blocks.The Clarke forward transformation block is responsible for transforming three axis,two-dimensional coordinates system of the stator to two axis reference frame.The Park forword block is responsible for translating two axis stator current α-β to d-q reference frame. The speed and angle estimator block has inputs of the two axis voltages and currents of α-βframe. As shown in Fig. 2, current feedback is obtained and compared with reference current resulting into current error. Thecurrent error is processed through PI controller, which generates voltage reference. The switching frequency of the inverter is 5000 Hz. Power factor is measured through zero crossing of voltage and current signals.

III. ROTOR RESISTANCE ESTIMATION

The conventional methods which are used to estimate the induction motor parameters are no-loadtest, dc test and locked rotor test. Locked rotor test is used conventionally for the estimation of rotor resistance. But to perform this test, the rotor has to remain stationary. Traditionally, the rotor shaft has to be locked mechanically during this test. Practically it is not possible to lock the rotor. For sensorless vector controlled induction motor drive, this test can’t be performed directly. Some modificationsare required in this test. Theadvanced locked rotor test is presented in the following section.

A. Advanced Locked Rotor Test

In order to perform this test, three phase inverter is required to be switched as single phase inverter.For this, during positive half cycle switch S1 of phase A is turned on and at the same time switches S6 and S2 of phases B and C respectively are also turned on as shown in Fig. 3. Similarly, during negative half cycle switch S4 of phase A is turned on and at the same time switches S3 and S5 of phase B and C respectively are turned on. The normal operating frequency on rotor is not same as that onstator. Applied stator frequency for this test is 25% or less of rated frequency.Due to this rotor remains standstill.

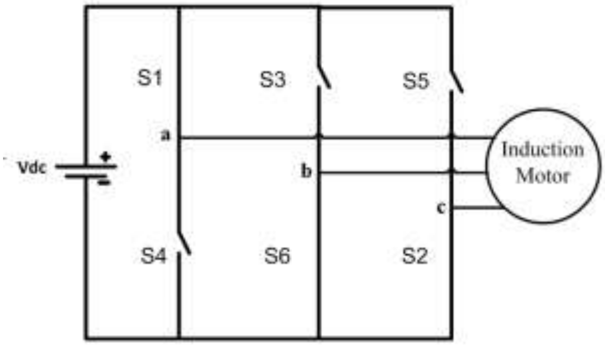

Fig. 3 Switching of inverter during positive half cycle

The complete flowchart of advanced locked rotor test is shown in Fig. 4.

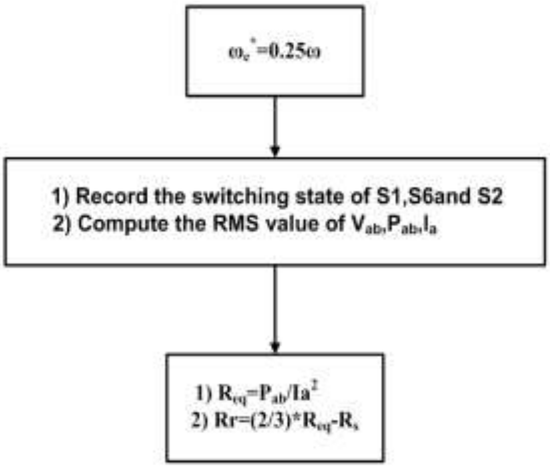

Fig.4 Flowchart of advanced locked rotor test

Block diagram of advanced locked rotor test is shown in Fig. 5. The current of stator phase A is obtained as feedback and compared with the reference current resulting into current error. The current error is processed through PI controller, which generates reference signal. This reference signal is processed through moving average filter which operates on eight previous samples and determines average of the same. Due to this output of PI remains as sine wave as shown in Fig. 6. This reference signal is applied as an input to the comparator which generates the pulses for inverter switches. Power factor and power is calculated using this reference signal. Rotor resistance is calculated as per the equations depicted in the flow chart. A deadband of 3.2 µs is applied between two switches of an inverter. For deadband compensation, deadband compensation factor is also calculated.The calculated deadband compensation factor is deducted from stator A-phase current(I_a) when it is positive and same will be addedto statorA-phase current when it is negative.

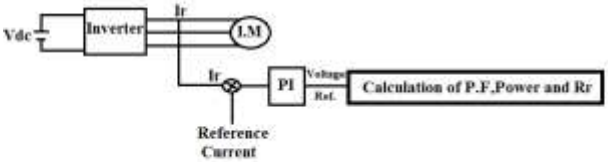

Fig. 5 Block diagram of advanced locked rotor test

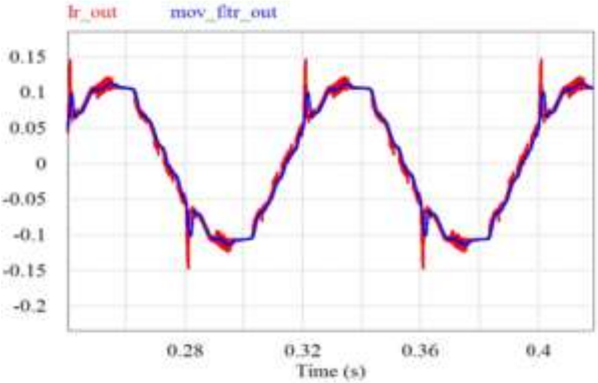

Fig. 6 Output of PI and moving average filter

IV. SIMULATION OF ADVANCED LOCKED ROTOR TEST

The presented technique for estimating the rotor resistance is simulated. The simulation is carried out for various standard rating three phase induction motors viz.(i) 10 hp, 415V,2900 rpm(ii) 100hp, 415 V, 3000 rpm(iii) 420hp, 415 V, 1480 rpm.The waveforms of stator A-phase current and estimated rotor resistnace(R_r)for 10hpinduction motor is shown in Fig. 7 and Fig. 8 respectively. The rms value of stator phase A current (I_a) is 13.3 A. The value of estimated rotor resistance for 10hp induction motor is 0.3639 Ω. The delay of 0.4 second is due to the acceleration time.Fig. 8 shows the line to line applied voltage of 10hp induction motor.

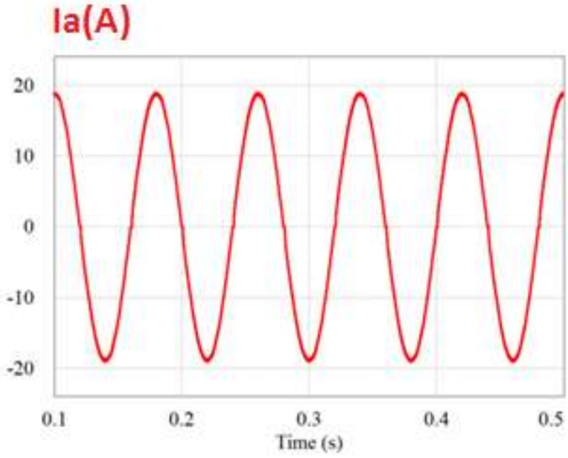

Fig. 7 Waveform of stator A-phase current
(X-Axis= 0.2s/div, Y Axis=10 A/div)

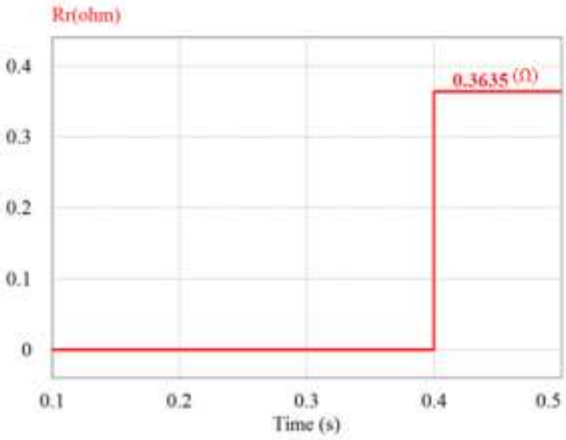

Fig. 8 Waveform of estimated rotor resistance R_r
(X-Axis = 0.1 Sec/div, Y-Axis = 0.1 Ω/div)

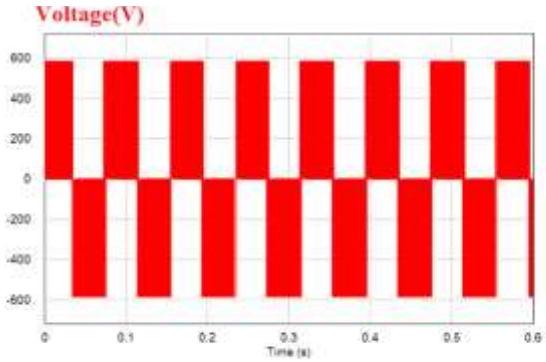

Fig. 9 Line to Line Voltage V_{ab}
(X-Axis=0.1 s/div,Y-Axis=200 V/div)

As shown in TABLE I, estimated rotor resistance per phase of 100 hp and 420 hp three phase induction motors are 0.0151 Ω and 0.0038 Ω respectively against the actual rotor resistance per phase of 0.0158 Ω and 0.0040 Ω respectively. It is analyzed that this technique estimates low value of rotor resistance of high power induction motors with negligible errors.

TABLE I

COMPRISON BETWEEN ESTIMATED AND ACTUAL VALUE OF ROTOR RESISTANCE OBTAINED FROMTHE SIMULATION

hp	**V_{rms}**	**I_{rms}**	**P.F**	**Power**	**Estimated R_r**	**Actual R_r**	**%Error**
10	23.89	13.31	0.89	283.44	0.3639	0.3783	3.8
100	20.02	123.6	0.54	1359.2	0.0151	0.0158	4.43
420	23.99	537.8	0.51	6570.9	0.0038	0.0040	6.86

V. CONCLUSION

Advanced locked rotor test for accurate rotor resistance estimation for three phase induction motor is presentedin this paper. Thetechnique is simulated for three different standard rating induction motors. Simulated results are shown and analyzed for 10 hp, 415 V, three phase induction motor. The estimated rotor resistance per phase is of 0.3639 Ω while actual rotor resistance per phase is 0.3783Ω. The rotor resistance is estimated with marginal error of 3.8 %.Rotor resistance is also estimated accurately for 100 hp and 420 hpthree phase induction motors with marginal error of 4.43 % and 6.86 % respectively.This advace locked rotor test to estimate rotor resistance is quite accurate techniquein order to enhace the performance of vector controlled induction motor drive ranging from low to high power rating.

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