High Performance Reluctance Synchronous Motor Drive using Field Oriented Control

K. Shalini[#1], D. Narmitha *[2], M. Pallavi[#3]
Assistant Professor, Dept. of EEE
shalini.sheelu@gmail.com
dama.narmitha@gmail.com
mahapallavi.m@gmail.com

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Abstract

The ability to improve the performance of Reluctance Synchronous Motors (RSM) using Field Oriented Control (FOC) method. For this purpose, the three-phase RSM is modelled in a rotor (d-q) reference frame. The FOC approach is then created and used to the machine model for a Reluctance Synchronous Motor in a rotor flux-attached spinning (d-q) reference frame. The results reveal that Field Oriented Control is a strong control method for the Reluctance Synchronous Motor, providing improved performance and quicker torque transients (i.,e. less torque settling time). Field Oriented Control has also demonstrated the capacity to increase motor stability and maintain synchronism under heavy loading circumstances.

Keywords:-Reluctance Synchronous Motor (RSM), Field Oriented Control (FOC), Rotating reference frame, machine modelling.

Introduction

Recent developments in electric machines are concerned mainly with higher efficiency operation and lower costs, in both lines start applications and in digital control variable speed drives. As the cost of losses becomes high, especially rotor losses, new AC motor configurations with low rotor losses (ideally zero) have become a rich field of research. Therefore; researchers have been strongly interested in brushless motors. Reluctance synchronous motor (RSM) is considered one of the brushless AC motors that have attracted great interests in recent researches [1-9]. Axially laminated synchronous motors and synchronous radially laminated motors are the two types of synchronous motors. [1, 2].

The stator design of these motors is the same as that of multi-phase induction motors. Researchers have recently been interested in reluctance synchronous motors as a potential substitute for ac induction motor drives. In comparison to a switched reluctance motor's doubly salient construction, RSM has a simpler structural design, with only the rotor visible and the stator covered in the same way as an induction machine. This saliency ratio has also been shown to have a substantial impact on torque density.[3-5]

RSM typically employs three types of rotors. Structures such as segmental, flux barrier, and axially laminated are employed. RSM has begun to be seriously evaluated as a prospective replacement.

In variable speed industrial applications, it is an in addition to other brushless machines (especially induction motors). The Field Oriented Control is used to boost a machine's performance Reluctance Synchronous such as a motor as achieving quicker transient torque and improving motor stability.

Machine modelling

Figure 1 depicts a two-pole reluctance synchronous motor. It has a three-phase stator coil and a prominent rotor. The stator windings are similar and separated by 120°, with Ns equivalent turns and a resistance of Rs. Windings are commonly thought to be dispersed sinusoidally. Because the reluctance synchronous motor's stator winding is sinusoidally dispersed, flux harmonics in the air gap contribute just one term to the stator leakage inductance.

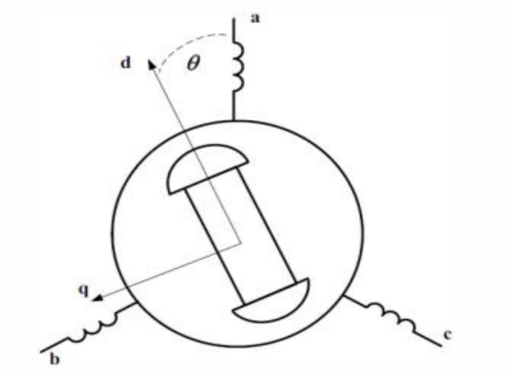

Fig.1. the considered d-q axes, mounted on rotor, of RSM with 2-poles.

Considered the rotor position as shown in figure 1, where (8) is the angular relationship between the rotor d-axis and the stator a-axis. the motor voltage equation in phase coordinates (abc-frame) are illustrated in equations (1) to (3).

$$V_a = \frac{d\lambda_a}{dt} + i_a R_s \quad (1)$$

$$V_b = \frac{d\lambda_b}{dt} + i_b R_s \quad (2)$$

$$V_c = \frac{d\lambda_c}{dt} + i_c R_s \quad (3)$$

Where,

$$\lambda_{abc} = L_{abc\,(\theta)} i_{abc} \quad (4)$$

$$L_{abc}(\theta) = \begin{bmatrix} L_{ls} & L_h & L_h \\ L_h & L_{ls} & L_h \\ L_h & L_h & L_{ls} \end{bmatrix} + L_O \begin{bmatrix} \cos(2\theta) & \cos(2\theta - 2\pi/3) & \cos(2\theta + 2\pi/3) \\ \cos(2\theta - 2\pi/3) & \cos(2\theta + 2\pi/3) & \cos(2\theta) \\ \cos(2\theta + 2\pi/3) & \cos(2\theta) & \cos(2\theta - 2\pi/3) \end{bmatrix} \quad (5)$$

Where L is stator self-inductance, Lh is useful mutual inductance, Lo is mutual inductance due to saliency, and PI is number of pole pairs in the motor.

The RSM's d-q model was created using the d-q frame of coordinates attached to the Figure l shows a rotor (rotor reference frame).The transformation matrix, used to transform from abc frame to d-q frame is.

$$\begin{bmatrix} V_d \\ V_q \\ V_0 \end{bmatrix} = 2/3 * \begin{bmatrix} \cos(\theta) & \cos(\theta - 2\pi/3) & \cos(\theta + 2\pi/3) \\ -\sin(\theta) & -\sin(\theta - 2\pi/3) & -\sin(\theta - 2\pi/3) \\ 1/2 & 1/2 & 1/2 \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \quad (6)$$

Figure 2 shows the circuit of RSM in d-q frame. Therefore, the voltage equations in the d-q frame for both stator and rotor are shown in the following equations:

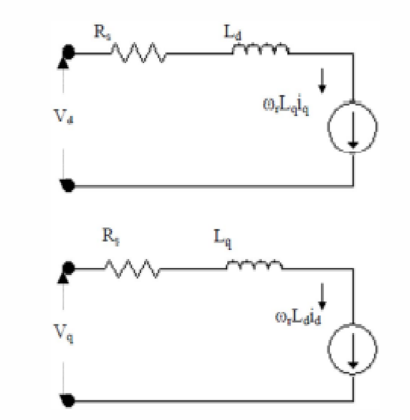

Fig. 2. Reluctance Synchronous Motor equivalent circuit in d-q frame

$$V_d = i_d R_s + \frac{d\lambda_d}{dt} - w_r \lambda_q \quad (7)$$
$$V_q = i_q R_s + \frac{d\lambda_q}{dt} + w_r \lambda_d \quad (8)$$
$$0 = i_{rd} R_{rd} + \frac{d\lambda_{rd}}{dt} \quad (9)$$
$$0 = i_{rq} R_{rq} + \frac{d\lambda_{rq}}{dt} \quad (10)$$

Where the stator and rotor d-q fluxes linkage equations are:

$$\lambda_d = L_d i_d + L_{md} i_{rd} \quad (11)$$
$$\lambda_q = L_q i_q + L_{mq} i_{rq} \quad (12)$$
$$\lambda_{rd} = L_{rd} i_{rd} + L_{md} i_d \quad (13)$$
$$\lambda_{rq} = L_{rq} i_{rq} + L_{mq} i_q \quad (14)$$

d-q of the stator and rotor inductances are expressed as the following:

$$L_d = L_{ls} + L_{md} \quad (15)$$
$$L_q = L_{ls} + L_{mq} \quad (16)$$
$$L_{rd} = L_{lrd} + L_{md} \quad (17)$$
$$L_{rq} = L_{lrq} + L_{mq} \quad (18)$$

Where Lmd and Lmqare the magnetizing inductances in the d, q axis respectively

FIELD ORIEND CONTROL METHOD

Field Oriented Regulate is all about using a vector to control stator currents. This control is based on projections are used to transform a three-phase time and speed dependent system into a two-coordinate (d and q co-ordinates) time invariant system. These predictions give a framework similar to direct current machine control. As input references, field-oriented controlled machines require two constants: the torque component (aligned with the coordinate) and the flux component (aligned with d co-ordinate) depicts in Figure 3.

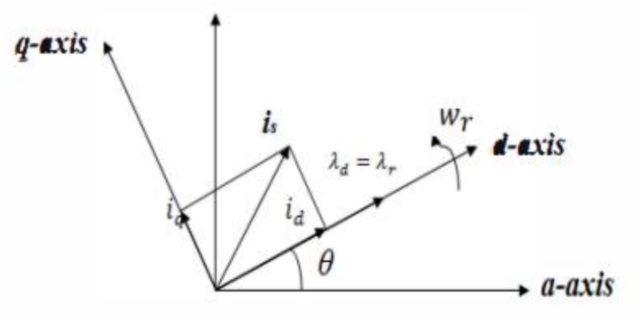

Fig. 3. Transformations from three phase to d-q coordinates

As a result, the FOC addresses the traditional scheme difficulties in the following manners:

• The ease of use with which a consistent reference may be obtained (The stator current's torque and flux components).

• direct torque control may be applied since the torque expression in the (dq) frame of reference is:

$$T_e = 3/2\, P_1(\lambda_d i_q - \lambda_q i_d) \quad (19)$$

Now using FOC strategy, all the rated flux will be in phase with the direct axis so Aq = 0 and (19) can be simplified to.

$$T_e = 3/2\, P_1 \lambda_d i_q \quad (20)$$

From (Equ 20), A linear connection by keeping the amplitude of the rotor flow Ad constant. Reluctance Management Voltage regulator methods are used to power a synchronous motor.

The actual currents d, q axis id, and iq are measured against the i (the flux reference) and iq * references (the torque reference). The output of these comparators is routed through a PI regulator, the outputs of which are Vd* and Vq*, which are then applied to a (d-q) to (a-b-c) converter. The converter outputs are sent into the Space Vector PWM. This block's outputs are the signals that operate the inverter.

SIMULATION RESULTS

The Field Oriented Control simulation results method of RSM and simulated by MATLAB software using the parameters of the 175Watt, 380 Volt RSM (parameters are mentioned in the Appendix). Objective functions of the controller are rotor speed control, motor performance improving and motor stability improving.

(A) ROTOR SPEED CONTROL

FOC of RSM may be used to achieve a broad range of speed control and improved performance in transient and steady-state operation. Figure 5 shows the control of the rotor speed of RSM at a sudden load 1 N.m at t=5 sec using FOC. Figure 4 (b) shows the torque waveform following quadrature component of the stator current of Figure 4(a) validating the condition of (20). Figure 4(c) illustrates the ability of the FOC RSM to produce a rotor speed that follows its reference speed.

At constant load 1N.M and variable speed 1000 to 1500

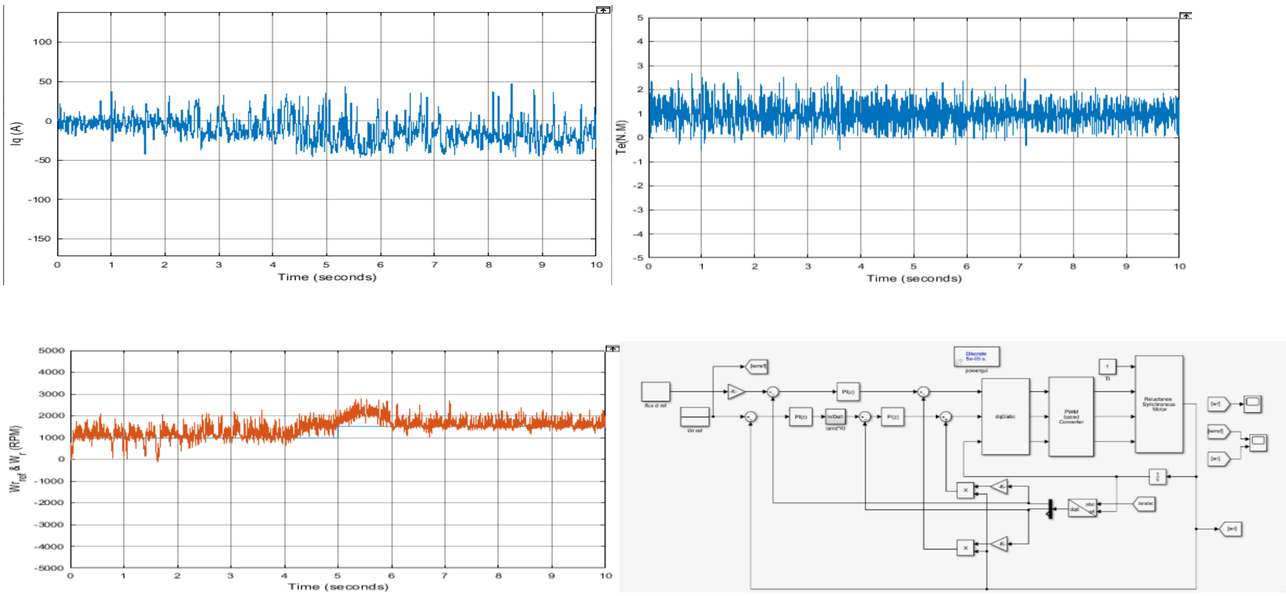

Fig. 4a) Stator quadrature current b) electromechanical torque c) Rotor speed versus time using FOC at a sudden load I N.m at t= 5 sec and Schematic diagram

At constant load 1 N.M and constant speed 1500

(B) MOTOR PERFORMANCE

In this section the performance of the motor operated with FOC compared to that of the motor when operated directly from a constant voltage constant frequency source are considered. Figure 6 indicates the advantages of the FOC control over direct operation. Table 1 summarizes this improved performance of FOC of RSM over direct supply operation in terms of steady state error, settling time and percentage over shoot.

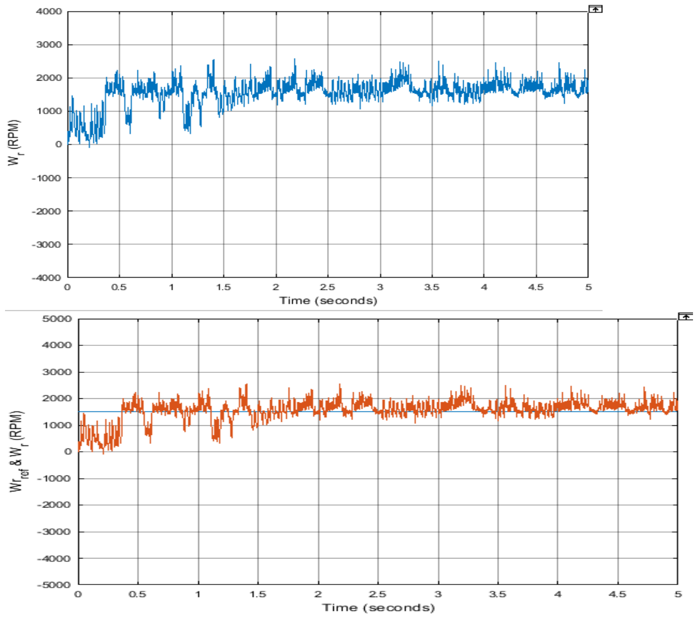

Fig. 5 Rotor speed of RSM a) using FOC of RSM

Variable speed 0N.M to 2N.M and constant speed 1500

Figure 7 shows the motor torque and speed responses using FOC. It can show that the FOC improved the performance of the motor and keeps its operation at the synchronous speed.

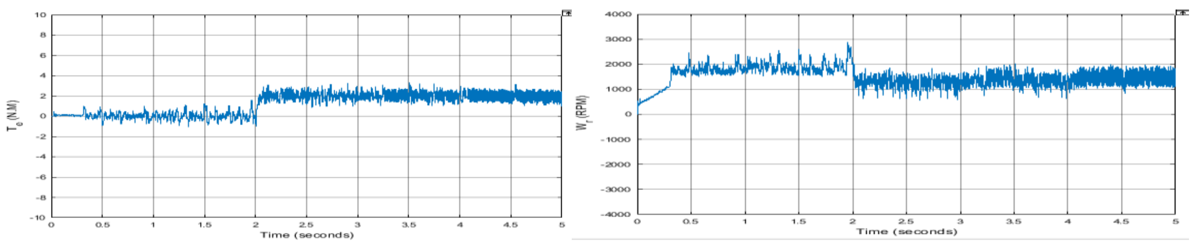

Fig.6 Torque and Speed respectively using FOC at sudden load 2 N.m at t=2 sec.

Variable speed 0N.M to 2N.M and constant speed 1500

Figure 9 illustrates the ability of the FOC RSM to maintain its stability under sudden load condition at higher values up to 4 N.m This load torque is exceeding double the machine rated torque; which ensures that the motor can survive severe torque disturbances. It is worth to mention that the machine current for this operating conditions is almost double the machine rated current. It can be also shown that with the aid of adaptive control the FOC RSM can keep stability even at higher load torque.

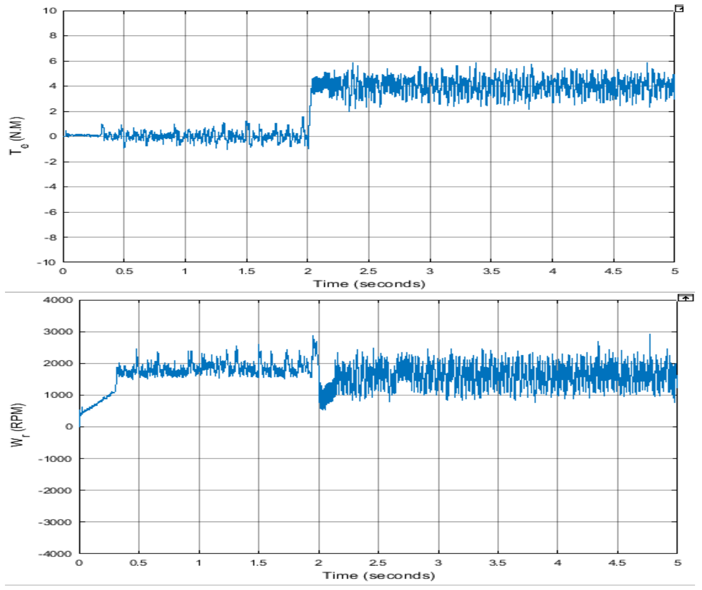

Fig. 7 Torque and Speed curves using FOC at sudden load 4 N.m at t=2 sec

Conclusion

This paper has presented the main concept of operation of the RSM; the mathematical modeling of the motor in d-q frame is also presented. Field Oriented Control (FOC) of RSM has been presented. FOC have proved to be a powerful strategy with the RSM, giving better performance and faster torque transient (i. e. less torque settling time). It was also shown that the RSM is simple in control for wide 186 speed range. FOC has also proved its ability to improve the motor stability and keeps its synchronism at certain load conditions, at which the direct line operation failed.

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