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Simulation Results of a Switched Reluctance Motor Based on Finite Element Method and Fuzzy Logic Control

W. Aljaism+

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Abstract. This paper presents simulation results for three phase, 6/4 poles and four phase, 8/6 poles switched reluctance motor (SRM). The main focus of this paper is to investigate the developed torque optimization for switched reluctance (SR) motors as a function of pole arc/pole pitch ratio for the stator and the rotor. This investigation is achieved through the simulation using Finite Element Method (FEM), Fuzzy Logic Control (FLC), MATLAB/SIMULINK.

Keywords: Switched Reluctance Motor, Simulation, FEM, FLC, MATLAB/SIMULINK.

1. Introduction

The switched reluctance motor is a new entrant in domestic appliance applications. Many electrical machine researchers are investigating the dynamic behaviour of switched reluctance motor (SRM) by monitoring the dynamic response (torque and speed), monitoring and minimising the torque ripple. The researchers are now focusing on switched reluctance motors and drives with only one or two phase windings so that applications for the technology are being created in low cost, high volume markets such as domestic appliances, heating ventilation and air conditioning and automotive auxiliaries[1-5].

The sensitivity study is performed by comparing the average torque developed for different stator as well as rotor pole-arc/pole-pitch ratios and choosing the ratio combination that produces the greatest value of average torque. The sensitivity analysis of SR motor geometry is carried out for stator- and rotor pole-arc/pole-pitch ratio, and radial air gap length as motor design variables by a few researchers. Finite element method FEM, which is very powerful tool for obtaining the numerical solution of a wide range of engineering problems. The original body or structure is then considered as an assemblage of these elements connected at a finite number of joints called “Nodes” or “Nodal Points”. [6-9].

Fuzzy logic is a powerful problem-solving methodology with a myriad of applications in embedded control and information processing. Unlike classical logic which requires a deep understanding of a system, exact equations, and precise numeric values, fuzzy logic incorporates an alternative way of thinking, which allows modelling complex systems using a higher level of abstraction, originating from our knowledge and experience. In 1965 Lotfi A. Zadeh published his seminal work "Fuzzy Sets” which described the mathematics of fuzzy set theory, and by extension fuzzy logic. This theory proposed making the membership function (or the values false and true) operate over the range of real numbers [0.0, 1.0] [10-15].

2. Design Optimization

2.1. Optimised Design for 3 Phase 6/4 Poles SRM.

FEM is a very useful tool in the solution of electromagnetic problems. This paper presents the torque optimization of a SRM by using a finite-element analysis. The effects of different rotor and stator shapes and

+ Corresponding author. Tel.: +0061 2 96293957; fax: +0061 2 96293957.
E-mail address: wadaha@yahoo.com.

sizes on the performance were investigated. Finite element method was used to simulate each shape of SRM, while various stator/rotor shapes are analysed keeping the same ampere-turns for various SRM shapes. The investigation was performed on 3 phase, 6/4 poles and 4 phase 8/6 poles base designs SRM, with various configurations as follows:

- Changing the shape and size of the rotor and stator.
- Dimensional variations for stator and rotor poles.

Torque optimization has been achieved as shown individually by dimensional variation on the stator, the rotor poles for the 3 phase, 6/4 poles SRM. After gathering the results of the highest developed torque for the stator, and the rotor poles, a new SRM optimized design is obtained. The base design and the optimized design for 3 phase, 6/4 poles SRM. The stator pole arc/pole pitch ratio (β) for the optimized SRM is 0.5; the rotor pole arc/pole pitch ratio γ for optimized SRM is 0.38. Figure 1 shows the flux density through the stator pole, air-gap, and rotor for 3 phase, 6/4 poles base and optimized cross-section design SRM. Figure 2 shows the graphical results for developed torque for the 3 phase, 6/4 poles reference base and optimised SRM designs. Developed torque is analysed when rotating the rotor from 0º to 45º for the optimized and base designs. The torque developed in the optimized design is less than the torque developed in the base design when rotor rotates from 0º to 5º; the torque developed for optimized design is higher than the developed torque for the base design when the rotor rotates from 5º to 45º.

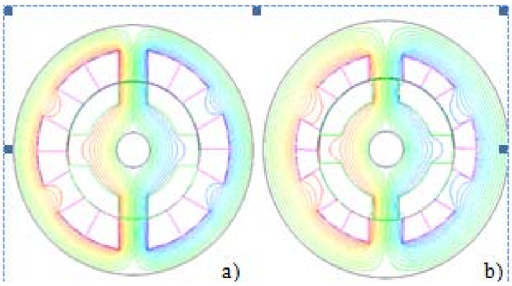

Fig. 1: Flux density for 3 phase, 6/4 poles; a) base design SRM, b) optimised design SRM

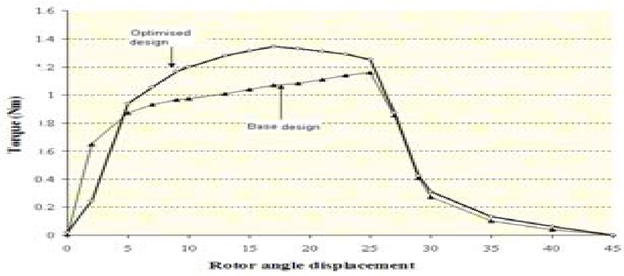

Fig. 2: Torque versus θ for base SRM and optimised SRM.

2.2. Optimised Design for 4 Phase, 8/6 Poles SRM

Since the torque optimization is performed by dimensional variation for stator, rotor poles of 3 phase, 6/4 SRM, so the same proposed dimensional variation method is implemented for 8/6 poles base SRM. Figure 3 shows the flux density through the yoke, stator pole, air-gap, and rotor for 4 phase, 8/6 poles base and optimized SRM. Figure 4 shows the comparative 4 phase, 8/6 a pole base and optimized designs SRM. As soon as the mmf varies from 200 to 1000 AT, the developed torque for optimized SRM is higher slightly than the developed torque of base SRM. The developed torque of the 4 phase, 8/6 poles optimized SRM increases rapidly compared with the developed torque of the 4 phase, 8/6 poles base SRM between 1000 to 4000 AT.

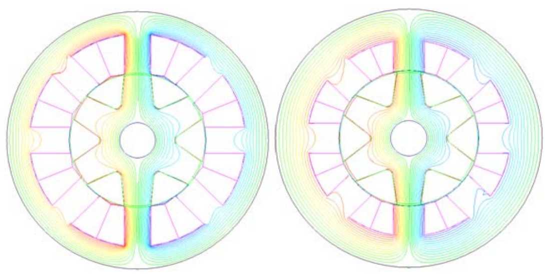

Fig. 3: Flux density for 4 Phase, 8/6 poles; a) base design, b) optimized design SRM.

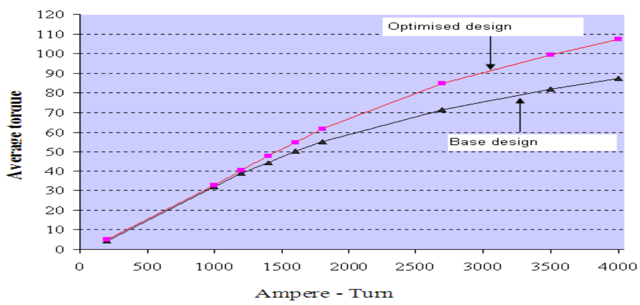

Fig. 4: Average Torque versus Ampere-Turn for 4 Phase, 8/6 Poles Base and Optimised SRM.

3. Simulation Results by MATLAB

MATLAB SIMULINK package is used to simulate the SR motor. The SRM designs were simulated with the MATLAB SIMULINK package and lock up table of the torque τ (θ, I) is used to represent the simulation, torque is a function of rotor position and current, which is extracted from the numerical data of the motor design by a finite elements method. The lock up table from SIMULINK library is used to represent the developed torque in the 3 phase, 6/4 poles base and optimized SRM and 4 phase, 8/6 poles base and optimized SRM, as the displacement angles are considered as a row parameters (horizontal parameters), that varied between (0° to 45°), and the mmf is considered as column parameters (vertical parameters), which is varied between (30 to 210 AT). This simulation is based on equation (1), where T is the torque, T_e is the electromechanical torque, T_l is the load torque, ω is the rotational velocity of the shaft, J momentum of inertia. Figure 4 shows how to multiply the developed torque table of SRM by momentum of inertia (1/J), then through single and double integration, ω and θ have been obtained as shown in Figure 4a for 3 Phase, 6/4 poles base SRM and Figure 4b for 3 Phase, 6/4 poles optimised SRM designs. Figure 5a shows 4 Phase, 8/6 poles base SRM and Figure 5b for 4 Phase, 8/6 poles optimised SRM designs.

$$T = T_e - T_l = J\frac{d\omega}{dt} \quad (1)$$

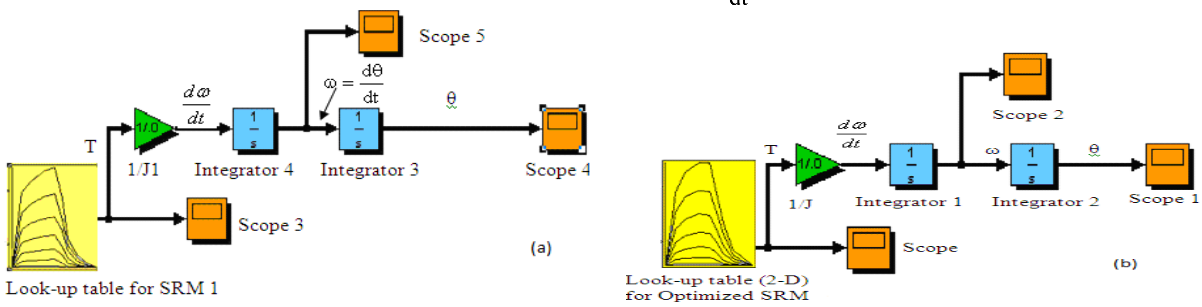

Fig. 4: Block Diagram for 3 Phase, 6/4 Poles: a) Base SRM, b) optimised SRM.

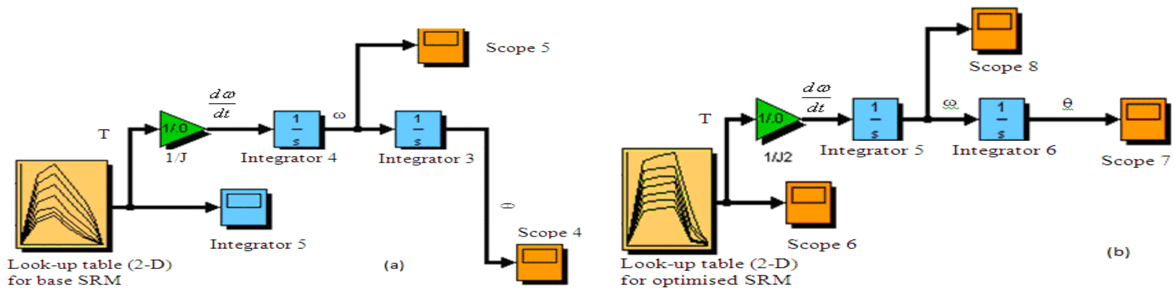

Fig. 5: Block Diagram for 4 Phase, 8/6 Poles: a) Base SRM, b) optimised SRM.

4. Fuzzy Logic Controller

Figure 6 shows how the fuzzy logic controllers (FLC) use fuzzy logic as a process of mapping from a given input (crisp numerical value) to an output (signal control u). This process has a basic structure that involves a fuzzifier, an inference engine, a knowledge base (rule data base), and a deffuzzifier, which transforms fuzzy sets into real numbers to provide control signals. Table 1 shows the rule matrix for the FLC, The antecedents linguistic variables (eω, ceω) are represented by the yellow highlighted zones and the consequent linguistic variables are represented by green highlighted zones. Both of them are represented by seven triangular membership functions. Error-dot = d(error)/dt, Speed error = $\omega_{ref} - \omega_{actual}$

Fuzzy logic controller generates current reference changes (ΔIref) based on speed error eω and its changes ceω. eω has its minimal value when the motor speed has its nominal value, 850 rad/sec, and is inverted to –850 rad/sec, then the speed error equals: eω = (-850) - (850) = - 1700 rad/sec. The maximum value, is +1700.

Error-dot = d(error)/dt, the changes of speed error (ceω) can be written in another form: ceω = eω(k+1) - eω(k) = (ω_{ref} − ω(k)) − (ω_{ref} − ω(k − 1)) = - (ω(k) − ω(k-1) = -Δ ω, Substituting ceω into the following equation ; $T = T_e - T_l = J\frac{d\omega}{dt} = j\frac{\Delta\omega}{\Delta t} = \tau \Rightarrow \Delta\omega = \frac{\Delta t}{j}\tau$.

$$|ce\omega| = \frac{\Delta t}{j}\tau = \frac{0.0013}{0.01*10^{-2}}*1.5 = 20 \;,\; \Delta t = 0.0013,\, J = 0.01*10^{-2} \,,\; \tau = 1.5.$$

Δt is the interruption time, J is the moment of inertia, τ is the developed torque in Nm and maximum absolute value for the ΔI_{ref} universe was obtained by trial and error. The initial limits for the universes after some manual changes of the antecedents (eω, ceω) and consequent (ΔIref) were: eω = -850, 850 rad/sec; ceω = -20, 20 rad/sec/sec; ΔI_{ref} = -1.5, 1.5 A. Figure 7 shows (ΔIref) generation by FLC, as soon as any antecedent's linguistic variables change or both (eω or ceω or both) during the process, then the output (ΔI_{ref}) changes accordingly. For example if the red line on speed error (eω) or the red line on the change of speed error (ceω) is varied, then (ΔIref) will vary accordingly. Results appear at the bottom of the third columns. Figure 8 shows the surface viewer of the FLC for switched reluctance motor. Two inputs (eω, ceω) are represented by the x-axis, while the output is represented by the y-axis as shown figure 8.

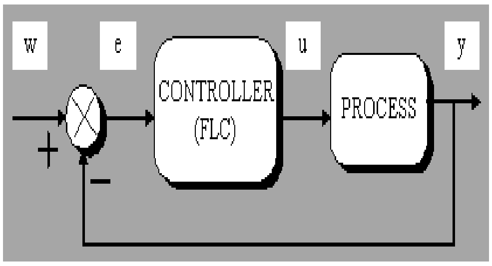

Fig. 6: FLC Structure

Table 1: The Rule Matrix

ew/cew	NB	NM	NS	ZE	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	ZE
NM	NB	NB	NB	NM	NS	ZE	PS
NS	NB	NB	NM	NS	ZE	PS	PM
ZE	NB	NM	NS	ZE	PS	PM	PB
PS	NM	NS	ZE	PS	PM	PB	PB
PM	NS	ZE	PS	PM	PB	PB	PB
PB	ZE	PS	PM	PB	PB	PB	PB

5. Conclusions

The incremental torque percentage for the optimized design 3 Phase, 6/4 Poles phase SRM is 11.5% greater than the developed torque of the base design 3 phase, 6/4 poles SRM. The incremental torque percentage of the optimized design for 4 phase, 8/6 poles SRM is 12.9% greater than the developed torque of the base design for 4 phase, 8/6 poles SRM. MATLAB-SIMULINK package is employed in this study relied on the results extracted from finite element method to show the speed of the optimized design 3 phase SRM is greater than the speed of the base design 3 phase SRM and the speed of the optimized design 4 phase SRM is greater than the speed of the base design 4 phase SRM. FLC is employed and generated current reference variations, based on speed error and its change, the objective of the FLC achieves a good performance and accuracy. FLC has performed well for the speed control of SRM, overcoming its nonlinearities.

6. Acknowledgement

Simulation results for switched reluctance motor is investigated and conducted by Dr Wada Lamaism using a finite element method, Fuzzy Logic Control (FLC), MATLAB/SIMULINK to achieve this task.

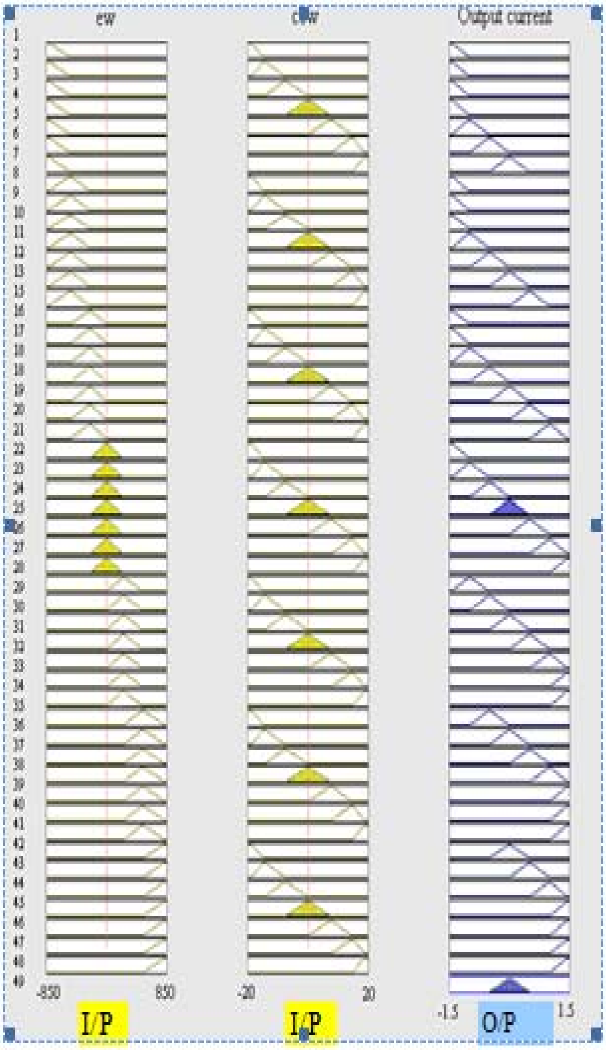

Fig. 7: Rules Viewer for SRM Fuzzy Logic Controller.

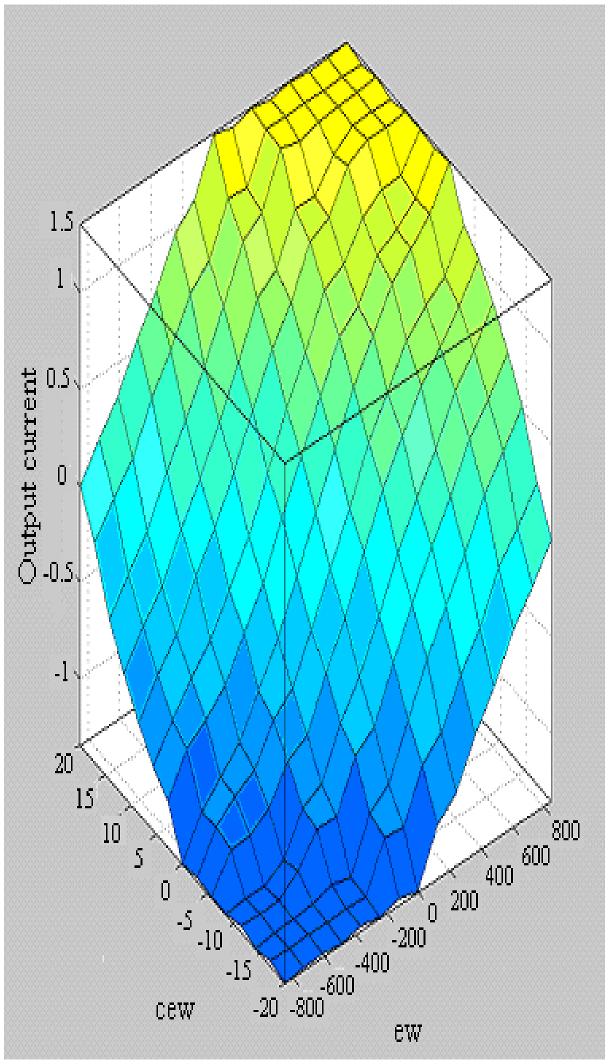

Fig. 8: Surface Viewer for SRM Fuzzy Logic Controller.

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