Analysis of 500 W 2000 rpm Switched Reluctance Motor using 2D FEMM

Intan Zurina Binti Ismail
Faculty of Electrical Engineering
University Technology Mara (UiTM)
40450 Shah Alam, Selangor, Malaysia
intan_zurina@yahoo.com

Abstract - **This paper represents the idea of using the FEMM simulation software as an alternative to other simulation software today. The FEMM is used to simulate the single-phase switched Reluctance Motor in order to gain the result of the motor and to compare the outcome this software. The single-phase Switched Reluctance Motor is a simplest electrical machine to construct where the motor only consist of the excitation winding stator and magnetic rotor with saliency. The 1phase switched Reluctance Motor is easy to construct by using this software.**

Keywords **- Switched Reluctance Motor (SRM), Finite Element Method Magnetics (FEMM)**

I. Introduction

A Switched Reluctance Motor (SRM) is rotating electric machine where both stator and rotor have salient poles. The stator winding is comprised of a set of coils, each of which is wound on one pole. SRM differ in the number of suitable combination of stator and rotor poles. The motor is excited by a sequence of current pulses applied at each phase. The individual phases are consequently excited, forcing the motor to rotate. The current pulses need to be applied to the respective phase at the exact rotor position relative to the excited phase [1]. The stator consists of simple concentric windings. There are neither windings or bar wires on the rotor. Stator windings on diametrically opposite poles are connected in series from to a single phase. When the stator pole pair is energized by the phase winding, the nearest rotor pole pair is attracted toward the position, where the magnetic path has the minimum reluctance. Thus, by energizing the consecutive stator phases in sequence, it is possible to develop a torque in either direction of rotation [2-4]. In a SRM, only the stator presents windings, while the rotor is made of steel lamination without conductors or permanent magnets. This very simple structure reduces greatly its cost. Motivated by this mechanical simplicity together with the recent advances in the power electronics components, much research has being developed in the last decade.

The SRM, when compared with the Ac and DC machines. This advantage is very reliable machine since each phase is largely independent physically, magnetically, electrically from the other machine phases and can achieve very high speeds (20000-50000 r.p.m) because of the lack of conductors or magnets on the rotor [5]. The SRM motion is produced because of the variable reluctance in the air gap between the rotor and the stator. When a stator winding is energized, producing a single magnetic field, reluctance torque is produced by the tendency of the rotor to move to its minimum reluctance position [6]. In a magnetic circuit, the rotating member prefers to come to the minimum reluctance position at the instance of excitation. While three rotor poles are aligned to the three stator poles, another set of rotor poles is out of alignment with respect to a different set of stator poles.

Then, this set of stator poles is excited to bring the rotor poles into alignment. Likewise, by sequentially switching the current into the stator windings, the rotor is rotated. The movement of the rotor, hence the production of torque and power, involves switching of current into stator windings when there is a variation of reluctance, therefore this variable speed motor drive is referred to as a switched reluctance motor. For the single-phase SRM, it offers simplest solution for starting and torque ripple without resorting to high numbers of phases. Hence it has been the most popular topology in its 3/3 form. Alternative single-phase machines with doubled-up pole numbers can provide a better solution for lower speed applications.

II. 3/3 SRM Design

The design and simulation of 3/3 SRM is done by using Finite Element Method Magnetics (FEMM). The finite element method (FEM) is one of the successful computational techniques for obtaining approximate solution to the partial differential equations that arise in many scientific and engineering applications. FEMM is a software package for solving electromagnetic problems using FEM. The program addresses 2D planar and 3D axisymmetric linear and nonlinear harmonic low frequency magnetic and magnetostatic problems and linear electrostatic problems. Its popularity is based on its open source distribution, simplicity, accuracy, and low computational cost, the great amount of users' contributed libraries and application and the development of the Lua extension language, used to add scripting / batch processing facilities to FEMM. It is divided into three parts:

a) The interactive shell (femm.exe), a multiple document interface pre-processor and a post-processor for the problems solved by the package.
b) The triangle.exe which segments the problem domain into a large number of triangles.
c) The solvers (fkern.exe for magnetic and belasoly for electrostatics). These take a set of data files that describe the problem and solve Maxwell's equations to obtain values for desired field throughout the problem domain. It has to be noticed that the value of potential in each triangle is approximated from the linear interpolation of its value at its three vertices [7].

Firstly, to design 3/3 SRM must be to set menu file, create a new problem is magnetic problem. After that, set menu problem: problem type is planar, length units in millimeters, and depth in 100. Set menu grid: grid size in 10 and coordinates in Cartesian. The preprocessor is always in one of five modes: the Point, the Segment, the Arc Segment, the Block, or the group mode. The first four are drawing modes and correspond to the four types of entities that define the problems geometry: nodes that defined specifics points in the problem domain, line and arc segment that connect the nodes forming boundaries and interfaces, and block labels that denote the material properties and mesh size associated with different closed regions. The fifth mode glues different objects together into parts so that entire parts can be manipulated more easily. The first task is to draw boundaries for the solution region.

The next step is the identification of the block materials properties. FEMM has a built-in library that allows a variety of materials (air, Solid Non-Magnetic Conductors, Silicon Iron and Copper AWG Magnet Wire). Materials properties can be altered while materials from external libraries or other models can be imported. Materials properties can be altered while materials from external libraries or other models can be imported. The next step is the identification of the block materials properties. FEMM has a built-in library that allows a variety of materials (air, Solid Non-Magnetic Conductors, Silicon Iron and Copper AWG Magnet Wire). The 3/3 SRM properties (number of turns and current) should be described. The outer diameter (D4) is 110 mm, D3=80mm, D2=41mm and D1=10mm. Set circuit current in and out is 4 A in series. Set the select block in group 6 at the rotor. The proposed model is as shown in Figure 1.

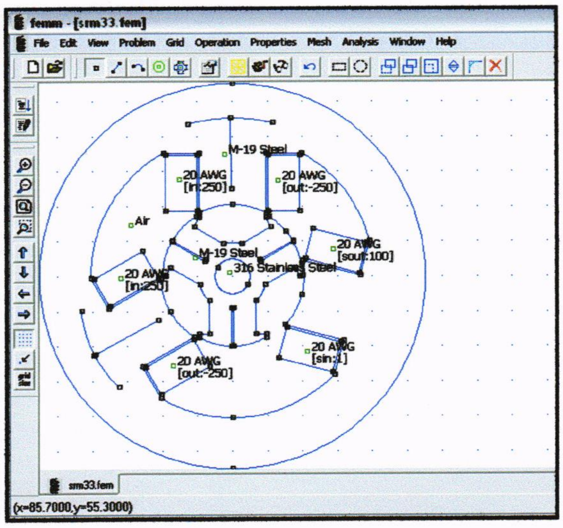

Figure 1: Proposed model

Specification of the properties of line segment or arc segment that are to boundaries of the solution domain is the final step in the model design. The next step is the discretization of the solution space as shown in Figure 2. FEMM breaks the problem down into a large number of triangles. Different mesh size values can be set in each area allowing an increased accuracy without a similar increase in computational cost. After the discretization of the problem domain we apply the finite element method. The time required for the simulation is highly dependent on the problem being solved. Solution times can range from less than a second to several hours, depending up on the problem size and complexity. Linear magnetostatic problems take the least amount of time. Harmonic problems take slightly more time, because the answer is in terms of complex numbers. The slowest problems to analyze are the nonlinear time harmonic, since multiple successive approximation iterations must be used to converge on the final solution.

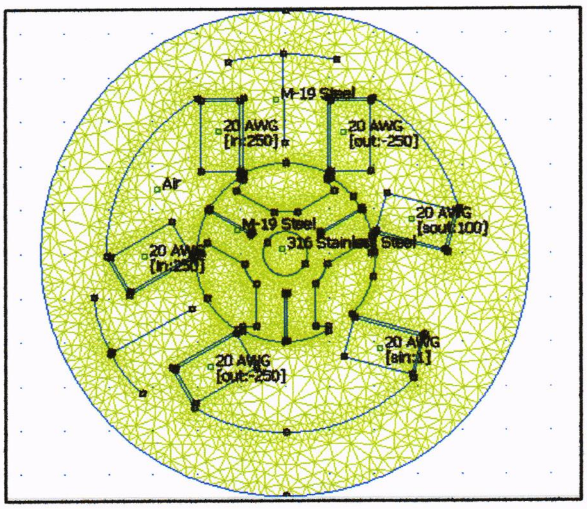

Figure 2: The discretized problem domain

Numerous representations are possible: In Figure 3 the magnetic field flux density plot as well the flux lines contour plot are illustrated offering a complete knowledge of the magnetic field.

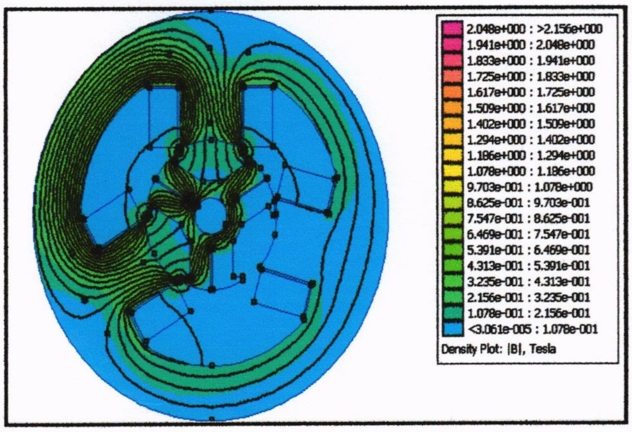

Figure 3: Magnetic flux field density representations

III. Result and Discussion

The result of the simulation for 3/3 SRM is based on the FEMM. After that, transfer the data from FEMM to MATLAB. The flux is saturate and injected into the current flux linkage position data. Figure 4 show the static flux linkage versus current curves.

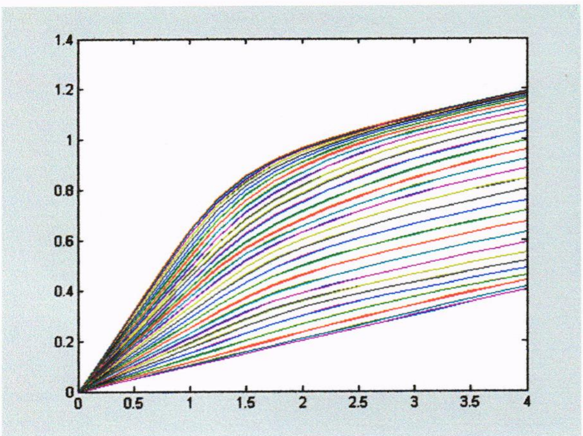

Figure 4: Static flux linkage versus current curves

The current for new time step is obtained by interpolation from the static curves. The result from the interpolation is used to inject into the torque proposed model which produce torque as output. The static torque versus position curves is shown in Figure 5.

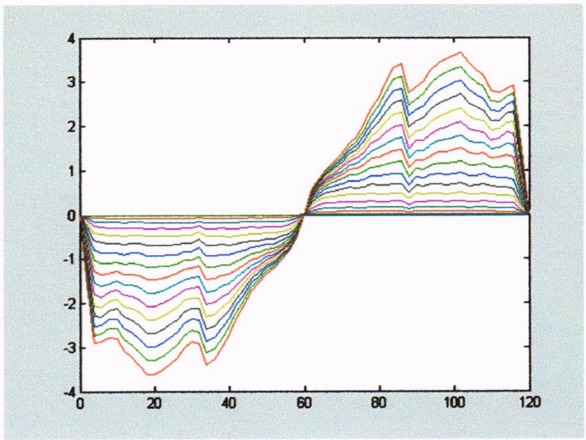

Figure 5: Static torque versus position curves

The torque for new time step is obtained by interpolation from static curves. The torque is used to measure the potential of the motor in a period of time when the motor is generated. When a rotor pole is equidistant from the two adjacent stator poles, the rotor pole is said to be in the "fully unaligned position". This is the position of maximum magnetic reluctance for the rotor pole. In the "aligned position", three rotor poles are fully aligned with three stator poles, (which mean the rotor poles completely face the stator poles) and is a position of minimum reluctance. When a stator pole is energized, the rotor torque is in the direction that will reduce reluctance. Thus the nearest rotor pole is pulled from the unaligned position into alignment with the stator field (a position of less reluctance). When the speeds are being injected at 2000 rpm, the alpha is 5, the beta is 16, the voltage is 220 V, the resistor is 0.2Ω, and the scycle is 120. The result is shown below. Figure 6 showed the waveform of the voltage, current and torque. The maximum current is 1.2487 A, the maximum torque is 1.4288 Nm, and the maximum power is 298.7675 W.

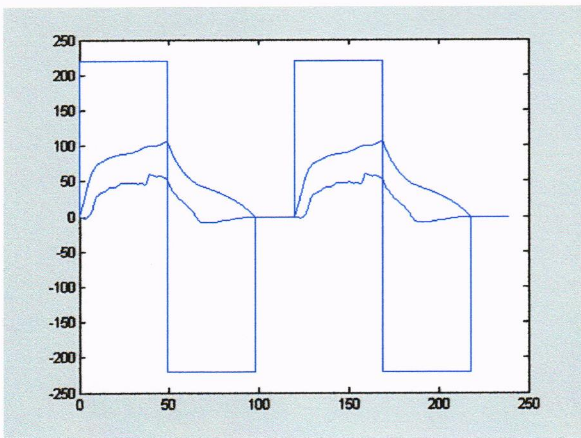

Figure 6: Voltage, 50xcurrent and 50xtorque waveform

For the result of the voltage, current and torque at alpha is 10 and at the same beta as shown in Figure 7. The maximum current is 1.6595 A, the maximum torque is 2.1937 Nm, and the maximum power is 458.7 W.

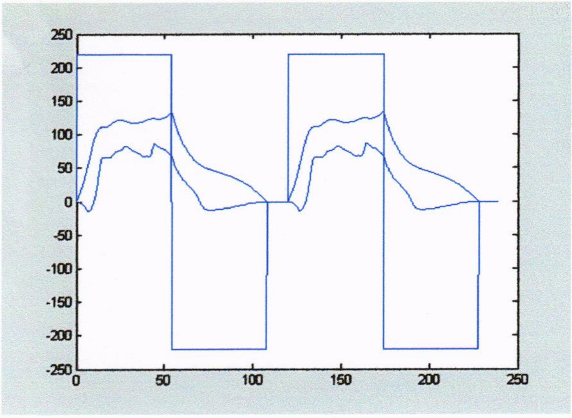

Figure 7: Voltage, 50xcurrent and 50xtorque waveform.

The result of voltage, current and torque at alpha is 15 and the same beta as shown in Figure 8. The maximum current is 2.2053 A, the maximum torque is 3.1772 Nm, and the maximum power is 664.3016 W.

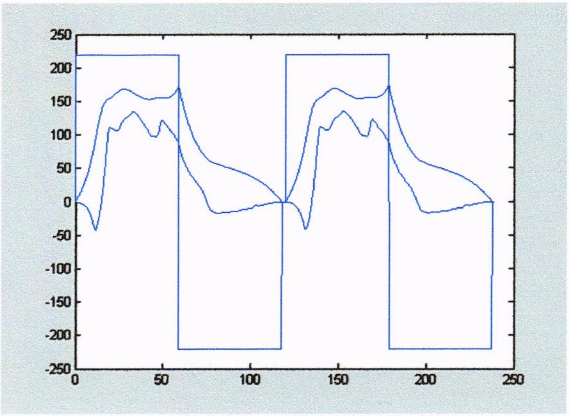

Figure 8: Voltage, 50xcurrent and 50xtorque waveform.

Figure 9 was show the result of voltage, current and torque at beta is 18 and the alpha is 5. The maximum current is 1.2014 A, the maximum torque is 1.4079 Nm, and the maximum power is 294.3977 W.

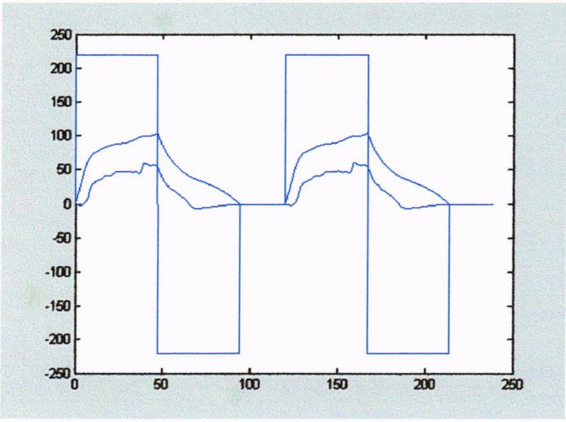

Figure 9: Voltage, 50xcurrent and 50xtorque waveform

The result of voltage, current and torque at the same beta and the alpha is 10 as shown in Figure 10.The maximum current is 1.6027 A, the maximum torque is 2.1787 Nm, and the maximum power is 455.5630 W.

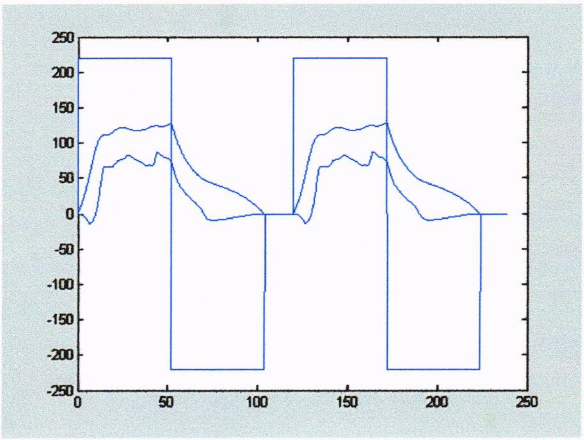

Figure 10:Voltage, 50xcurrent and 50xtorque waveform.

Figure 11 was show the result of voltage, current and torque at the same beta and the alpha is 15. The maximum current is 2.1326 A, the maximum torque is 3.1756 Nm, and the maximum power is 663.9448 W.

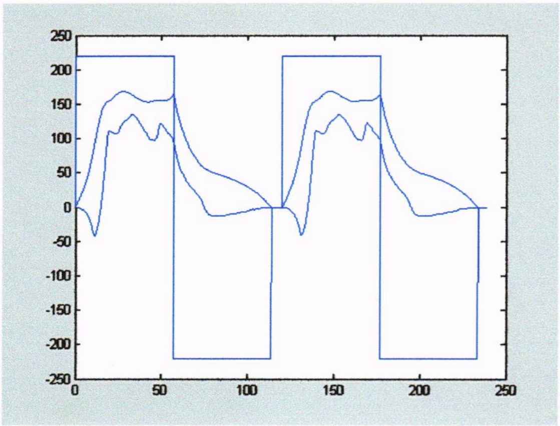

Figure 11: Voltage, 50xcurrent and 50xtorque waveform.

The result of voltage, current and torque at the beta is 20 and the alpha is 5 as shown in Figure 12. The maximum current is 1.1581 A, the maximum torque is 1.3687 Nm, and the maximum power is 286.1954 W.

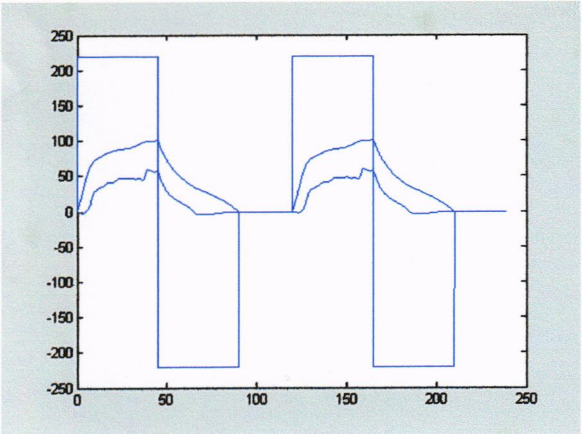

Figure 12: Voltage, 50xcurrent and 50xtorque waveform

Figure 13 was show the result of voltage, current and torque at the same beta and the alpha is 10. The maximum current is 1.5523 A, the maximum torque is 2.1384 Nm, and the maximum power is 447.1251 W.

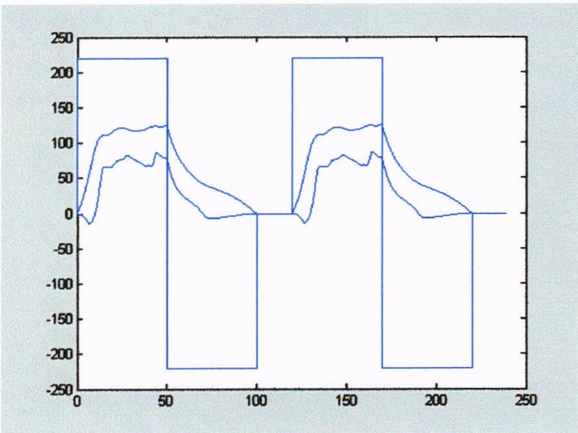

Figure 13: Voltage, 50xcurrent and 50xtorque waveform

The result of voltage, current and torque at the same beta and the alpha is 15 as shown in Figure 14. The maximum current is 2.0698 A, the maximum torque is 3.1372 Nm, and the maximum power is 655.9304W.

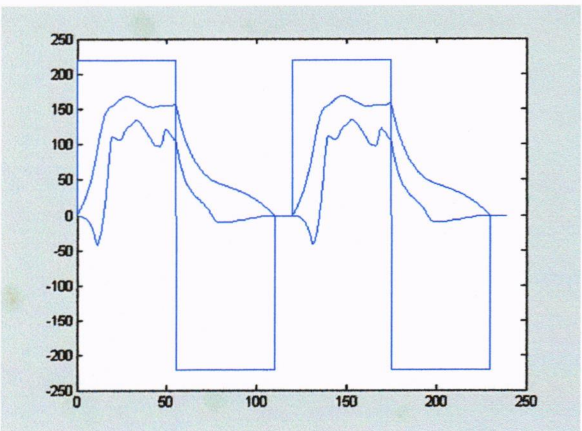

Figure 14: Voltage, 50xcurrent and 50xtorque waveform.

Figure 15 was show the result of voltage, current and torque at the beta is 22 and the alpha is 5. The maximum current is 1.1173 A, the maximum torque is 1.3141 Nm, and the maximum power is 274.7951 W.

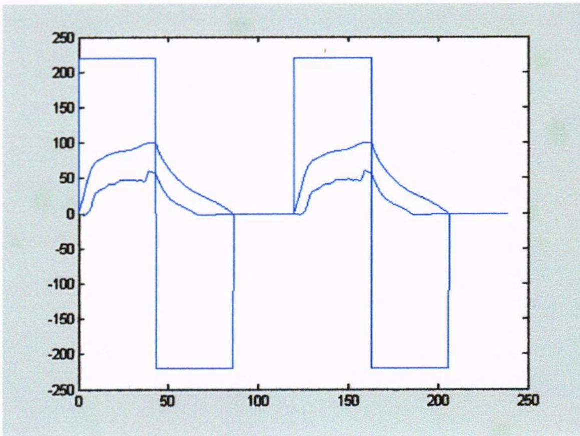

Figure 15: Voltage, 50xcurrent and 50xtorque waveform

The result of voltage, current and torque at the same beta and the alpha is 10 as shown in Figure 16. The maximum current is 1.5061 A, the maximum torque is 2.0759 Nm, and the maximum power is 434.0681W.

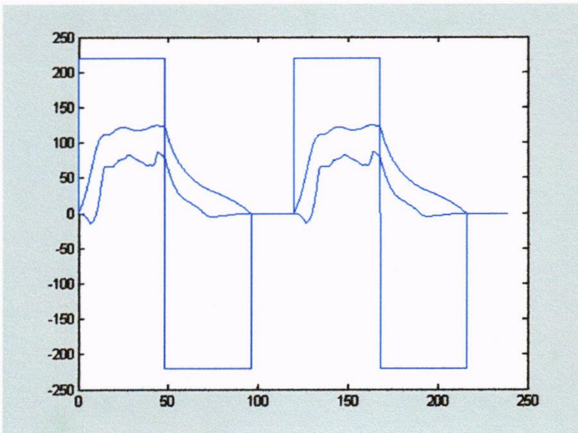

Figure 16: Voltage, 50xcurrent and 50xtorque waveform

Figure 17 was show the result of voltage, current and torque at the same beta and the alpha is 15. The maximum current is 2.0140 A, the maximum torque is 3.0671 Nm, and the maximum power is 641.2750 W.

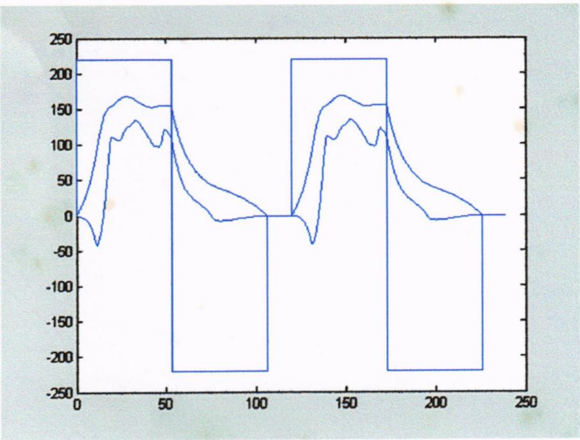

Figure 17: Voltage, 50xcurrent and 50xtorque waveform.

Figure 18 was show the graph power versus alpha.

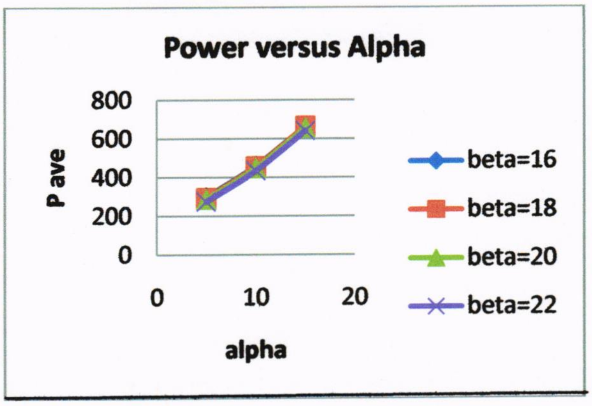

Figure 18: The graph power versus alpha.

Figure 19 was show the graph torque versus alpha.

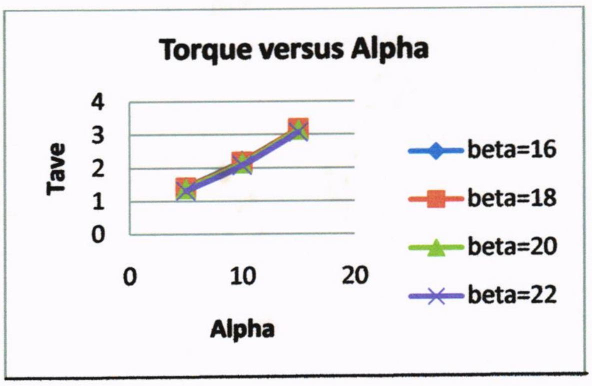

Figure 19: The graph torque versus alpha.

Based on the both graph between power versus alpha and torque versus alpha, the best alpha is 15 which the alpha is unaligned position. Then the best beta is 16 which the beta is aligned position. The beta is 16 and the alpha is 15 because the SRM produce the high power.

IV. CONCLUSION

The simulation of single-phases SRM is completely implemented. The results have shown that the FEMM simulation software produce the data almost the same as the MATLAB software. This proves that FEMM is an alternative for the other simulation software. FEMM data provide the same as the MATLAB. Alternative single-phase machines with the doubled-up pole numbers can offer a better solution for lower speed application. But again watch-out for the ripple especially in voltage control single-pulse operating mode. Common usages for an SRM include application where the rotor must be held stationary for long periods and in potentially explosive environments such as mining because it lacks a mechanical commutator. The phase windings in a SRM are electrically isolated from each other, resulting in higher fault tolerance compared to inverter driven AC induction motors. The optimal drive waveform is not a pure sinusoid, due to the non-linear torque relative to rotor displacement, and the highly position dependent inductance of the stator phase windings. Applications for SRM are used in some washing machine designs and commonly used in the control rod drive mechanisms of nuclear reactors.

REFERENCES

[1]. Switched Reluctance Motor (basic operation of the Switched reluctance motor), 8 August 2009 (http://www.fleadh.co.uk/srm.htm).

[2]. J Skalicky , " Mathematical Model Switched Reluctance Motor ".

[3]. Chalupa, J Diplomavo prace, Brno,1994

[4]. Rajashekara K, Kawamura A, Matsuse K Sensorless Control of AC Motor Drives, ISBN 0-7803 1046-2, New York, IEE Press, 1996

[5]. Leonardo EI J Pract Technol, " Sliding Controller of Switched Reluctance Motor".

[6]. Soares F.P.J., Costa Branco Simulation of a 6/4 Switched Reluctance Motor Based on Matlab/Simulink Environment, Aerospace and Electronic System, IEEE Transactions, 2001,37,p.989-1009.

[7]. K.B.Baltzis, "A Simple, Fast, and Accurate Open Source Electromagnetic Tool in Science and Engineering", University of Thessaloniki, November 2008.