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Switched Reluctance Motor Initial Design for Electric Vehicle Using RMxprt

Kasrul Abdul Karim[1], **Nurfaezah Abdullah**[2], **Auzani Jidin**[3], **Tole Sutikno**[4]
[1,2,3] Faculty of Electrical Engineering, Universiti Teknikal Malaysia Melaka, Malaysia
[4] Department of Electrical Engineering, Universitas Ahmad Dahlan, Yogyakarta, Indonesia

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ABSTRACT

This paper presents a design and development of 8/6 switched reluctance motor for small electric vehicle using analytical method. The absent of permanent magnet, inherent fault tolerance capabilities, simple and robust construction make this motor become more attractive for small electric vehicle application such as electric scooter and go-kart. The switched reluctance motor is modelled using analytical formula in designing process. Later, the designed model is analyzed using ANSYS RMxprt software. In order to achieve 5kW power rating and to match with the design requirement, the switched reluctance motor model has been analyzed using RMxprt tools for the preliminary parameters design process. This tools is able to predict the output performance of motor in term of speed, flux linkage characteristic, output torque and efficiency.

Corresponding Author:

Kasrul Abdul Karim,
Department of Electrical Engineering,
Universiti Teknikal Malaysia Melaka (UTeM),
Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia.
Email: kasrul@utem.edu.my

1. INTRODUCTION

The emission of noxious gases of internal combustion engine (ICE) is now becoming a major issue to environmental pollution. Moreover, ICE also has lack of efficient due on small quantity of fossil fuel which burning up during the combustion process. In view of that scenario, the Electric Vehicles becomes promising solution to overcome this issue. Fully Electric Vehicles can constitute as zero emission vehicles, which an electric motor is used for propulsion and battery as storage devices [1]. It is important to design and develop the electric motor that able to handle sudden large toque and able to operate in harsh environment. In order to meet the requirement of starting, accelerating and climbing, the electric motor has to give constant power above base speed in order to adapt maximum speed and sudden acceleration for overtaking. It also should be able to give higher efficiency over a wide speed range to extend the EVs endurance mileage [2]-[3].

For current the electric vehicle development, the interior permanent magnet (IPM) and the induction motor (IM) are more dominant as a traction force for both hybrid EVs and fully EVs. However, the Switched Reluctance Motor (SRM) that has simple and rugged construction, wide speed range, and high torque density, high level of fault tolerance capabilities, magnet free rotor, low inertia, and potentially low cost production exists as an attractive candidate for EV application [4]. The proposed 8/6 switched reluctance motor is shown in Figure 1 and the geometry parameter will be determined by using analytical formula and the complete dimension will be constructed using ANSYS RMxprt software.

The ANSYS RMxprt is a flexible and easy to used motor design software especially for young researchers. It uses a combination of analytical and magnetic circuit equations to predict the performance of the designed motor. It also provides the easy to use motor template-driven graphical interface that allows user to key-in the pre-calculate motor dimension, type of material and the running setup to speed up the preliminary design.

The next section will explain the design process of SRM and followed by the simulation results in term of speed, flux linkage and torque. The targeted power rating is 5kW with the efficiency of 80%.

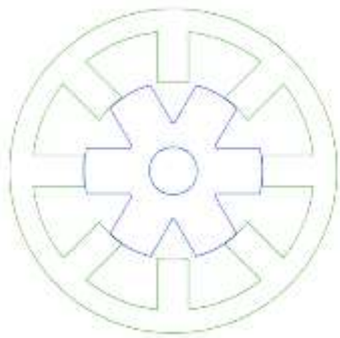

Figure 1. The proposed 8/6 switched reluctance motor

2. DESIGN STEP

In developing a switched reluctance motor (SRM) a proper design procedure must be performed to ensure the efficient performance of the motor. In this paper, the dimension of SRM will be defined using an analytical method. The step describes in [5] has been used to find the basic dimension of switched reluctance motor. The procedure using an analytical technique has been derived from machine characteristics. It will provide the initial motor dimensions and excitation conditions and later on it will use to analyze in RMxprt software. The procedure starts with input parameter as shown in Table 1.

Table 1. general input parameters

No	Parameter	Value	Description
1	Power	5kW	Rated power
2	Electric loading, Asp,	25000<Asp< 90000	Specific electric loading
3	k	for non-servo, 0.25<k<0.70, which is k set to 0.475	Ratio between length to bore
3	Input Voltage	96 V	8 battery connected in series
4	Length of air gap, lg	0.5mm	

It then followed by the series of equations in order to calculate the initial dimension of SRM.

Step 1- Set the outer diameter in the range of 0.57-0.64 for outer stator

Step 2- Define stack length

$$Length = k \times D \tag{1}$$

Step 3- Define air gap cross sectional area

$$Ag = \left(\frac{D}{2} - lg\right)\left(\frac{\beta r+\beta s}{2}\right) - Length \tag{2}$$

Step 4- Define area of stator pole

$$AAsp = \left(\frac{D*L*\beta s}{2}\right) \tag{3}$$

Step 5- Define stator pole flux

$$\varphi = B * Asp \tag{4}$$

Step 6- Define magnetic fled intensity

$$Hg = \left(\frac{B*Asp}{2\mu o*Ag}\right) \tag{5}$$

Step 7- Define allowable current and assume maximum allowable current density

$$Tph = \left(\frac{Hg*(2*\lg\ \ )}{Ip}\right) \tag{6}$$

Step 8- Define area of conductor

$$ac = \left(\frac{Ip}{Jc*\sqrt{q}}\right) \tag{7}$$

Step 9 -Width of stator pole and stator slot

$$Wsp = D\sin*\beta s/2 \tag{8}$$

Step 10- to define stator yoke thickness (*bsy*) it have to be consider below condition as for mechanical robustness and minimization of vibration

$$Wsp > bsy > 0.5wsp \tag{9}$$

Step 11- Define height of stator pole

$$hs = \left(\frac{Do}{2}\right) - \left(\frac{D}{2}\right) - bsy \tag{10}$$

Step 12- To define rotor back iron thickness (*bry*) the consideration of large air gap is must to provide high ratio between inductance aligned and unaligned inductance.

$$0.5wsp < bry < 0.75\ wsp \tag{11}$$

Step 13- Rotor pole height

$$hr = \left(\frac{D}{2}\right) - (lg) - bry \tag{12}$$

Based on the steps of analytical method, initial dimension for SRM is determined as in Table 2 below. The design then, input in RMxprt to determine the output performance in term of torque, winding and inductance profile.

Table 2. Initial motor dimension

Description	Initial Values	Unit	Description	Initial Values	Unit
Stator outer diameter	200	mm	Rotor outer diameter	109.5	mm
Stator bore diameter	110	mm	Rotor bore diameter	30	mm
Stator yoke thickness	14	mm	Rotor yoke thickness	15	mm
Stator embrace	0.45		Rotor embrace	0.5	
Stack length	100	mm			

3. SIMULATION RESULT

Through this section, a switched reluctance motor as in Figure 1 is designed and model using RMxprt. This tool provides an analytical and magnetic circuit equation to forecast the output performance of the motor. The modeling of switched reluctance motor is integrated with shaft position feedback to synchronize the commutation of phase current with precise rotor position. The simulation is running using constant power analysis and has been optimized to operate at 3000rpm. This motor that has lower number of poles is designed to run at high speeds because it has been found that the higher the speed, the lower is the volume and size of the motor. A Reduction gear before the load side can be applied to achieve the desired torque [6].

The simulation result from the RMxprt will be explained first in this section. Figure 2, shows the magnetization characteristic of propulsion switched reluctance motor. The simulation runs from aligned position at zero degree to unaligned position at 78 degrees in ten-degree steps. At 78 degree electrical angle, the flux linkage reaches 0.13Weber.

It also shows the flux linkage curve from unaligned to aligned position of rotor. The SRM ultimate performance could be determined using magnetization and flux linkage characteristic. When the rotor poles align with stator pole phase, it has a maximum inductance with magnetically saturated easily. On the other hand, in an unaligned position it has a minimum inductance. As magnetic saturation is directly proportional to a rotor position, the magnetization curve and the rotor position is an important factor to strategize the motor switching and to determine the ultimate output power.

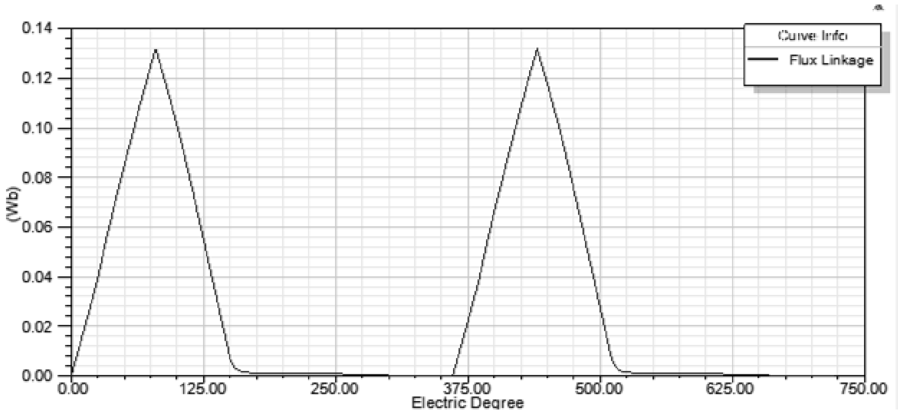

Figure 2. Flux linkage curve

The efficiency of the designed motor is shown in Figure 3. In order to maintain 80 percent of efficiency, the motor should operate at speed above 1200 revolution per minutes. It also has a wide speed range for higher efficiency. To reach maximum efficiency, an optimization technique could be implementing to further reduce the total losses which include stator copper losses, hysteresis losses, eddy current losses, friction and windage losses. To drive a heavy load while maintaining the efficiency require proper selection of reduction gear with minimum mechanical losses.

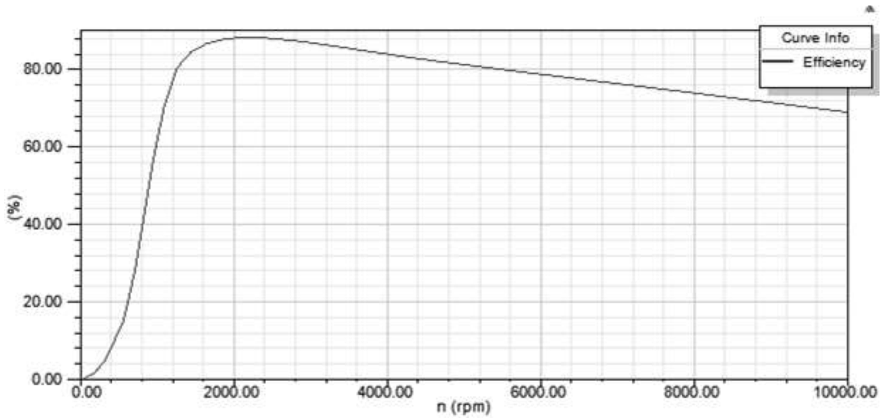

Figure 3. Efficiency to speed curve

Figure 4 show torque-speed characteristic of the designed motor. The starting torque is around 17Nm and it can be seen that an initial torque is on edge due to jerk phenomenon. From the curve, as the rotor rotates at 1000 rpm, the estimated output torque is 50N.m.

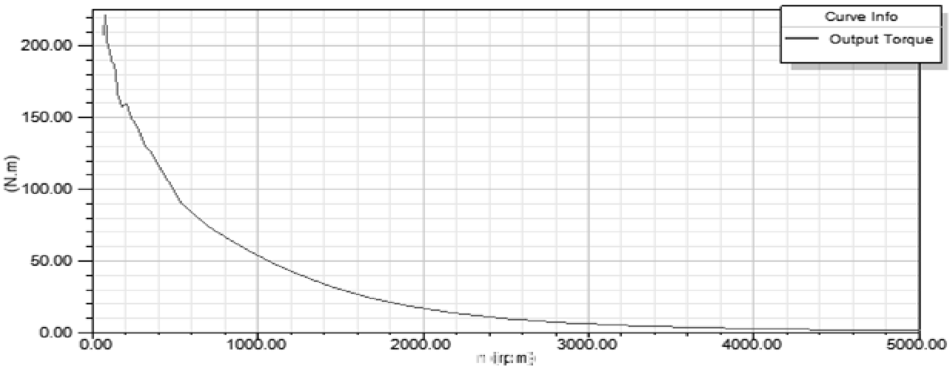

Figure 4. Output Torque and speed curve

The switching sequence for SRM is mainly based on its inductance profile either on the single excitation or multi excitation [7]. In Figure 5 it shows that the air gap inductance at aligned and unaligned position of stator pole. For configuration of 8 slot 6 pole SRM, the inductance profile will repeat at every 45 degree due to the stator pole number. The angle of stator pole arc and rotor pole arc is properly selected to eliminate negative torque and thus reduce unnecessary losses during the operation of the motor. Normally, the rotor pole arc is bigger than stator pole arc. In this case, to produce the positive torque, the phase excitation occurs at 0 electric degrees with trigger pulse width of 90 electrical degrees.

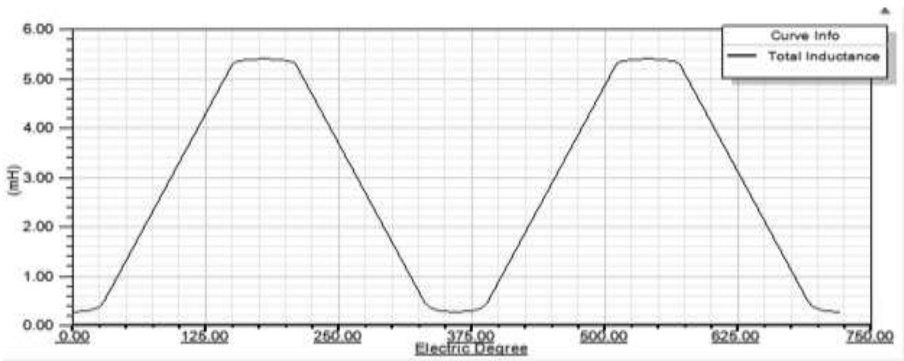

Figure 5. Air Gap inductance curve

As the rated input voltage is 96V, the required number of turn for each stator pole is also low. This will increase the input current as the torque increase. The selection of wire diameter balance with slot's fill factor for cooling purpose must be properly executed. Figure 6 show the phase current of the SRM.

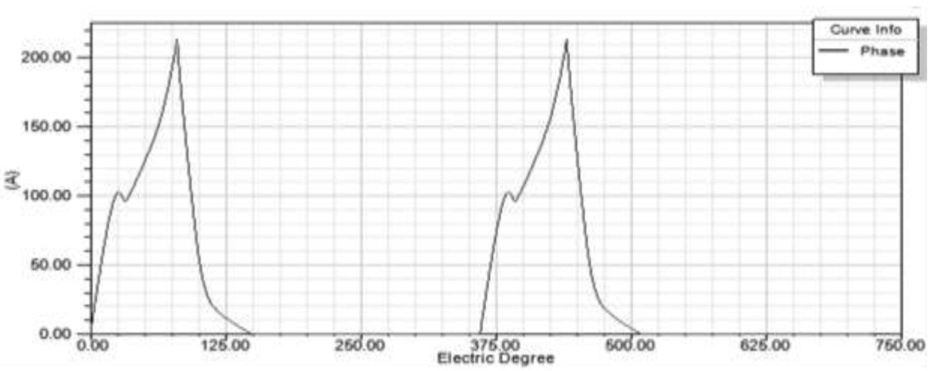

Figure 6. Rated phase current

Performance | Design Sheet | Curves

FULL-LOAD OPERATION DATA

Input DC Current (A):	62.2836
Phase RMS Current (A):	66.2422
Phase Current Density (A/mm^2):	7.9167
Frictional and Windage Loss (W):	5.62308
Iron-Core Loss (W):	182.797
Winding Copper Loss (W):	502.221
Diode Loss (W):	74.196
Transistor Loss (W):	199.536
Total Loss (W):	964.373
Output Power (W):	5014.86
Input Power (W):	5979.23
Efficiency (%):	83.8713
Rated Speed (rpm):	1405.77
Rated Torque (N.m):	34.0656

Figure 7. Full load operation data

4. CONCLUSION

Based on the simulation result, analytical formula has been used to determine the preliminary dimension of a switched reluctance motor. The full load operation data show that the designed motor able to achieve 5kW of output with the efficiency more than 80%. The Rmxprt has been utilized to provide quick performance analysis for the proposed SRM with less hassle. Later, this proposed design has to be strengthened with another design tool to enhance the output performance. The optimization step has to be performed in order to achieve desired performance. Through this output performance, the result will be used to construct the motor for further work.

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BIOGRAPHIES OF AUTHORS

Kasrul Abdul Karim received the M.Sc. from University of Bradford and Ph.D. degrees from the University of Nottingham, UK, in 2003 and 2011,respectively. He is currently a Lecturer with the Department of Power Electronics and Drives, Faculty of Electrical Engineering, Universiti Teknikal Malaysia Melaka, Durian Tunggal, Malaysia. His research interests include electrical machine design, power electronics, and electric vehicle.

N.Abdullah received the Diploma in Electrical Engineering (Mechatronics) from Universiti Teknologi Malaysia,(UTM) in 2007, and B.Eng. in power electronics and drives from Universiti Teknikal Malaysia Melaka (UTeM), in 2012. Currently pursuing studies in M.Sc. Electrical Engineering in Universiti Teknikal Malaysia Melaka .Her research interest include the fielf in machine design, photovoltaic system and power electronic.

Auzani Jidin (S'09) received the B.Eng. degrees, M.Eng.degrees and Ph.D. degree in power electronics and drives from Universiti Teknologi Malaysia, Johor Bahru, Malaysia, in 2002, 2004 and 2011, respectively. He is currently a Lecturer with the Department of Power Electronics and Drives, Faculty of Electrical Engineering, Universiti Teknikal Malaysia Melaka, Durian Tunggal, Malaysia. His research interests include the field of power electronics, motor drive systems, field-programmable gate array, and DSP applications.

Tole Sutikno received his B.Eng degree in Electrical Engineering from Diponegoro University, Indonesia in 1999, the M.Eng. degree in Electrical Engineering from Gadjah Mada University, Indonesia in 2004, and Ph.D degree Electrical Engineering from at Universiti Teknologi Malaysia (UTM), Johor Bahru, Malaysia in 2016. He is currently an Associate Professor in the Department of Electrical Engineering, Universitas Ahmad Dahlan (UAD), and Indonesia. His research interests include the field of power electronics, industrial electronics and informatics, embedded systems and electric drives and FPGA applications areas. He is an Editor-in-Chief/Managing Editor/Editor for some Scopus indexed journals in Electrical Engineering, Computer Science and Informatics areas.