Designing Of A Model Switched Reluctance Motor

Vundyala Vaishnavi Reddy
Electrical and Electronics Engineering
Vardhaman College of Engineering[JNTUH]
Hyderabad, Telangana, India.
Email- vaishnavireddy17eee@vardhaman.org

Kadmur Bharath Kumar Reddy
Electrical and Electronics Engineering
Vardhaman College of Engineering[JNTUH]
Hyderabad, Telangana, India.
Email- bharathkumarreddy17eee@vardhaman.org

Rahul Verma
Electrical and Electronics Engineering
Vardhaman College of Engineering[JNTUH]
Hyderabad, Telangana, India.
Email- rahulverma17eee@vardhaman.org

Chinthapally Bharath
Electrical and Electronics Engineering
Vardhaman College of Engineering[JNTUH]
Hyderabad, Telangana, India.
Email- bharath17eee@vardhaman.org

***Abstract*—The increasing demand for extremely high-performance machines requires more accurate design procedures.The use of Switched reluctance motor is gaining popularity for use in electric vehicles due to the presence of permanent magnet-free rotors. This paper is proposed to design a 6/8 pole and 8/10 poles switched reluctance motor for a rated speed of 25-250 rpm and rated torque of 1.0 kg-m.Switched Reluctance Motor is designed to optimize the torque produced by 3 phase 6/8 pole Switched Reluctance Motor (SRM) and 4 phase 8/10 pole Switched Reluctance Motor (SRM).Additionally, the switching sequence is prominent in the Switched Reluctance Motor.**

***Index Terms*—Electric vehicle, 6/8 pole Switched reluctance motor, 8/10 pole Switched reluctance motor, machine design, torque.**

I. Introduction

The Switched Reluctance Motor(SRM) drive is based on an extremely old theory. According to the principle, "When the magnetically salient rotor is placed in a magnetic field then the flux flow through the rotor, it tries to move toward the minimal reluctance position". Scientists around the world are trying with this principle to make an uninterrupted electrical motion in the first part of the 19^{th} century. Finally, in 1838, W.H Taylor was granted a patent for an electromagnetic engine. However, as compared to AC and DC machines, his machine's fundamental flaw is torque pulsations. In Today's world of variable-speed drives, SRM drives are the most essential developing technology. Advantages of SRM include machine performance, power density, torque density, high speed, weight, volume, and robustness. The ever-increasing pollution and energy scarcity prompted automakers to investigate novel designs and technologies in order to enhance efficiency. The use of high-efficiency motors saves a lot of energy. Apart from performance, torque density is another significant area where these new motors shine Permanent Magnet Synchronous Motors (PMSM) are employed in the EV market. But rare-earth is utilised to make these permanent magnets which are expensive, so switched reluctance motors have grown in popularity in recent years. [2] While efficiency and torque densities are satisfactory, the SRM is one of the most affordable motors available

II. Working

The switched reluctance motor has made its way into the variable speed drive market because of advancements in machine design and magnetic material. The motor is cost-effective in both manufacturing and operation due to its brushless construction. In SRM (Switched Reluctance Motors), currents are switched within the motor's stator windings using a magnetic circuit. This switching mechanism is done by using some power electronic devices. Unlike BLDC motors, this motors stator contains similar windings, but its rotor is made up of steel laminations. [3] These rotor poles are salient in nature. The term "switched reluctance", explains two important things about machine configuration: (a) switched, the motor is operated in a continuous switching mode, only after the advancement in power electronics. (b), reluctance, the reason for the mechanical torque on the rotor. [1]

From figure 1, The rotor is first aligned with stator phase R, and the circuit reluctance is lowest at this point. Unaligned phases P and Q have the largest reluctance, with phase P having the maximum reluctance. As a result, PhaseP has the lowest inductance

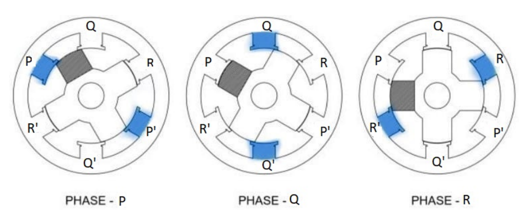

Fig. 1. Working of SRM.

Phase R is turned off and Phase P is energised for anti-clockwise rotation using commutation. As a result, the rotor is pushed to align itself with Phase P.Phase P's current is brought to zero as rapidly as possible because the torque for phase A becomes negative as it attempts to keep the rotor n the aligned position once completely aligned. Phase B has now been activated. This cycle is repeated in the anti-clockwise direction, resulting in a smooth rotating motion. With regard to the rotor position, phase inductance follows a trapezoidal trajectory, and this curve is known as the machine's "Inductance-Profile".

To ensure the rotor pole moves toward the active stator pole when the poles are switched, the actions should be precisely timed. Stator current commutation for these motors is regulated based on the exact location of the rotor. Rotor position is sensed by Hall Effect sensors or encoders. The stepping angle of these motors is wider compared to stepper motors because they have fewer poles. The main application of stepper motors is in positioning applications where step fidelity and high resolution are essential. In contrast, SRMs are commonly used when power density is a vital concern. There are no wound rotors, no magnets, and low inertia in these motors. These motors can get faster and have greater acceleration because of permanent magnet rotors. Between Switch-Reluctance Motors(SRMs) and stepper motors differs the stator structure. In an SRM, each phase is self-contained, meaning if one or more phases fail, the motor will still function, albeit with reduced torque output. Motors with switched reluctance produce a different sound than stepper motors. Activating the stator poles results in a distortion of the stator due to radial forces. This can produce a lot of noise. As a result, radial forces shift the stator.

III. Modelling and designing of machine parts

Initially, in this paper, we intended to select the dimensions of the machine. Later the machine is designed using these parameters and then fabricated.

A. Selection of Dimensions

SRM requires a rated power output, rated speed, peak phase current value, and available DC bus voltage Vdc to design SRM.The rated speed and power output will make us know the rated torque Tn to be developed:

$$W_n * T_n = P$$

In general, the size of a machine depends on the required power output. Therefore, power is directly proportional to the size of the machine (volume of the machine)

$$P \alpha V$$

$$P = KV$$

Units of K is watts/ unit volume The volume is expressed as:

$$= L * W * Dm^3$$

$$= \Pi r^2 hm^3$$

therefore,

$$P = K * 0.25 \Pi d^2 hm^3$$

We know that total power input to the motor is equal to the power stored in magnetic field+ losses + mechanical power output. Therefore, it is always preferred to calculate the parameters of the machine with respect to the output of the machine [4] i.e. torque. Therefore,

$$T = K * 0.25 \Pi d^2 hm^3$$

Here, although volumes are known it's important to introduce a shape factor (a relation between rotor diameter and the length) to proceed further. Designers take this clue from given engineering specification and utilize one of the following simplifications:

- New/free design (no constraints):
$$D = L, V = \Pi D^3$$
- Custom design: Choose a ratio k1 (D/L) representing D/L:
$$V = 0.25 * D^3 \Pi k1 * m^3$$
therefore,
$$T = 0.25 * D^3 \Pi k1 * m^3$$

The rotor doesn't have magnets or coils to it. It is a solid salient- pole rotor made often laminated steel. The rotor is the rotating part of the machine

B. Rotor Diameter

Rotor diameter can be calculated by using torque formula, D in torque equation is the rotor diameter expressed as,

$$D_r^3 = \frac{T}{0.2 * K * K1 * \Pi}$$

C. Stator Diameter

The SRM's stationary component is the Stator. The stator diameter should be large enough to accommodate the rotor, which means the stator radius should be larger than the rotor radius. It should be able to accommodate field coils for producing flux in the magnetic circuit, which means that the stator's outside diameter is proportional to the height of the field coils. To avoid flux saturation, the yoke should be thick enough. This can be accomplished by ensuring that the stator and rotor dimensions are sufficiently different. We may conclude from the above that the stator radius is the sum of the rotor radius, Air gap (Ag), pole height (Tp), and yoke thickness (Ty). Therefore,

$$R_s = R_r + A_g + T_y + T_p$$

The air gap should be as minimal as feasible, but it should be higher than 0.5 percent of the rotor diameter according to best standards. Pole height is related to field coils and must be higher than the field coil height. Because this dimension requires iteration in a design, a general assumption is made. Yoke thickness can be calculated by equating area (A) to the product 2*Ty*Lstk where area can be obtained from

$$A = \frac{\phi}{B}$$

But in general, the stator diameters are in the range of (160-250) percentage of rotor diameter.

D. Slot Depth

To get less copper loss winding area should be increased, so the stator pole height should be as high as possible. In general, the slot depth is 20 to 30 times the air-gap depth(Ag). The magnetic flux density can be calculated using the number of turns, current, Mu-zero, and Mu-iron (B). We can calculate circuit flux using the obtained flux density and core area (Ac). For a particular air gap, we may calculate the device machines force, and hence the torque output.

E. Calculating Number of Turns

The total resistance (Rt) offered by the air gap, core, rotor, and pole height is calculated and it is 1438538 ohms. For 24V input voltage,power 40.83 ,the current is 1.70125 amp .Let us assume that the machine has 60 percent efficiency, then the current at 60 percent efficiency is 2.8 amps. Initially, we assumed the number of turns as 400. Therefore MMF is 1120.

$$\phi = \frac{NI}{R}$$

$$B = \frac{\Phi}{A}$$

From the above two formulas, we will get B(flux density) as 0.315 when the number of turns is 400. To obtain B(flux density)as 0.4, the total number of turns required is 507.

IV. Results

We have calculated the rotor diameter for different k1 values.

EQUAL		1	10	100
	K	25000	25000	25000
	D/L	1	1	1
	Dr,M	0.037073	0.079872	0.17208
	Dr,mm	37.07	79.87	172.08
	Lsk,mm	37.07	79.87	172.08
LONG		1	10	100
	K	25000	25000	25000
	D/L	0.5	0.5	0.5
	Dr,M	0.04671	0.100633	0.216807
	Dr,mm	46.71	100.63	216.81
	Lstk,mm	93.42	201.27	433.61
SHORT		1	10	100
	K	25000	25000	25000
	D/L	1.6	1.6	1.6
	Dr,M	0.031697	0.06829	0.147126
	Dr,mm	31.70	68.29	147.13
	Lstk,mm	19.81	42.68	91.95

Fig. 2. Rotor diameter for different k1 values

Likewise, we calculated rotor diameter for different values of k1 and selected a rotor diameter that best fits our requirement. We calculated all the dimensions of the motor that are required to design for two motors. The finalized calculations of 6/8 pole SRM and 8/10 pole SRM are shown in Figure 3 and Figure 4 respectively.

voltage	24
power	40.83
Air gap	2 mm
Rotor angle	24.5 deg
Rotor pole width	9.3 mm
Stator diameter	100 mm
Stator angle	22.5 deg
Stator pole width	11.5 mm
Stack length	24.68 mm
Rotor diameter	60 mm
Number of turns per phase	507
Number of phases	4
Slot depth	10 mm
Flux density	0.4

Fig. 3. 6/8 pole SRM.

voltage	24
power	40.83
Air gap	2 mm
Rotor angle	22 deg
Rotor pole width	9.3 mm
Stator diameter	100 mm
Stator angle	18 deg
Stator pole width	11.5 mm
Stack length	24.68 mm
Rotor diameter	60 mm
Number of turns per phase	507
Number of phases	5
Slot depth	10 mm
Flux density	0.4

Fig. 4. 8/10 pole SRM.

A. Designing SRM in AutoCAD

The machine parts are designed with the dimensions calculated above.The machine parts designed in AUTOCAD are shown Figure 5.

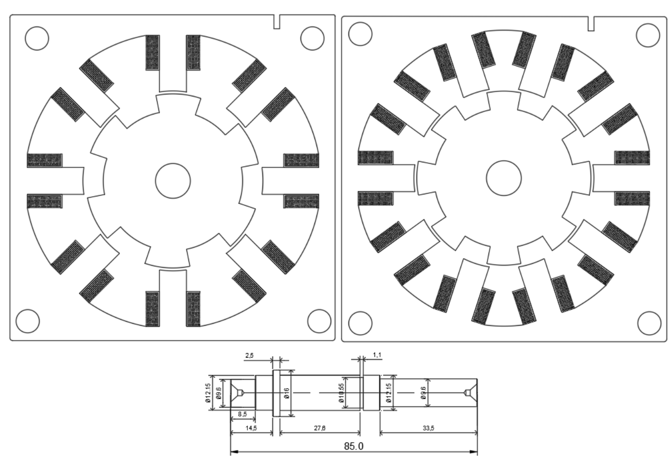

Fig. 5. Rotor and stator of 6/8 and 8/10 pole SRM.

B. Finite Element Analysis

The Finite Element Method (FEM) is used to solve problems that are formulated as field problems.Accurate and reliable results are obtained by using FEM.The flux distribution in the SRM during perfect and partial alignment of stator and rotor poles are shown in Figure 6 and Figure 7.

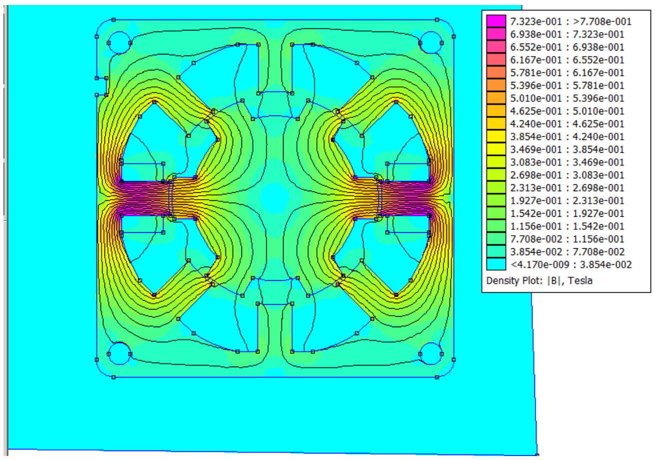

Fig. 6. Flux distribution at perfect alignment

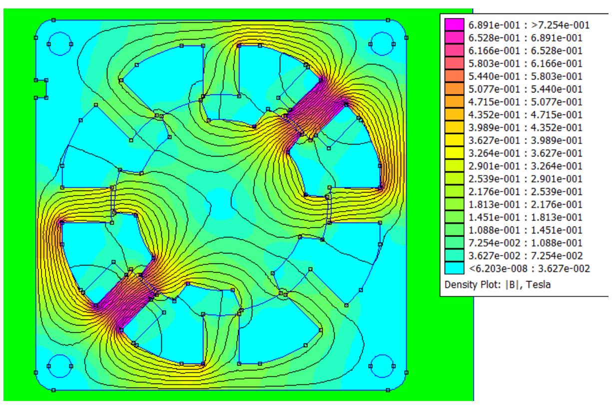

Fig. 7. flux distribution of the SRM

C. Fabrication

After completion of designing in AutoCAD, the machine parts need to be manufactured. We employed a laser cutting method for fabrication. The material used for the machine parts is magnetic iron.After fabrication the machine is shown in the Figure 8.

V. Conclusion

Researchers and scientists within the motor field attempt to manufacture the commutated SRM in the motor series at an inexpensive cost. These machines don't have a rotor ladder, thus there's no rotor loss. The distribution of magnetic iron in the machine determines its potency, and therefore the influence of this distribution changes the efficiency of the machine.

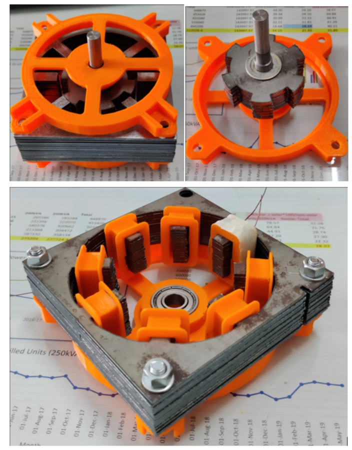

Fig. 8. machine after fabrication

VI. Future Work

Drive details and the performance results are planned to be included in further papers,this paper importantly covers the key design approach for the SRM. Further analysis is required to work out the most effective SRM design. For example, the number of stator coil poles exceeds the number of rotor poles in conventional configuration. So, completely different sizes and configurations should be explored.

One should undergo a deep study to understand the other polarity configuration, like 4/6, so as to optimize the torsion and improve the efficiency. It's necessary to study the stator and rotor combos with odd and even poles such as 8/3poles, 3/2 poles, and 5/3 poles. Employing a bit of permanent magnet material within the SRM rotor will improve motor performance.

References

[1] @phdthesisaljaism2007switched, title=Switched reluctance motor: Design, simulation and control, author=Aljaism, Wadah Abass, year=2007, school=University of Western Sydney (Australia)

[2] @inproceedingsbukhari2018design, title=Design of a high speed 18/12 switched reluctance motor drive with an asymmetrical bridge converter for electric vehicles, author=Bukhari, Abid Ali Shah and Ali, Safdar and Shaikh, Shahid Hussain and Soomro, Toufique Ahmed and Lin, Zhengyu and Cao, Wenping, booktitle=2018 International Conference on Computing, Mathematics and Engineering Technologies (iCoMET), pages=1–6, year=2018, organization=IEEE

[3] @articleyildiz2019investigation, title=Investigation of the effect of stator and rotor pole ratios on torque and efficiency in Inverted Switched Reluctance Motor, author=YILDIZ, Ahmet and Polat, Mehmet, journal=Journal of Engineering and Technology, volume=3, number=1, pages=12–24, year=2019

[4] @bookref5, title=Switched reluctance motor drives: modeling, simulation, analysis, design, and applications, author=Krishnan, Ramu, year=2017, publisher=CRC press