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Study and Simulation of Switched Reluctance Motor Drive Circuit for EV Application

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Abstract

In recent years, an increase in emissions and a decrease in fossil fuels cause environmental pollution and its main air pollution, so we must restore the emissions of vehicles, and this can be achieved with the help of electric propulsion. An electric vehicle is a vehicle powered by an electric motor and powered by a rechargeable battery that can be charged with electricity. It also promotes the use of renewable energy. A rare earth magnet is a primary requirement for most engines. China is the supplier of more than 90% of rare earth magnets in the world and its price is high due to the scarcity of this magnet. So, we need to reduce the use of magnets and this can be achieved by using SRM motors in electric cars due to their reliable structure, high speed, fault tolerance and magnet less design. The main disadvantages of SRM are torque ripple, low power density, low power factor and small extended speed range. To solve this problem, we use an asymmetric bridge converter topology for a 0.5 kW, 2000 rpm, 8/6 SRM drive. Thus, the analysis and problem of Switched Reluctance Motor and the use of power transformers to minimize torque ripple were identified using Ansys Maxwell software (RMxprt tool).

Keywords: *Asymmetric Bridge Converter, Electric Vehicle, Rare Earth Magnet, RMxprt Tool, Switched Reluctance Motor (SRM), Torque Ripple*

1.0 Introduction

In recent years, the increase in emissions and the reduction in fossil fuel shave resulted in environmental and air pollution, so we need to achieve zero-emission vehicles and this can be achieved through electric propulsion. Electric vehicles are vehicles powered by electric motors and rechargeable batteries that can be charged with electricity. It also promotes the use of renewable energies. Different types of motors are used in electric vehicles: (a) Switched reluctance motor (b) DC series motor (c) Brushless DC motor (d) Permanent magnet synchronous motor[1]. Most engines use rare earth magnets for main requirements. China supplies more than 90% of the world's rare earth magnets, but its price is high due to its lack of these magnets. Therefore, the use of magnets needs to be reduced, and the reliability, speed, fault tolerance, and low magnet design of the SRM engine in electric cars are achieved. The main disadvantages of the SRM are torque vibrations, low power density, low power factor, and limited speed ranges[2].

To overcome these disadvantages, we use an asymmetric bridge converter topology for 8/6 SRM motors. An evaluation method for power converters previously published in the Switched Resistance Motor (SRM) drive system was proposed to determine the appropriate converters for SRM-based Electric Vehicle

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(EV) drive systems. From an engineering perspective, four factors are considered as follows: (a) transformer efficiency (b) transformer reliability (c) transformer ability to reduce torque ripple (d) increase power productivity. So, the analysis and problem identified in Switched Reluctance Motor and the use power converters to minimize torque ripple.

1.1 Switched Reluctance Motor

Modified Reluctance Motor is used in Electric Vehicles (EV) and Hybrid Electric Vehicles (HEV), it has a simple and durable structure, the ability to work at high speed and safe operation. The name "switched reluctance" describes two features of the machine configuration: (a) Switched, the machine must operate in a continuous switching mode (b) Reluctance, it is a true reluctance machine in the sense that both the rotor and stator have a variable reluctance magnetic circuit[3].

SRM has many advantages:

- Simple and durable structure.
- It is quieter work.
- It requires less maintenance.
- Its reliability of.
- High starting torque.
- Safe operation.

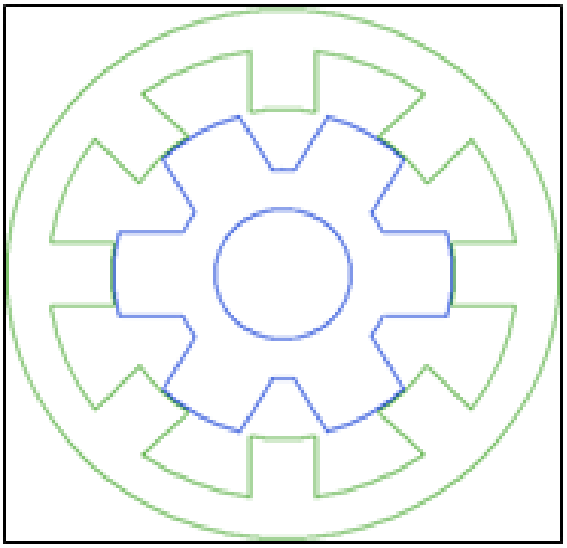


Figure 1. 8/6 SRM.

2.0 Converter Topology

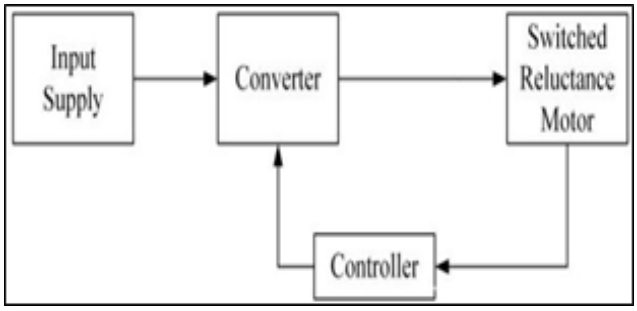


Figure 2. Basic SRM drive[4].

2.1 Requirement of SRM Converter

Switched Reluctance Motors (SRMs) require a converter to control the power flow to the motor windings. Here are some requirements of a converter for a switched reluctance motor:

- The converter must be able to provide the required voltage level and current to drive the motor.
- The converter must be able to switch the current flow to the motor windings at a high frequency to provide precise control of the motor. The switching frequency should typically be in the range of 5 kHz to 20 kHz.
- The converter must be able to implement a control algorithm that can accurately control the current flow to the motor windings. The control algorithm must be able to adjust the phase currents in response to changes in the rotor position.
- The converter must have protection features such as overvoltage, undervoltage, overcurrent, and overtemperature protection to ensure safe operation of the motor and converter.
- The converter should be designed for high efficiency to minimize losses and maximize the energy conversion efficiency of the motor.
- The converter should be compact and lightweight to minimize the space and weight requirements of the overall motor system.
- The converter should be designed to be cost-effective to make the overall system economically feasible.

2.2 Types of SRM Converters

To operate the SRM-driven transformer, a constant voltage DC circuit is used, which can be generated either by AC-DC converters or directly from batteries. The choice of appropriate converters and control systems depends on the specific requirements and performance criteria of the SRM application[5,6].

2.2.1 R-Dump Converter

Figure 3 shows a type of R dump converter this is one of the configurations of a single switch (a transistor) and a single diode per phase. The value of resistor R determines power loss and switching voltage.

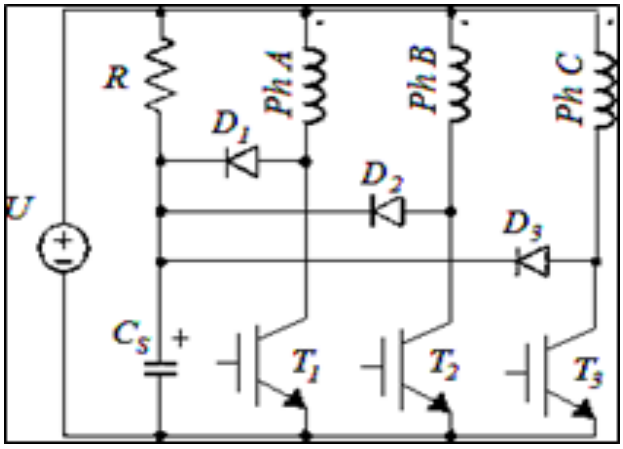


Figure 3. R-Dump converter[7].

When T1 is turned off, the current flows freely through the D1 diode, charges Cs, and then through the external resistance R. This resistor partially dissipates energy stored in the voltage phase[8].

2.2.2 C-Dump Converter

This type of converter is considered to be an auxiliary voltage source converter[9], as shown in Figure 4, because phase demagnetization energy is transferred to an auxiliary voltage source, i.e., a discharge capacitor that restores an intermediate circuit or switches directly to the next phase.

In this transformer, T1 is assumed to be activated to the a-phase of the energizer. When phase current exceeds the reference value, T1 is off, allowing diode D1 to move forward, and the current path is closed by the discharge

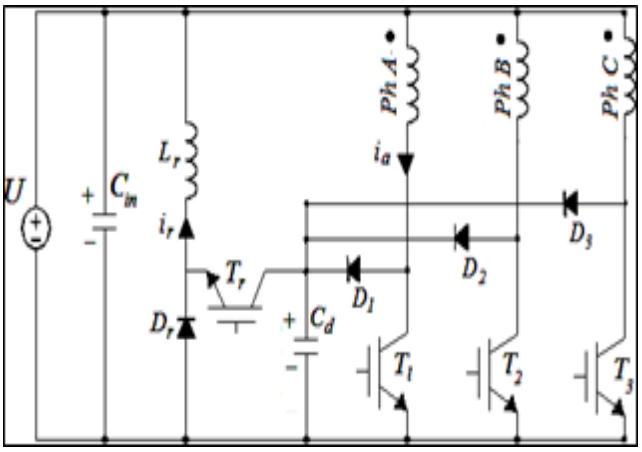


Figure 4. C-Dump converter[7].

capacitor Cd, thereby increasing the voltage and speeding up asymmetric demagnetization. The advantages of the C-dump converter are: the use of fewer switching devices that can control phase-independent current, the full regenerative capability, the rapid commuting of the coil[8].

2.2.3 C-Dump with Freewheeling Converter

The problems of a conventional C-dump converter can be overcome by adding a free-wheeling transistor T_f as shown in Figure 5.

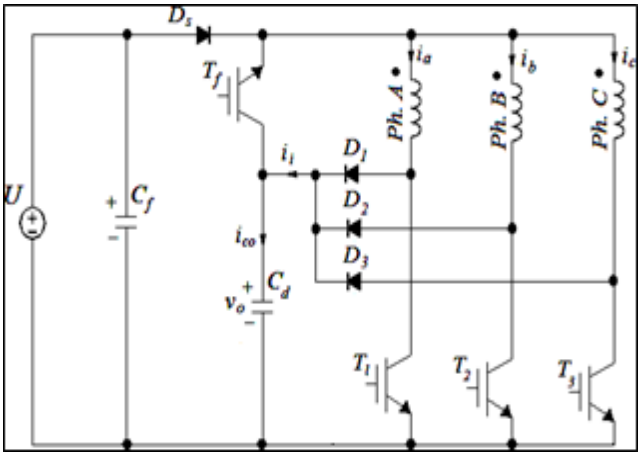


Figure 5. C-Dump with Freewheeling converter[6].

Activate step a; transistor T1 is energized. When the phase current exceeds the specified value, T1 is

deactivated to charge Cd. When the capacitor Cd voltage exceeds the DC source voltage, Tf conducts and the current passes through the path of the machine phase, the diodes D1 and Tf (see the machine phase voltage is almost zero).

2.2.4 Asymmetric Bridge Converter

The excitation current of the three-phase reluctance motor is controlled by asymmetric bridge converters, commonly known as H bridges. Figure 6 shows the configuration of the motor's asymmetric bridge converter.

The transformers with two power switches and two diodes can operate three current modes of multipolar switching strategy: magnetization, freewheeling, and demagnetization. Using this strategy, the system's internal current control loop can improve frequency response and reduce current ripple. When using unbalanced transformers, SRM can be controlled by current or voltage control.

Compared to voltage control, current control offers important advantages in terms of accurate phase current control. This precise control allows you to precisely regulate the torque and reduce the torque flow or noise.

The imbalanced bridge transformer provides greater flexibility in controlling machine currents by applying input voltage values and independently controlling all phases, especially in high-speed operations. Furthermore, the transformer remains highly fault-tolerant, even if one switch is damaged, and it can still reduce the power level. It offers maximum control flexibility, limits the voltage of the switching element to a specific supply voltage value and generates minimal noise[8].

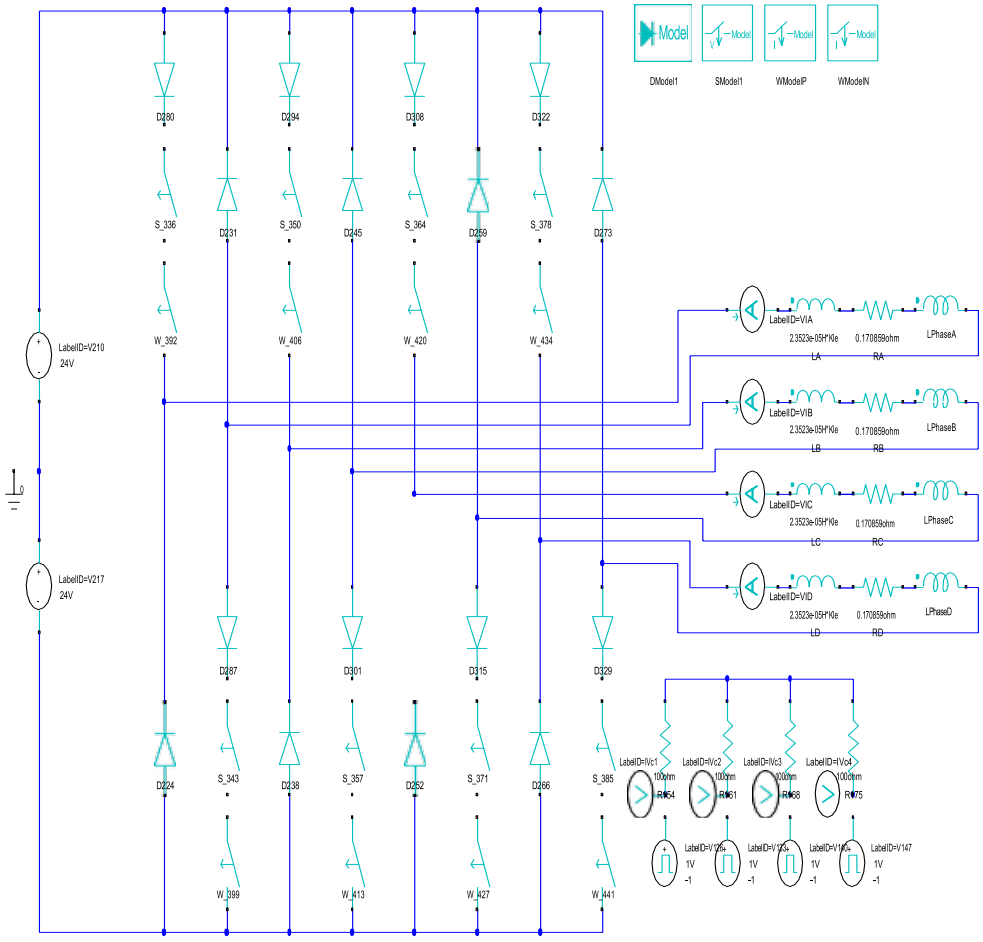


Figure 6. Asymmetric Bridge converter.

One of the disadvantages of converters is that there is always a switch in the current conduction path, leading to loss increases and the need for larger cooling cooling heat storage tanks. In addition, the transformer produces relatively low demagnetization voltage when operating at high speeds[10,11].

3.0 Performance Analysis

4.0 Simulation Results

We have extracted some important features from the SRM engine and covered them in the following paragraphs:

4.1 Efficiency vs Speed Characteristics

The estimated efficiency is 89.0484% at the 2000 rpm speed, according to the corresponding circuit diagram

Table 1. Half voltage type circuit

Sr. No.	Parameter	Evaluated value	Unit
1	Output power	469.904	W
2	Rated torque	12.3004	N-m
3	Efficiency	50.2696	%
4	Rated speed	364.804	rpm
5	Total loss	464.86	W

Table 2. Full voltage type circuit

Sr. No.	Parameter	Evaluated value	Unit
1	Output power	494.051	W
2	Rated torque	2.3572	N-m
3	Efficiency	89.0484	%
4	Rated speed	2001.46	rpm
5	Total loss	60.7606	W

Table 3. Coupled coil type circuit

Sr. No.	Parameter	Evaluated value	Unit
1	Output power	494.051	W
2	Rated torque	2.3572	N-m
3	Efficiency	89.0484	%
4	Rated speed	2001.46	rpm
5	Total loss	60.7606	W

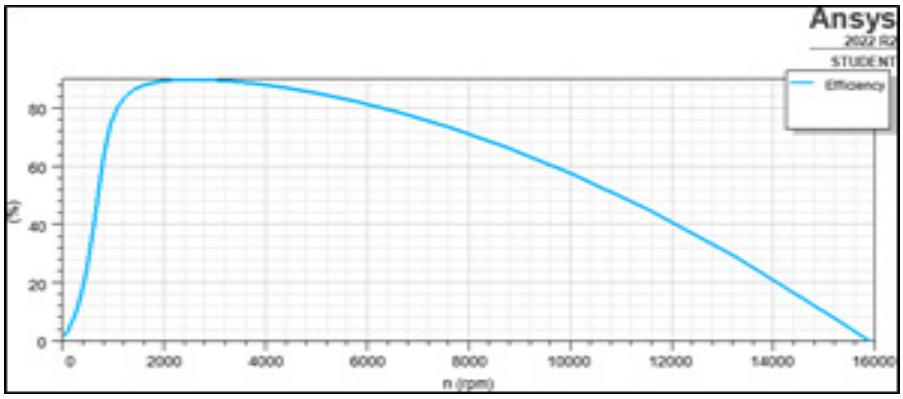


Figure 7. Full voltage type circuit.

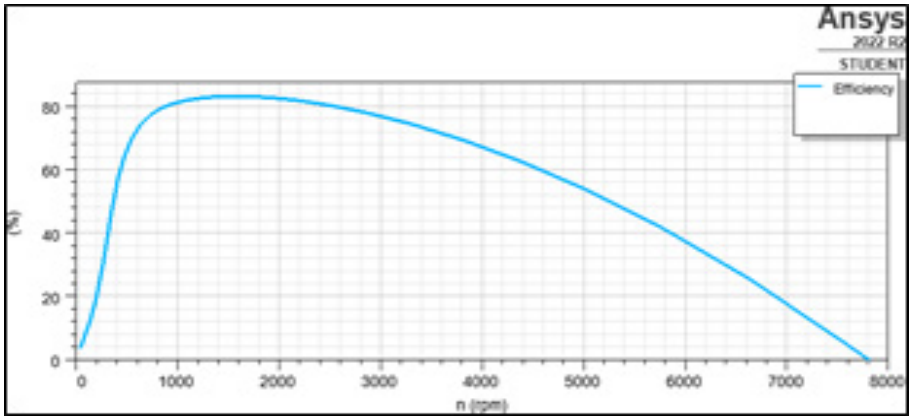


Figure 8. Half voltage type circuit.

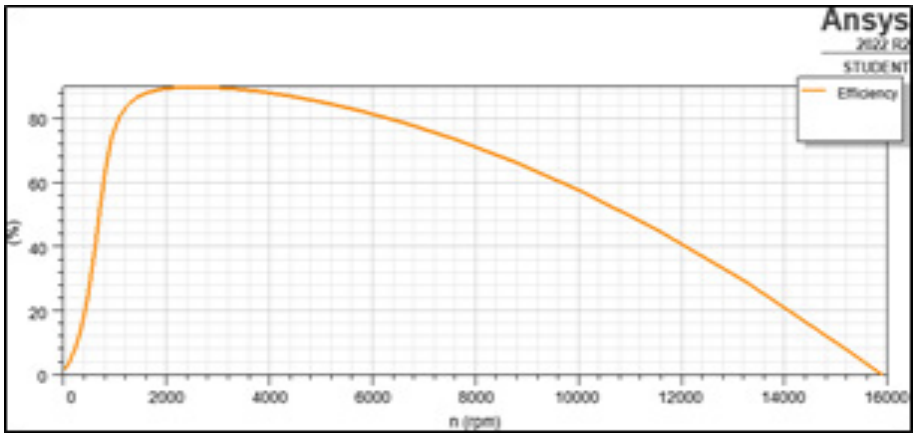


Figure 9. Coupled coil type circuit.

for a full voltage type circuit. The circuit efficiency, as illustrated in the Figure 7 will decrease proportionally with increasing speed.

An estimated efficiency is 50.2696% at 2000rpm, based on the diagram of a half voltage type circuit that can be seen in Figure 8. In addition, as mentioned in

the above diagram, a circuit's efficiency decreases with increasing speed.

The combined coil type circuit is shown in Figure 9 above. Based on an estimate of 2000 rpm, the efficiency shall be 89.0484%. The efficiency decreases with increasing speed according to the curve.

4.2 Output Power vs Speed Characteristics

Figure 10 indicates that the output power is 494.051W at a rate of 2000 rpm, which decreases as speed increases.

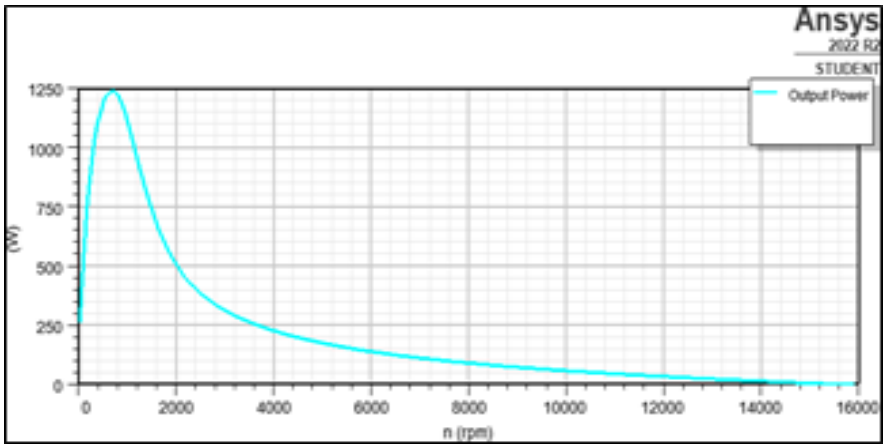


Figure 10. Full voltage type circuit.

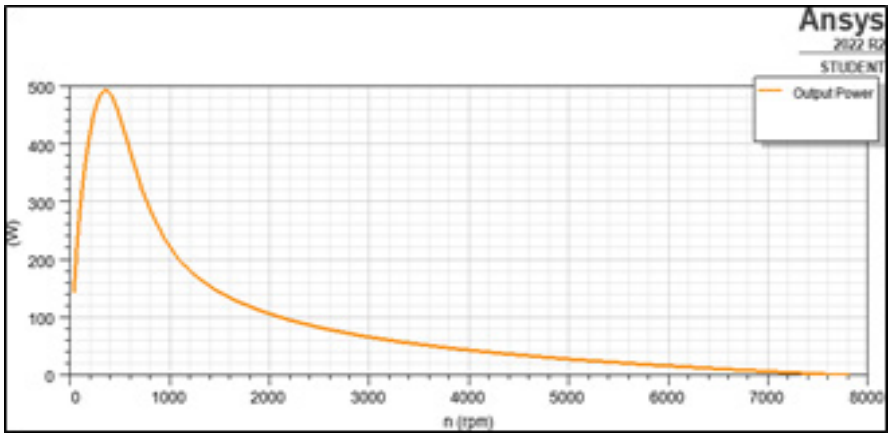


Figure 11. Half voltage type circuit.

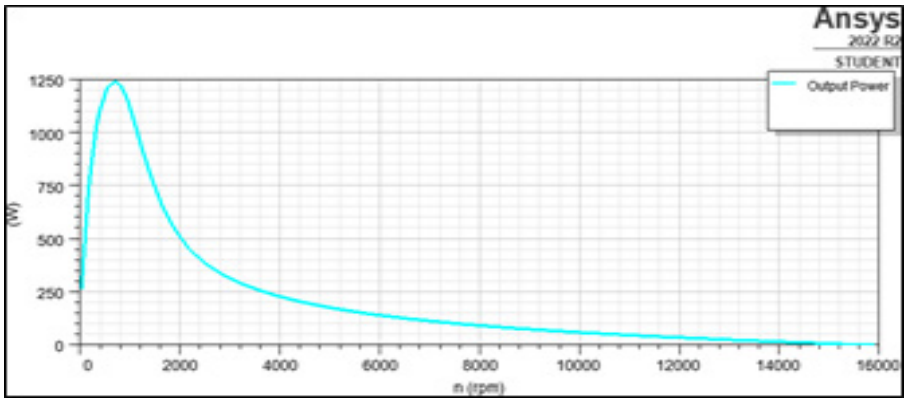


Figure 12. Coupled coil type circuit.

In Figure 11, it can be observed that the output power is 469.904 W when the speed is 2000 rpm, and as the speed rises, there is a corresponding decrease in the output power.

Figure 12 shows a coupled coil type circuit and the power on this curve is 494.051 W at a rated speed of 2000 rpm and in this diagram the power decreases with increasing speed.

4.3 Output Torque vs Speed Characteristics

The torque and speed characteristics of the full voltage circuit are presented in Figure 13. The curve is showing torque of 2.3572 N-m, and can be seen to decrease as the speed increases.

Figure 14 shows the torque and speed characteristics of half voltage type circuit. The curve shows a torque of 12.3004 N-m, and it can be noted that the Torque is decreasing with an increase in speed.

In Figure 15, the torque and speed characteristics of the coupled coil circuit are presented. The curve shows 2.3572 Nm torque, and we can see that there is a decrease as the speed increases.

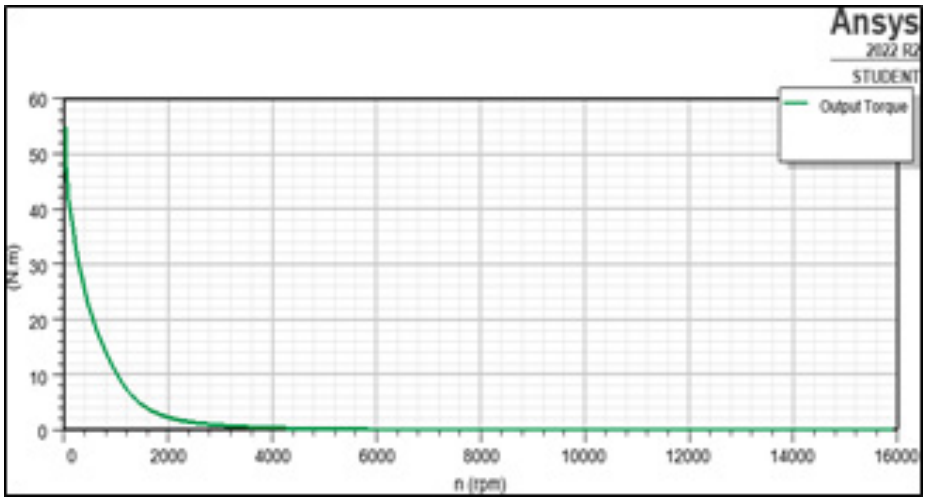


Figure 13. Full voltage type circiut.

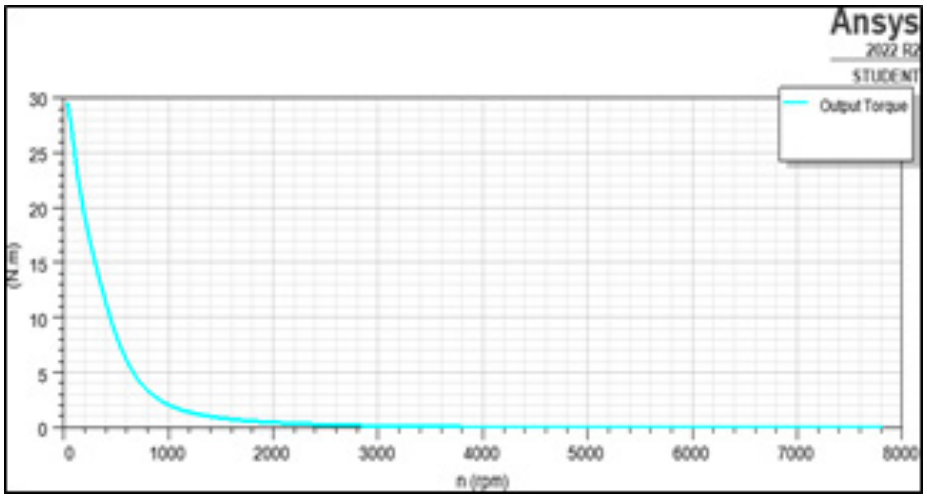


Figure 14. Half voltage type circuit.

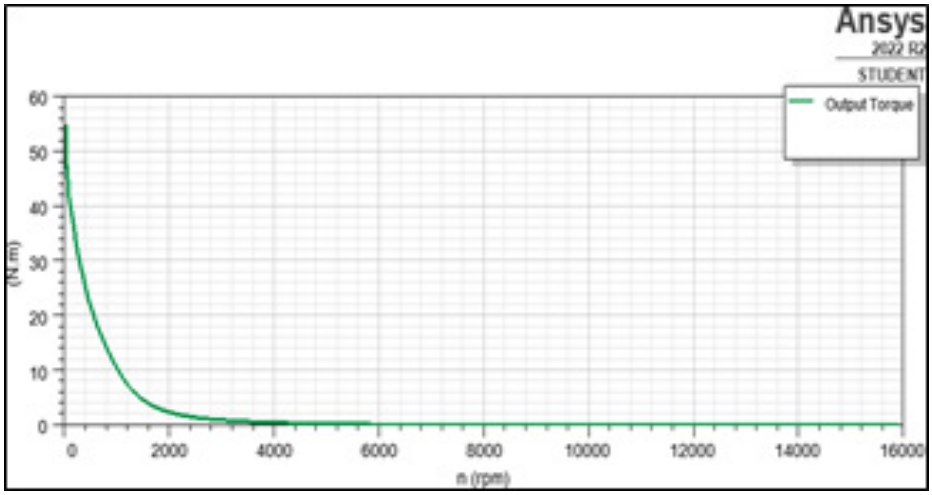


Figure 15. Coupled coil type circuit.

Table 4. General data

Sr. no.	Name	Value	Unit
1	Rated Output Power	0.5	Kw
2	Rated Voltage	48	V
3	Given Rated Speed	2000	Rpm
4	Frictional Loss	8	W
5	Windage Loss	0	W
6	Type of Load (Constant Power)	-	-
7	Type of Circuit (Full -Voltage)	-	-
8	Lead Angle of Trigger in Elec. Degree	0	-
9	Trigger Pulse Width in Elec. Degree	115	-
10	Total Transistor Voltage Drop	0.5	V
11	Total Diode Voltage Drop	0.5	V
12	Maximum Current for Chopped Current Control	575	A
13	Minimum Current for Chopped Current Control	100	A
14	Operating Temperature	75	Celsius

4.4 Torque Ripple Characteristics

The torque ripple characteristics of the SRM are presented in Figure 16. To mitigate this disadvantage, an asymmetric bridge type converter topology is employed for the 8/6 SRM drive, and the simulation is performed using Ansys Maxwell (RMxprt tool) software.

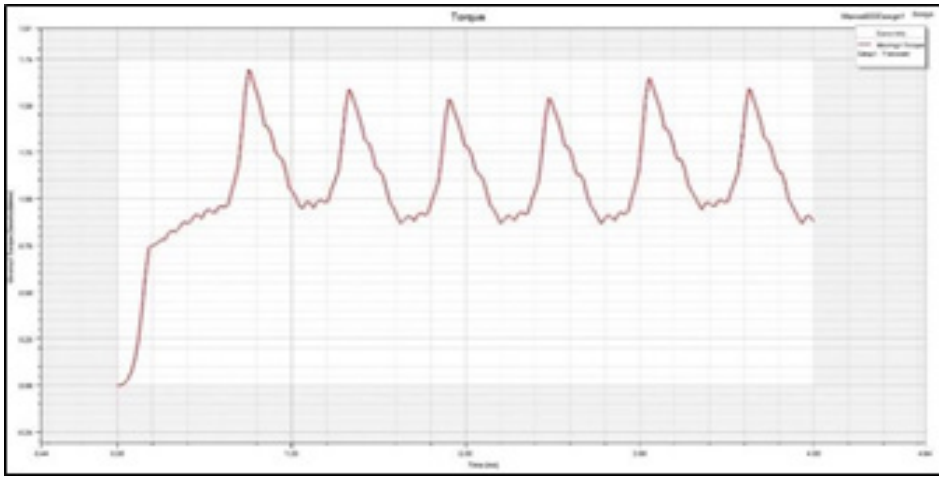


Figure 16. Full voltage type circiut.

Table 5. Full load operation

Sr. no.	Name	Value	Unit
1	Input DC Current	11558.6	mA
2	Phase RMS Current	7886.88	mA
3	Phase Current Density	3788840	A_per_m^2
4	Frictional & Windage Loss	8005.84	mW
5	Iron Core Loss	0.682013	mW
6	Windage Copper Loss	42511.7	mW
7	Transistor Loss	8010.22	mW
8	Diode Loss	2232.19	mW
9	Total Loss	60760.6	mW
10	Output Power	494051	mW
11	Input Power	554811	mW
12	Efficiency	89.0484	%
13	Rated Speed	2001.46	Rpm
14	Rated Torque	2.3572	N-m

5.0 Conclusion

The article suggests that the 8/6 Switched Reluctance Motor (SRM) drive's use of the asymmetric bridge converter topology is well-suited for high-speed operation. The ability of the converter to achieve rapid current decay and rise rates leads to a minimal error rate. As a result, the SRM has an effective efficiency of 89.0484%.

The unbalanced bridge converter, which does not require the addition of a resistive commutation circuit or an inductor to the transformer configuration, is suitable for use with high power switched resistor drive systems known as SRMs. The risk of substantial heat and copper losses is eliminated by this design. Consequently, in view of these applications it is considered as the most suitable converter.

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