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TORQUE RIPPLE & SPEED ANALYSIS OF 10/8 POLE SRM UNDER HEALTHY & CONVERTER FAULT CONDITIONS

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Abstract* – *Switched Reluctance Motor (SRM) is quiet attract the variable drives market by its unique characteristics such as constructional simplicity, built-up inexpensive, extensive speed variety, fault tolerance and high temperature capability. Even though it has several advantages, acoustic noise due to torque ripple is the chief reason to avoid this motor in the industrial applications. The electronic or power converter plays a vital role in the SRM drive. The failure of power converter components also leads to torque ripple. In this paper, torque ripple and speed variation analysis of 10/8 pole SRM under healthy and power converter fault conditions are presented. This is done by using MATLAB® Simulink software and analysing result graphs are clearly plotted at the end.

Keywords - Power converter faults, Speed variation, SRM drives, Torque ripple.

I. INTRODUCTION

Switched Reluctance Motor (SRM) drives are more familiar in the variable drives market. It has been attracts by its unique characteristics such as simple arrangements, doubly salient, singly excited, speed ranges above 30,000 Revolution Per Minute (RPM), less maintenance, fault & high temperature tolerance. In SRM, though various combinations of stator pole (N_s) and rotor pole (N_r) numbers are used. The commonly used SRM motor N_s/N_r ratios are 4/2, 6/4, 8/6, 10/8 are used for 2 phase, 3 phase, 4 phase, 5 phase motor respectively [1], [2]. Its constructional view of basic 4/2 pole SRM is shown in the Fig. 1. Both the stator and rotor has salient poles but only stator has windings. The rotor has no permanent magnets and windings. The motor works on the principle of minimal reluctance. The rotor starts to rotate when the supply is given to the winding which is wound over the stator coil.

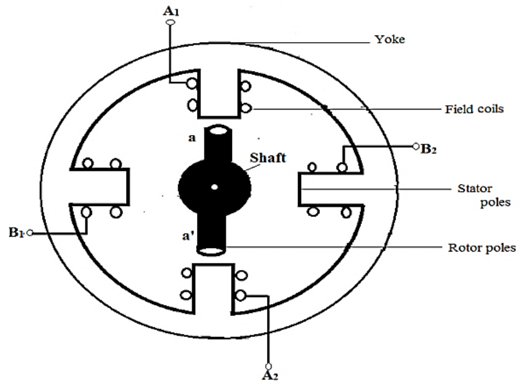

Fig.1. Constructional View of 4/2 SRM

The inward salient pole of stator and outward projection of rotor pole configuration is blameable for the magnetic attraction between motor phases, but it is also blameable for the torque ripple, mainly at high-speed operating conditions and during phase commutation. However, a smooth operation can be achieved if an appropriate control strategy is implemented. Several improved control strategies have been proposed in order to minimize the torque ripple [3], [4], [5].

The analysis & influence of rotor structure on fault identification indices variations for SRMs. It also presents a brand new configuration for dual-channel SRM referred to as decoupled DCSRM beneath traditional and open-circuit fault operations. To realize fault-tolerant operation, a bearing strategy of open-circuit faults for the DDCSRM drive is conferred. The key of the fault-tolerant management strategy is to keep up the rotor speed because the traditional driving operation

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[6]. A brand new algorithmic program for period identification of power convertor faults in SRM drives is planned. The planned algorithmic program effectively detects the electrical converter faulty section and is capable of localizing the faulty power switch [7]. A comprehensive technique for eccentricity fault identification in SRM throughout offline and stand still modes. During this technique, the fault signature is achieved by process the differential currents resulted from injected high frequency diagnostic pulses. In this paper presents the power converter fault investigation technique by using MATLAB Simulink software and results analysed in the following sections.

II.PROPOSED ERROR INVESTIGATION SYSTEM

A. *Block diagram of the proposed technique:*

The Alternating Current (AC) supply of 230 V is given to the uncontrolled rectifier which consists of four parallel diodes connected in two arms. The rectified Direct Current (DC) voltage contains some harmonics; it can be filtered by using capacitive filter or commonly called as dc link filter. The rectified pure dc voltage is given to the electronic or power converter. Here, classical power converter is used to analyse the healthy and faulty conditions. It consists of power switches and freewheeling diodes in two arms per phase which is directly connected with the main winding of the SRM. The general block diagram of SRM drive system is shown in the Fig.2.

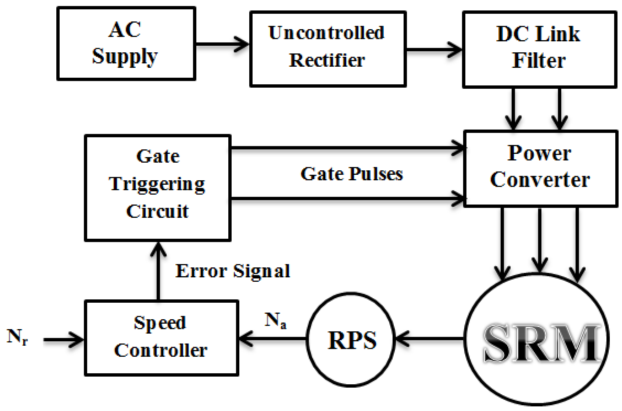

Fig.2. General Block Diagram of SRM Drive System

The Rotor position Sensor (RPS) is connected by the shaft to the rotor. It gives the speed output to the controller and reference speed is also given to the controller. Based on the difference, error signal is generated. It gives as input to the gate triggering circuit; gate pulses are generated used to turn on the power switches which are present in the electronics converter. This is a closed loop operation of SRM drives. Normally SRM faults are classified as electrical & power converter faults. The power converter fault & its analysing methods are made by using MATLAB.

B. Mathematical Model of SRM

The mathematical model of the SRM is inconsistency over a complete operating region. The parameters used in SRM are changing continuously because of its highly non-linear characteristics. The SRM motor is analysis with general mathematical equations [8].

The phase voltage can be written as

$$V = iR + \frac{d\lambda}{dt} \qquad (1)$$

where, V is the DC bus voltage , i is the phase current, R is the resistance in the phase winding, iR is the ohmic drop and λ is the flux linkage.

The inductance of the SRM is changing continuously w.r.to the position of the rotor. The inductance profile of SRM is shown in the Fig. 3.

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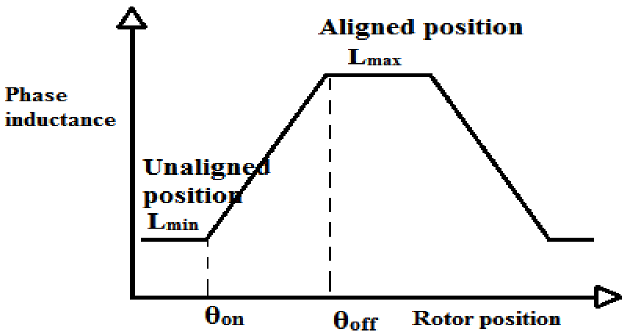

Fig.3. Inductance profile of SRM

The rate of change of magnetic energy can be obtained by multiply current, i in the above equation and it can be written as

$$Vi = i^2R + Li\frac{di}{dt} + i^2\omega\frac{dL}{d\theta} \quad (2)$$

The magnetic energy stored can be written as

$$Wmag = \frac{1}{2}Li^2 \quad (3)$$

$$\frac{dWmag}{dt} = \frac{d}{dt}\left(\frac{1}{2}Li^2\right) \quad (4)$$

The instantaneous torque T is the ratio of mechanical output power (P_{mech}) to the rotor speed (ω) and is given as

$$T = \frac{1}{2}i^2\frac{dL}{d\theta} \quad (5)$$

From the above equation,

T α square of the current & change in inductance,

T α 1 / change in the rotor speed.

C. Power Converter Faults:

Power converter or electronic converter plays a vital role in the SRM motor drive. It is impossible to run the motor without the power converter. It consists of power semiconductor switches and power diodes in the two arms per phase. The SRM starting torque is high so it consumes more phase currents while starting of motor. Hence, Insulated Gate Bipolar Transistor (IGBT) is a current controlled device which is used as switch in the converter circuit. The power converter faults can be classified as

i) Converter Switch Faults &

ii) Freewheeling Diode Faults.

i. Converter Switch Faults:

The IGBT switches S_1 & S_2 are used in parallel at the two arms of the power circuit to limit the starting current of the motor by reducing the turn on or current conduction time. Normally, IGBT faults occurred due to the high temperature condition. If any switch fault occur in one phase, the phase current and voltage to the corresponding phase is zero. But the slight increase the current value to all other phases to attains the required speed level. Fig.4. Shows the schematic representation of converter switch faults.

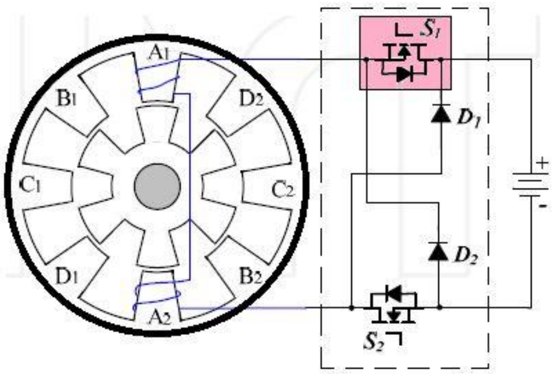

Fig.4. Schematic Diagram of Converter Switch Faults

ii. Freewheeling Diode Faults:

Freewheeling diodes are used to provide the path for current conduction. When the current reaches the reference value, the converter changed into the current regulation mode. During this mode, the current is maintained at the reference value by switching ON one of the phase switches, while leaving the other one continuously OFF till the commutation time is reached. Till such time it maintains as any one diode as active. When the commutation mode, phase starts to demagnetize through the two diodes and the energy is transferred from the motor phase to the dc source or to the conducting phase of the motor.

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The freewheeling diode fails due to the overload condition or continuous running of motor over a long time. During the failure occur, current & voltage pattern changes slightly. So, torque ripples also increases it produces acoustic noises in the environment. The speed is slightly decreased from the reference speed.

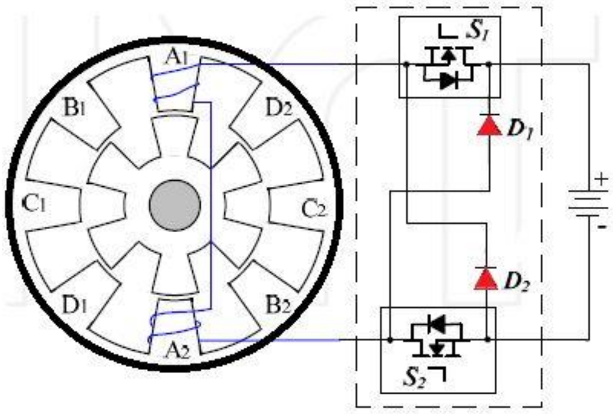

Fig.5. Schematic Diagram of Freewheeling Diode Faults

III.SIMULATION & ANALYSIS

A.MATLAB Simulation

The simulation of the proposed error investigation system consists of ac source, uncontrolled rectifier, dc link filter, speed controller, gate triggering circuit, power converter, phase activation & position sensing block and SRM. The simulation circuit of SRM under healthy condition is shown in the fig. 5.

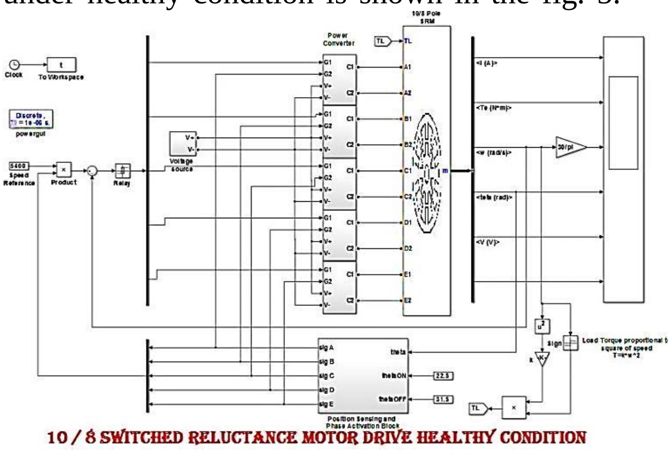

Fig. 5. Simulation circuit of 10/8 SRM under healthy condition

The pure dc voltage is given as input to the power converter by rectifying ac supply and the filter the harmonics using capacitive filter. The SRM phase windings are excited by input supply through the power converter. Each phase consists of two semiconductor switches and diodes. The speed feedback is taken from the motor and given to the controller. The error signal is generated by the difference of the reference and actual speed. The phase activation blocks consists of turn on and turn off angle. The calculation of turn on & turn off angle is given below.

- ✓ Turn on angle,α $= \frac{\pi}{N_r}$ (degree)
- ✓ Turn off angle,β = α + $\frac{2\pi}{q*N_r}$ (degree)
- ✓ Mod input angle = 2α (degree)

  Where,

  N_r = Number of rotor poles,

  q = Number of phases.

Calculation:

i)For 3Φ, α $= \frac{\pi}{4} = 45^0$ & β $= 45^0 + \frac{2\pi}{3*4} = 75^0$

ii)For 5Φ,α$=\frac{\pi}{8}=22.5^0$ &β$=22.5^0 + \frac{2\pi}{5*8} = 31.5^0$

Table 1. Parameters Used in the Simulations

Si.No	*Motor Specifications*	*Value*
1	Number of stator poles	10
2	Number of rotor poles	8
3	Number of phases	5
4	Aligned Inductance(mH)	23.6
5	Unaligned Inductance(mH)	0.67
6	Input Voltage	230V
7	Maximum flux linkages(wb)	0.486

B.Results & analysis:

i) Under Healthy Condition:

The output voltage of the SRM motor is linearly distributed throughout all the five phases of the motor corresponding to the input of 230v dc. The output phase current of the SRM is 12A and it also linear in nature. The rotor speed attains its reference speed of 5500 rpm in 0.7 sec. Due to the benefits of

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conventional converter, torque ripple is relatively less. The output electromagnetic torque of multi-phase SRM is 14.5Nm. The output waveforms of phase voltages, phase currents, electromagnetic torque and rotor speed is shown in the fig. 6.

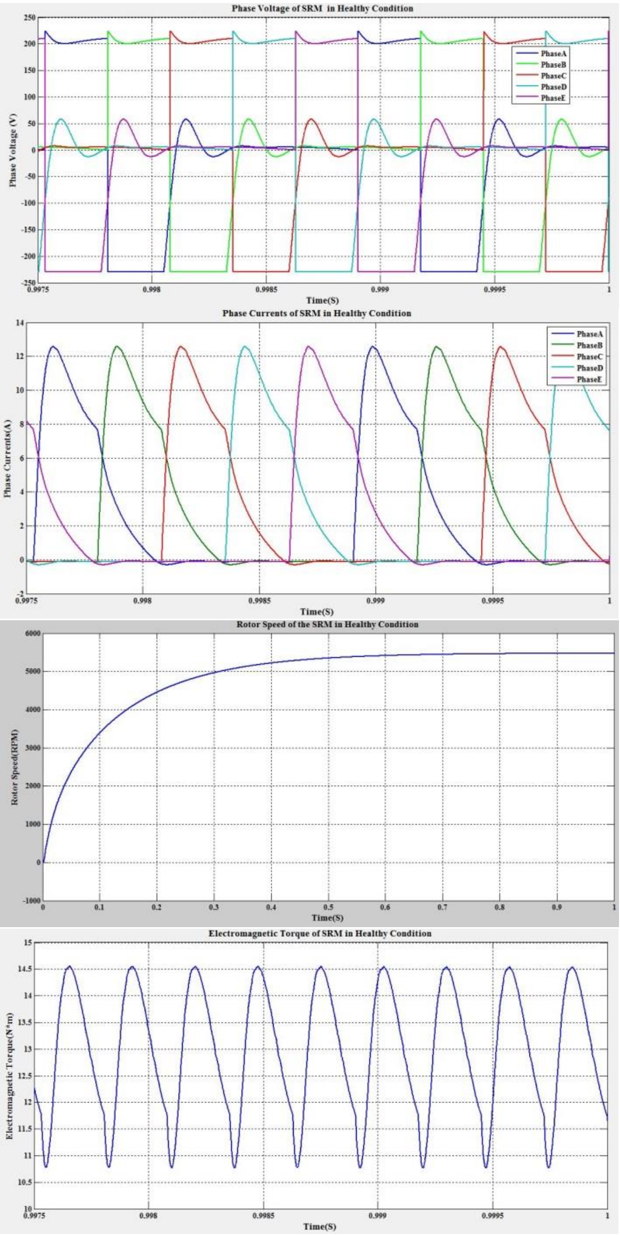

Fig.6. Output waveforms of 10/8 pole SRM under healthy condition

ii) Under Converter Switch Fault Condition:

The output voltage of the SRM motor is linearly distributed to all phases except the faulty phase of the motor corresponding to the input of 230v dc. The fault phase E has zero voltage throughout the operation. The output phase current of the remaining phases of SRM is 14A that is gradually rises from the normal value under healthy condition to attain the reference speed. Even though the rotor speed is unable to attains 5500 rpm.

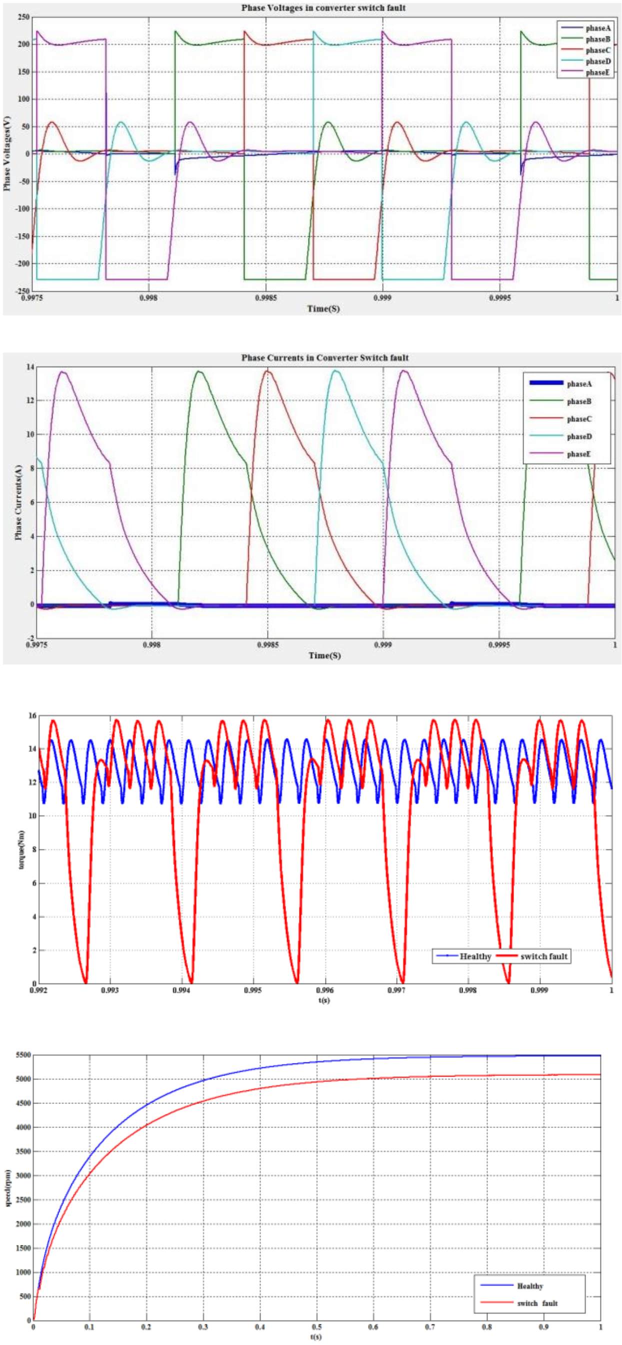

Fig.7. Output waveforms of 10/8 pole SRM under converter switch fault condition

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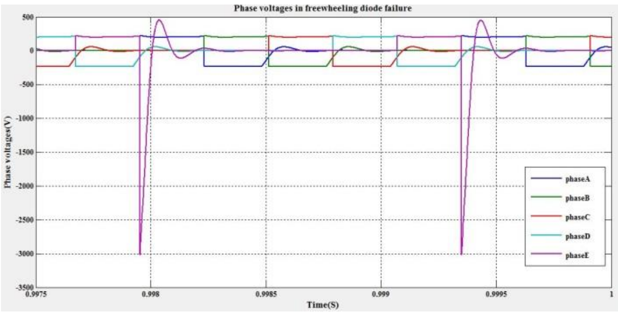
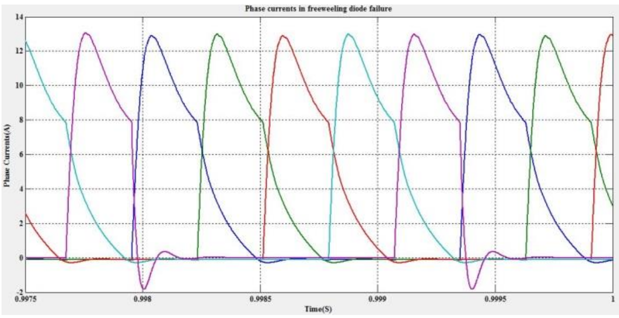
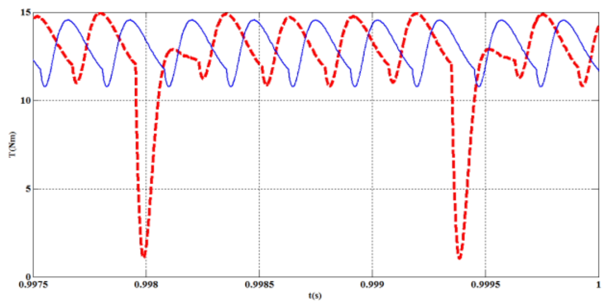
Due to the single phase fault torque ripple is relatively high. But it tries to attain the reference speed, so torque has 1/3 times reduced or zero. The maximum value of output electromagnetic torque in multi-phase SRM is 16Nm. The output waveforms of phase voltages, phase currents, electromagnetic torque and rotor speed is shown in the fig. 7.

iii) Under Freewheeling Fault Condition:







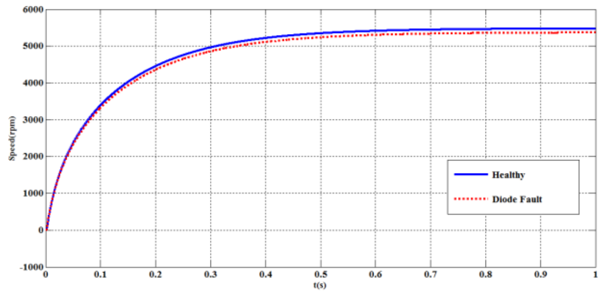


Fig.8. Output waveforms of 10/8 pole SRM under freewheeling fault condition

The output voltage of the faulty phase E of SRM motor is non-linearly distributed throughout the operation corresponding to the input of 230v dc. The phase current is slightly increasing to satisfy the given required speed parameter. So the output phase current of the SRM is 13A and it also linear in nature. The rotor speed attains its reference speed of 5400 rpm in 0.7 sec. Similar to the converter switch fault, torque ripple is relatively high and sometimes it attains 0Nm. Owing to the torque variation, fluctuations also present in the speed output. The output electromagnetic torque of multi-phase SRM is 15Nm. The output waveforms of phase voltages, phase currents, electromagnetic torque and rotor speed is shown in the fig. 8.

Table 2. Comparison values of output parameters

Parameter	Healthy	Switch Fault	Diode Fault
Phase Current A	**12**	**14**	**13**
Phase Voltage V	**Linear**	**Non linear**	**Non linear**
Electro magnetic torque Nm	**14.5**	**16**	**15**
Rotor Speed RPM	**5500**	**5100**	**5400**

IV. CONCLUSION

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The power converter faults analysis of 10/8 pole SRM motor drive using MATLAB Simulink are discussed in this paper. The SRM motor withstands the high temperature and also during the fault conditions with reduced output speed level. But the torque ripple slightly increased and produces some acoustic noises, it makes noisy environment. From simulation result analysis, SRM is able to run during the power converter faults. The simulation results and its values are tabulated clearly.

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