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Inverter fault Analysis in Permanent Magnet Synchronous Motor using Matlab & Simulink

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Abstract

The automation is highly expanded in industrial processes for a variety of applications, reliability, survivability, continuous operation and other fault-related issues are becoming major concerns in the development of advanced. AC machine drive systems.[1] there is a need to analyse the faults of permanent magnet synchronous motor. In this paper I am trying to analyse the performance of synchronous motor under various inverter faults. There are many faults but in this paper I am dealing with only single phase open circuit, single, double & three phase short circuit. Now a days synchronous motor is gaining importance hence their analysis is a necessity for the industrial application.

1. Introduction

Permanent magnet synchronous motors (PMSMs) have been widely used in many industrial applications. Due to their compactness and high torque density, the PMSMs are particularly used in high-performance drive systems such as the submarine propulsion. The permanent magnet synchronous motor eliminates the use of slip rings for field excitation, resulting in low maintenance and low losses in the rotor. The PMSMs have the high efficiency and are appropriate for high performance drive systems such as CNC machines, robotic and automatic production systems in the industry.

Modelling and simulation is usually used in designing PM drives compared to building system prototypes because of the cost. Having selected all components, the simulation process can start to calculate steady state and dynamic performance and losses that would have been obtained if the drive were actually constructed. This practice reduces time, cost of building prototypes and ensures that requirements are achieved.

In works available until now ideal components have been assumed in the inverter feeding the motor and simulations have been carried out. In this work, the simulation of a PM motor drive system will be developed using Simulink. The simulation circuit will include all realistic components of the drive system. A comparative study associated with SPWM inverter fed PMSM under healthy and converter fault conditions will be made.

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2. Pmsm Drive Simulink Modeling

A permanent magnet synchronous motor is fed from a variable frequency voltage source inverter for control of speed and excluding the need of external starting module. For starting permanent magnet synchronous motor without external starting module they are supplied through an inverter varying its AC output frequency from zero to rated value. The voltage source inverter receives DC voltage at its input side and converts this DC input to variable frequency AC output.

There are following three modules in the Simulink modelling of permanent magnet synchronous motor drive. They are as follows:

- Gate Pulse Generator Module
- Inverter Module
- Motor Module

2.1 Gate Pulse Generator Module

In Gate pulse generator module Sine Pulse Width Modulation technique is used for generation of gate pulses for the switching of six inverter switches. This is done by comparing three Sine pulses with a triangular wave.

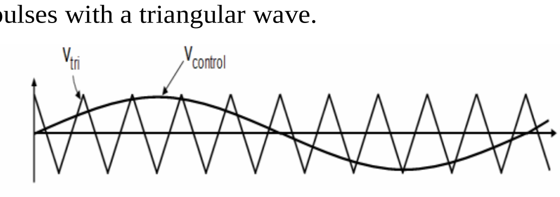

Figure 1 Pulse Width Modulation Switching Logic

Where Vtri is common triangular wave which is compared with three control Sine pulses having a amplitude of 'm' (m≤1) and a relative phase difference of 120 degree with each other.

When Vcontrol is higher than Vtri in amplitude upper switches in the Inverter Module switched ON and output is Vdc/2 while for higher value of Vtri lower switches are switched ON and output is –Vdc/2.

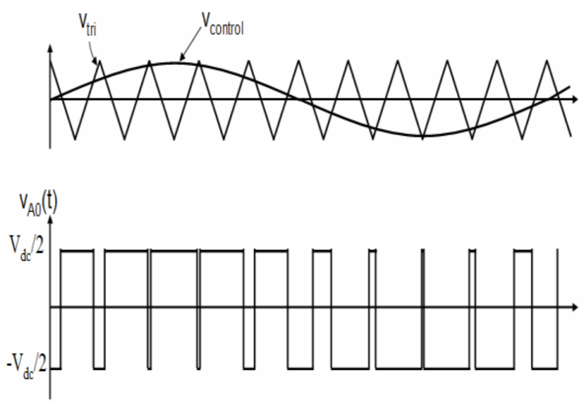

Figure 2 Phase 'A' output Voltage waveform

The frequency input to the sine pulse generator is provided by a set of blocks which generates required sine wave frequency for the generation of gate pulses. The block shown below generates frequency signal to be fed to the sine pulse generator according to the reference speed 'N' provided by the constant block.

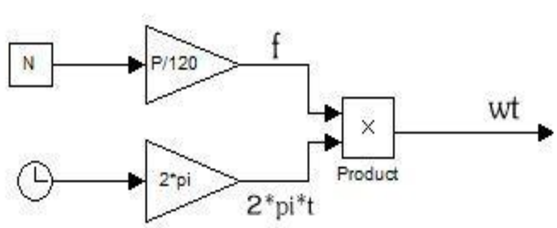

Figure 3 Frequency Generation Block

wt = (2*pi*f)*t

The module shown below uses a multiplexer it receives two signal one is 'wt' and second is 'm' determining the amplitude of Sine pulse. After multiplexing the output is a row vector having two signals [u1 u2].

Where u1 = 'wt' and u2 = 'm'.

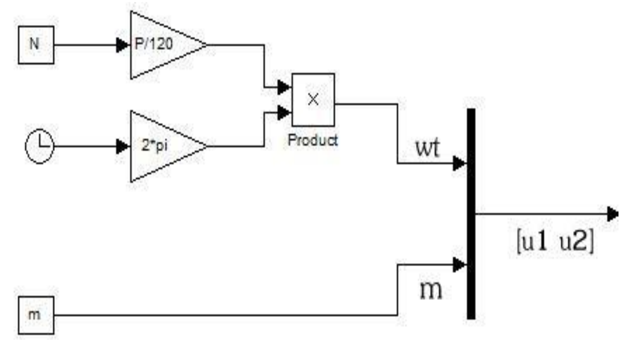

Figure 4 Multiplexer block

The frequency and amplitude signal goes into 3 Sine pulse generator blocks. The output of these blocks are three Sine pulses with relative phase difference of 120 degree with each other.

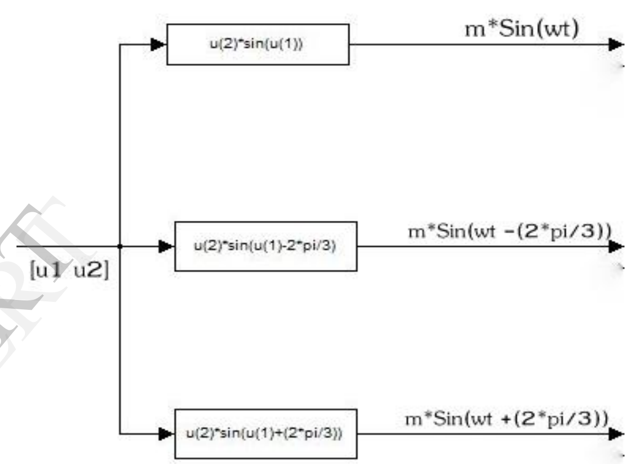

Figure 5 Sine Wave Generation Module

Now gate pulses are generated by comparison of three sine waves (120 degree displaced with each other) with triangular wave. Two gate pulses are generated for each phase namely (G1, G2), (G3, G3), (G5, G6).

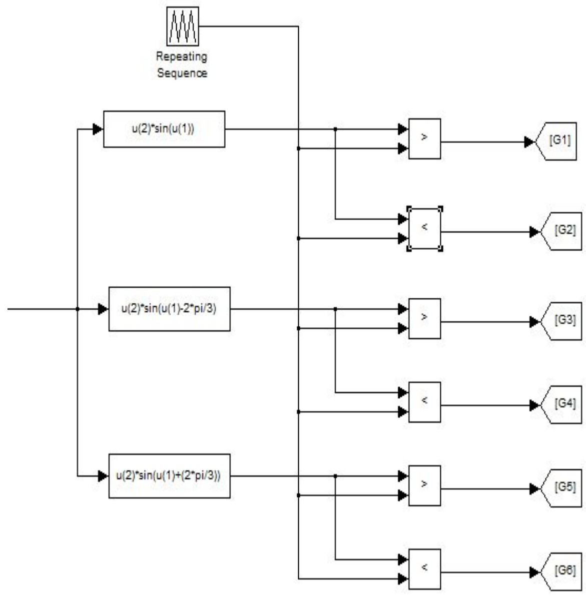

Figure 6 Comparison of Sine and Triangular wave for Gate Pulse Generation

The complete Gate Pulse generator module by comprising the above described sub modules is shown below. It takes reference speed signal as its input and generates six gate pulses for switching six switches of three phase Sine PWM inverter.

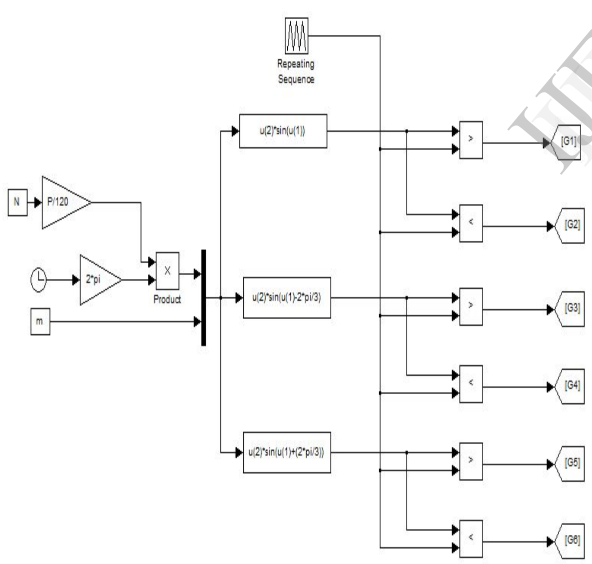

Figure 7 Complete Gate Pulse Generator without fault Module

Now in order to introduce faults in the inverter module we have modified the above shown gate pulse generator by introducing a fault module between the comparator output and go to block providing signal routing to the inverter switches.

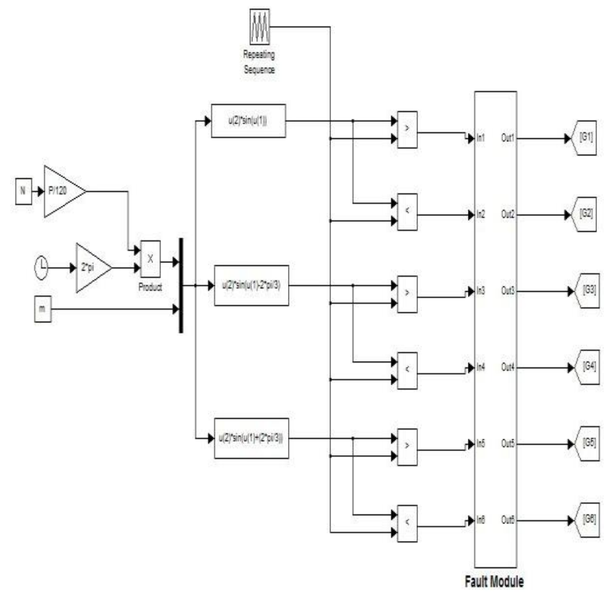

Figure 8 Complete Gate Pulse Generator with fault Module

The internal view of Fault Module is shown in figure below. This fault module blocks the gate pulses of those switches in which we would like to introduce fault. Here In1, In2, In3, In3, In5, In6 are six gate pulse inputs G1, G2, G3, G3, G5, G6 and s1, s2, s3, s3, s5, s6 are post fault gate signals either zero or one.

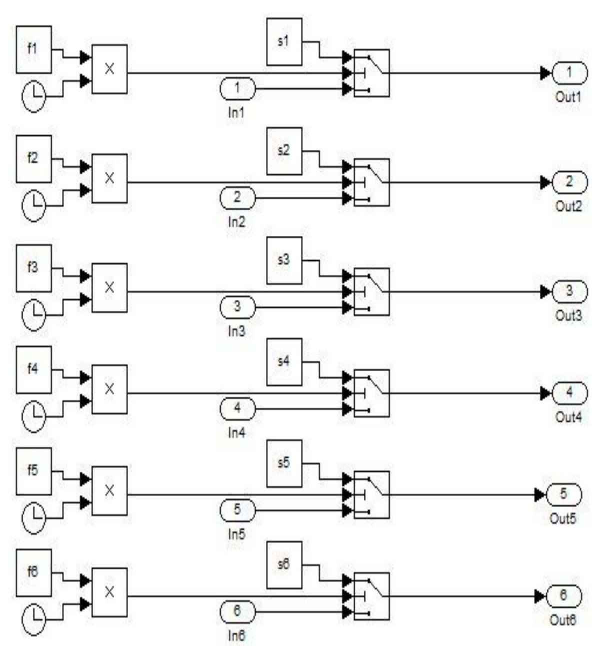

Figure 9 Inside View of Fault Module.

2.2 Inverter Module

The six gate pulses generated from Gate Pulse Generator module are supplied to a three phase inverter. This inverter modulates the input DC voltage to variable frequency AC output according to the pulse width modulation technique.

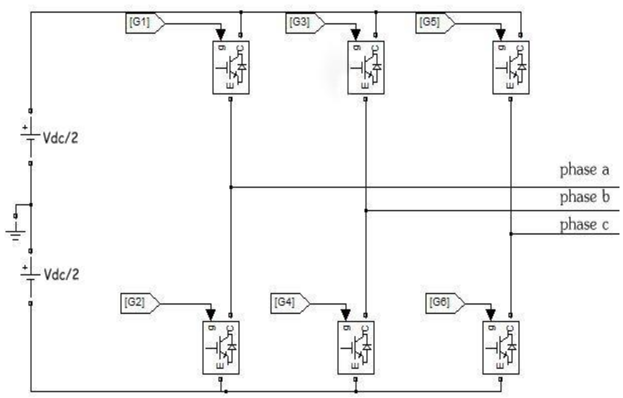

Figure 10 Inverter Module

The peak fundamental phase voltage output from the above described SPWM inverter will be:

$V_{ao} = m*(Vdc/2)$

Where 'm' is amplitude of Sine wave (m≤1) keeping amplitude of triangular wave at '1'.

2.3 Motor Module

The Permanent Magnet Synchronous Machine block operates in either generator or motor mode. The mode of operation is dictated by the sign of the mechanical torque 'T' (positive for motor mode, negative for generator mode). The sinusoidal model assumes that the flux established by the permanent magnets in the stator is sinusoidal, which implies that the electromotive forces are sinusoidal.

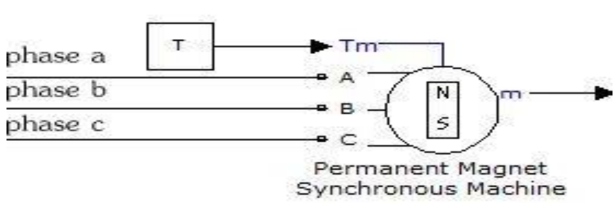

Figure 11 Motor Module

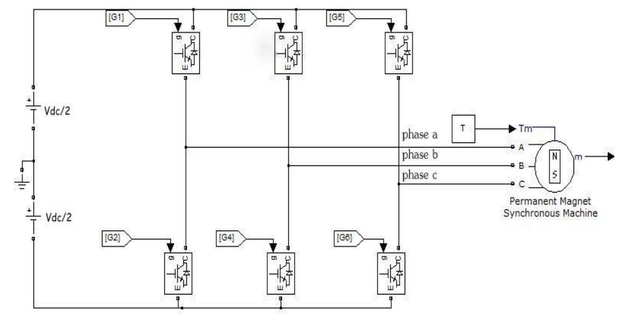

Figure 12 Pulse Width Modulated Inverter fed PMSM

Now this permanent magnet synchronous motor is supplied from three phase Sine Pulse Width Modulated Inverter as shown in the figure above.

3. SIMULATION RESULTS AND DISSUSSION

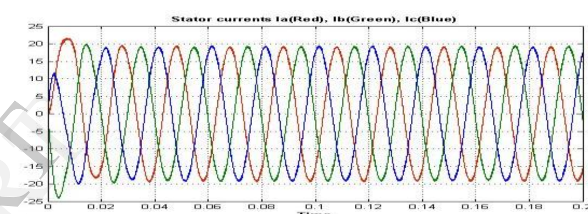

Figure 13 PMSM Stator Current under healthy condition

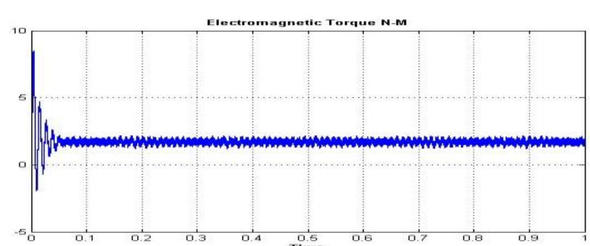

Figure 14 Electromagnetic Torque during healthy condition

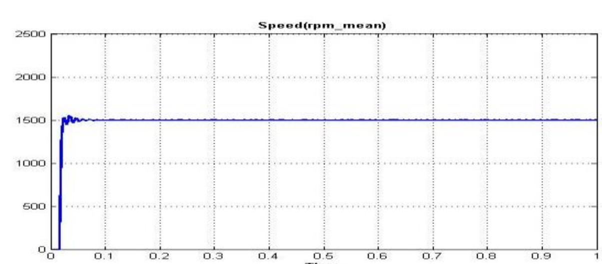

Figure 15 Motor Speed during healthy condition

Simulation of inverter fed PMSM drive is carried out in three conditions.

- In first condition drive is made to run under normal condition without any fault.
- In second condition to introduce single phase open circuit fault in phase ‘a’ gate signals G1, G2 in post fault conditions are made ‘0’.
- In third condition to introduce single phase short circuit fault gate signal G1 and G2 of IGBT of phase leg ‘a’ is made ‘1’ and ‘0’ respectively during post fault period.

After collection of simulation results of PMSM drive under healthy conditions and under open phase fault and single switch short circuit fault condition, analytical discussions are made by comparative study of permanent magnet synchronous motor response under faulty and healthy conditions results are presented.

3.1 SIMULATION RESULTS UNDER SINGLE PHASE OPEN FAULT

The single-phase open circuit may be caused by switch-on failure of both transistors of a same leg in inverter, an electrical failure in one of the inverter phase legs, or a rupture between one phase winding terminal and periphery supply.

In this case, the motor in fact is operated by the rest 2 phases, because no current flows in the fault phase winding. We are using gate signal for control of the IGBT of inverter. To introduce single phase open circuit fault at phase ‘a’, G1 and G2 gate signals during post fault conditions are made ‘0’.

The simulation results for the single phase open circuit fault are displayed as follows:

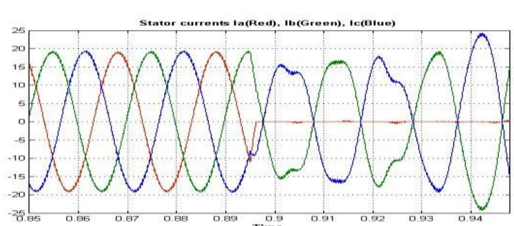

Figure 16 Stator Current during open phase fault

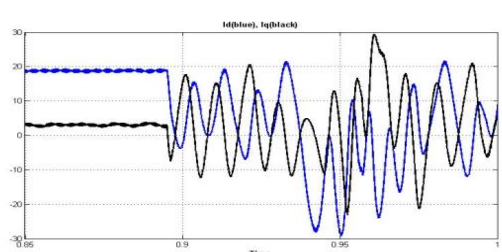

Figure 17 d-q axis Current during open phase fault

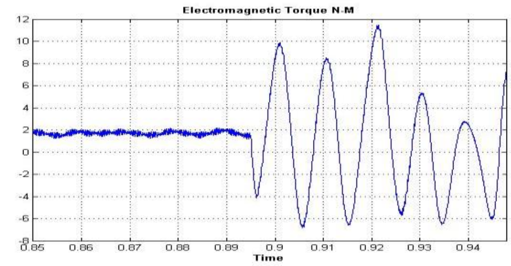

Figure 18 Electromagnetic Torque during open phase fault

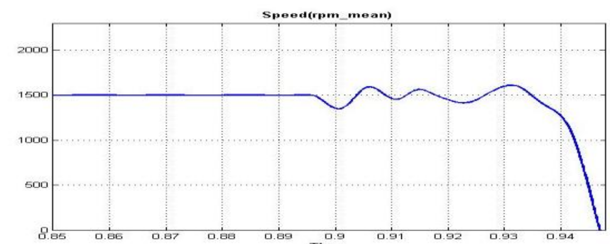

Figure 19 Motor Speed during open phase fault

Figure 4.7 shows the gate signals G1 and G2, as the fault occurs the gate signals G1 and G2 are ‘0’, and the IGBT 1 and IGBT 2 are turned off. The phase ‘a’ is open circuited and does not send any current to the motor. The phase ‘b’ and ‘c’ is connected and supply current to the motor. The Figure 4.8 shows the stator current after open phase fault, after the fault the phase ‘a’ current is zero because the motor terminal of phase ‘a’ is open. It can be seen the currents become 2 phases with 180^o electrical position difference after fault happens. In Figure 4.9, although the mean values of the d and q-axis currents are not varying too much, but the great pulse of d-axis current is a potential danger to irreversibly demagnetize the PM. On the other hand, in Fig.4.10 and 4.11, the post-fault mean electromagnetic torque is almost zero and hence cannot maintain the pre-fault speed [6].

3.2 Simulation Results Under Single Phase Short Circuit Fault

A transistor cannot switch off, which results the complementary one to be switched off by a transistor protection circuit. The other potential reason is a phase terminal rupture and ground of phase terminal. Here in order to introduce single phase short circuit fault gate signals G1 and G2 are made ‘1’ and ‘0’ respectively during post fault condition.

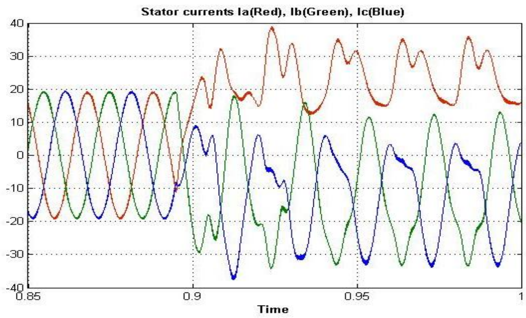

Figure 20 Stator Current during single phase short circuit fault

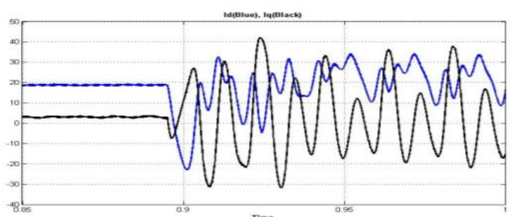

Figure 21 d-q axis Current during single phase short circuit fault

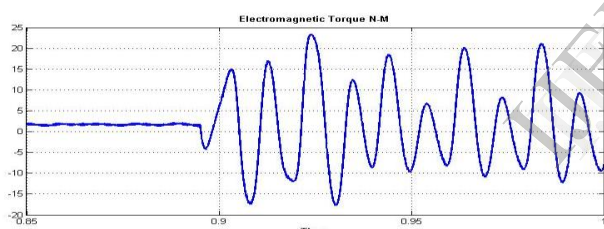

Figure 22 Electromagnetic Torque during single phase short circuit fault

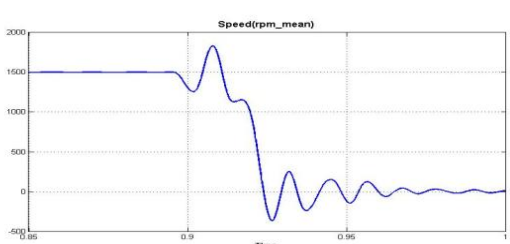

Figure 23 Motor Speed during single phase short circuit fault

In figure 4.13, the current of fault phase gets dominantly positive after 0.895 sec, and the polarities of other 2-phase currents are negative. This accords with the wye connection of 3-phase windings, and the sum of 3-phase currents always is zero. Due to the dominant dc component, the fault phase current is limited by the phase resistance. Despite the high current is applied to motor, the average of generated torque as shown in Figure 4.15 is zero. Due to the positive and negative great torque pulse the motor speed falls. Compared with the open phase post-fault results, the single-short circuit is the most dangerous fault. The huge short circuit current not only is possible to lead to irreversibly demagnetizing of PM, but also could burn the armature coil [3],[6].

4. Conclusion

This project analyzed the potential faults of PMSM in single inverter leg. According to the logic analysis results, a series of dynamic simulations for these faults are established in Simulink@ MATLAB. Especially, the constructions of key modules have been shown in the project. Finally, according to the proposed simulation models, the two faults including single-phase open circuit, single-phase short circuits are implemented successfully. The validity of these simulation methods has been explained and analyzed depending on the result waveforms.

Compared with the open phase post-fault results, the single-short circuit is the most dangerous fault. Single phase short circuit gives the highest transient peak current. The open-circuit fault represents a relatively beginning operating condition, particularly if the machine's back-emf is low (i.e., low) and the post-fault control strategy is to immediately remove the switch gate pulses.

Table 1 comparison of results

parameter		Motor in healthy condition	Open phase fault	Single phase short circuit	Two phase short circuit	Three phase short circuit
Peak Stator current (amp)	Ia	19.45 to -19.3	.71 to -.1	38.2 to -14	23.3 to -11.2	6.3 to -6
	Ib	19.45 to -19.3	26 to -30.5	19.7 to -31	35 to -11.2	4.6 to -6.5
	Ic	19.45 to -19.3	30.7 to -26	20.6 to -31.5	14.9 to -37.5	7.3 to -6

Peak Electromagnetic torque(N-m)	2.145 to 1.27	16.3 to - 12.8	20.9 to - 18.4	21.7 to - 15.7	3.82 to - 1.3
Peak speed(rpm)	1545 to 1467	4070 to - 5080	4960 to - 3890	4680 to - 4730	2100 to 675
Direct axis peak current(amp)	19.45 to 18.9	21.7 to - 29.8	25.8 to - 27.1	30.4 to - 28	6.17 to - 2.82
Quadrature axis peak current(amp)	3.45 to 2.1	29.5 to - 23	37.6 to - 33.2	39.2 to - 28.3	6.9 to - 2.38

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