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Total Harmonic Distortion Analysis during Inverter fault in Permanent Magnet Synchronous Motor using Matlab & Simulink

[1] Shashank Gupta, [2] Dr. Anurag Tripathi
[1]Sr. Lecturer, MPEC, Kanpur, [2]Associate Professor, IET, Lucknow

Abstract

In order to diagnose various potential faults in AC machine drive system and thereby optimize design or enhance protection, the fault results prediction is very important. Unfortunately, it is difficult, expensive and dangerous to test the faults, particularly for the initial design process or high power machines. Thus, the proper computer-aided simulation model for post-fault results prediction becomes much valuable and meaningful in various industrial processes for a variety of applications, reliability, survivability and continuous operation. There is a need to analyse the faults of permanent magnet synchronous motor. In this paper I am trying to analyse the THD of various parameters of permanent magnet synchronous motor under various inverter faults. There are many types of faults but in this paper I am dealing with only single phase open circuit, single, double & three phase short circuit. Now a day's synchronous motor is gaining importance hence their analysis is a necessity for the industrial application.

1. Introduction

In automotive filed, permanent magnet synchronous motor (PMSM)has been widely used to be Integrated Stator/Generator, Electric Power Steering, and even traction of Hybrid Electric Vehicle. The PMSM is usually controlled in the maximum torque per ampere (MTPA) method and flux weakening method. The MTPA method applies maximum current to winding in order to produce great torque. And the flux weakening method applies demagnetizing current to PM in order to raise motor speed. Once a fault happens, a great pulse current or backwash voltage may be generated, which can result in irreversibly demagnetizing action in permanent magnet, exploding in dc capacitor, or damage in IGBT's and motor coils [1]-[4]. Considering the functions of PMSM in automobile, the safe

operation of PMSM becomes much important as well as good performance.

In order to diagnose various potential faults and thereby optimize design or enhance protection, the fault results prediction is very important. Unfortunately, it is difficult, expensive and dangerous to test the faults, particularly for the initial design process or high power machines. Thus, the proper computer-aided simulation model for post-fault results prediction becomes much valuable and meaningful. 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 low maintenance is required. 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 Modelling

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.

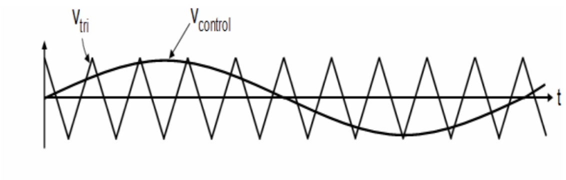

Figure 1 Pulse Width Modulation Switching Logic

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.

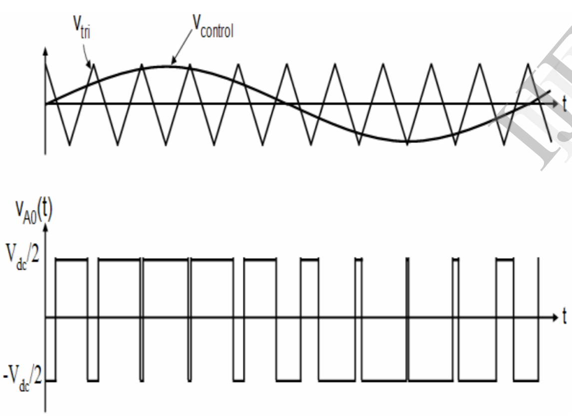

Figure 2 Phase 'A' output Voltage waveform

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.

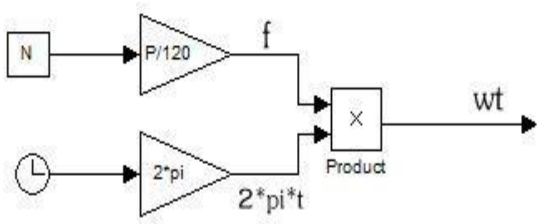

Figure 3 Frequency Generation Block

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'.

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

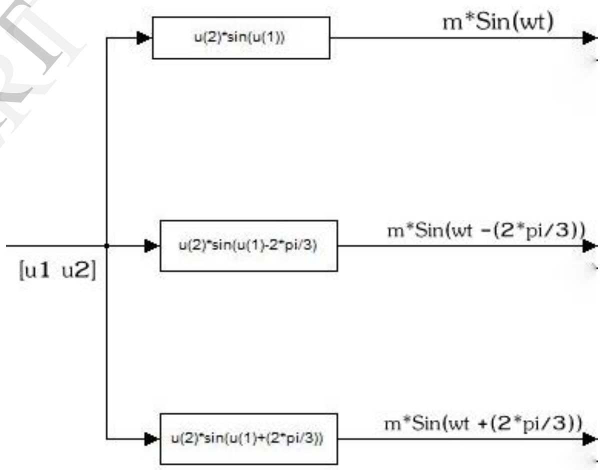

Figure 4 Sine Wave Generation Module

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).

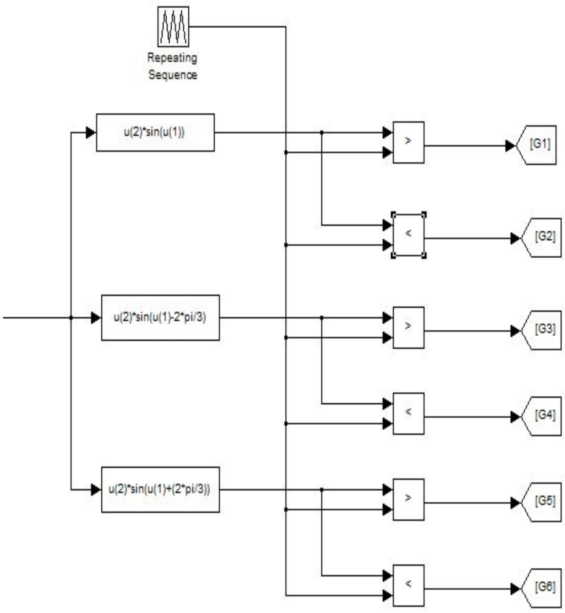

Figure 5 Comparison of Sine and Triangular wave for Gate Pulse Generation

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.

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.

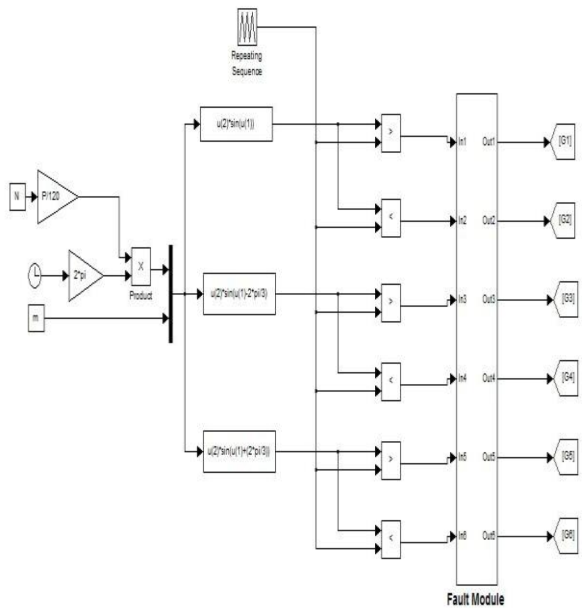

Figure 6 Complete Gate Pulse Generator with fault Module

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.

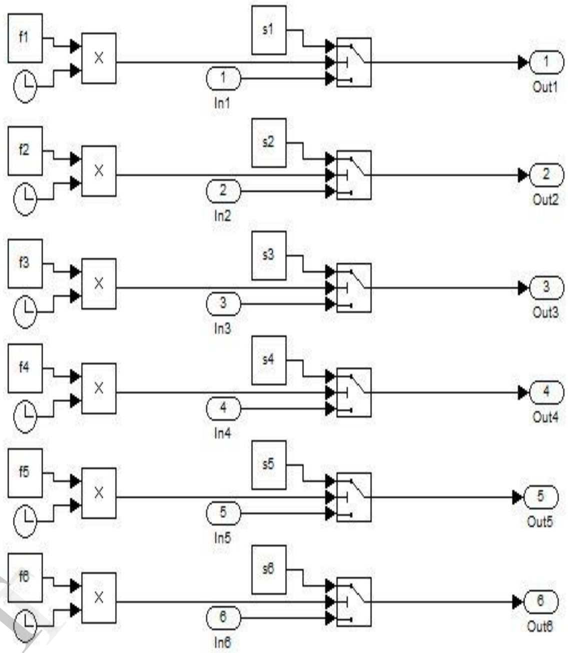

Figure 7 Inside View of Fault Module.

2.2 Inverter Module

A three phase inverter is supplied from Gate Pulse Generator module. This inverter modulates the input DC voltage to variable frequency AC output according to the pulse width modulation technique.

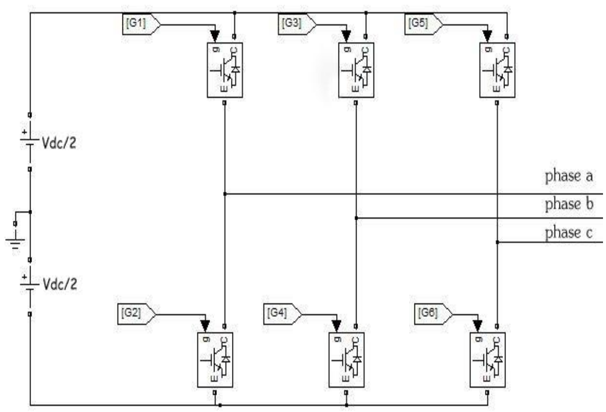

Figure 8 Inverter Module

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

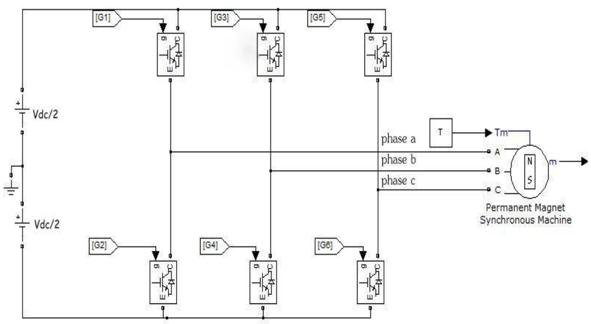

Figure 9 Pulse Width Modulated Inverter fed PMSM

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

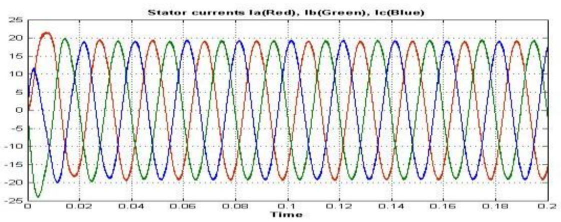

Figure 10 PMSM Stator Current under healthy condition

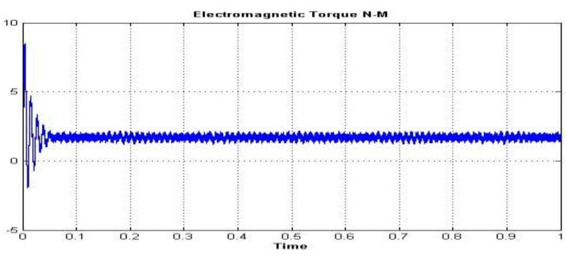

Figure 11 Electromagnetic Torque during healthy condition

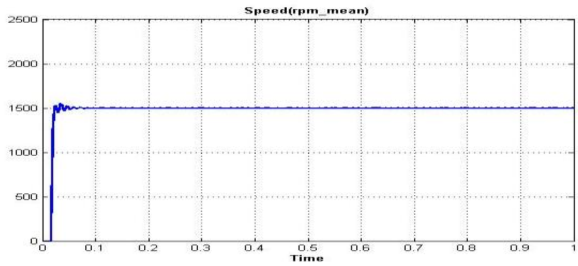

Figure 12 Motor Speed during healthy condition

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In first condition drive is made to run under normal condition without any fault.

After collection of simulation results of PMSM drive under healthy conditions we find that Ia current has THD 1.72%, Ib(1.68%) & Ic(1.69%). This analysis gives result that all most we are getting sinusoidal current wave in the three phases. Torque & speed are almost constant about their mean position but varying at high frequency and low amplitude about its mean position.

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:

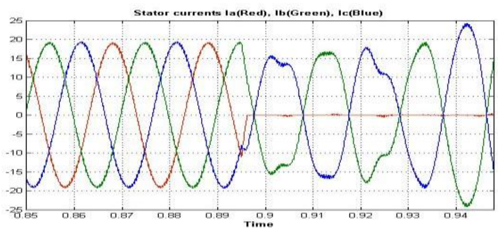

Figure 13 Stator Current during open phase fault

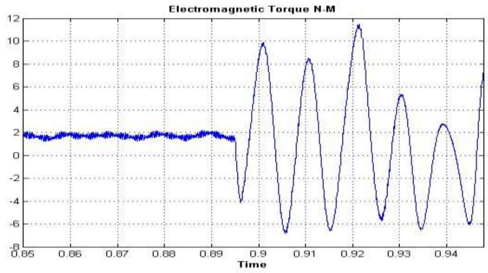

Figure 14 Electromagnetic Torque during open phase fault

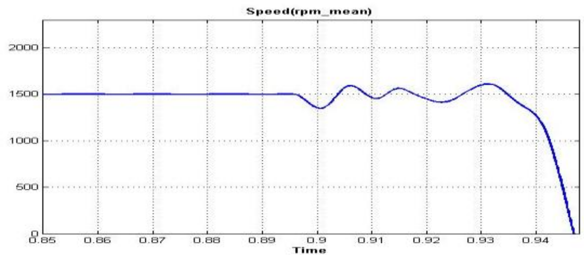

Figure 15 Motor Speed during open phase fault

The fault occurs when 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. THD in Ia current increases to about 187.51%. THD of Ib &Ic also increase with values 16.26% &15.48% respectively. THD of torque & speed have values 187.51% &130.59%. Torque & speed have lower values of THD compared to the health condition.

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.

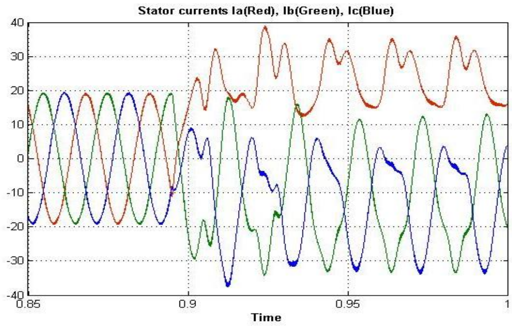

Figure 16 Stator Current during single phase short circuit fault

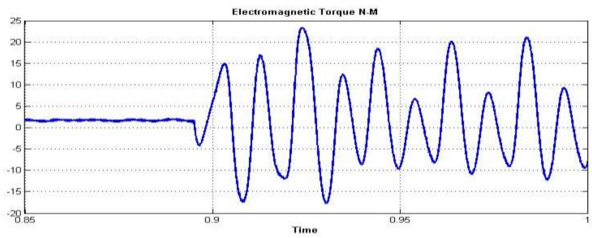

Figure 17 Electromagnetic Torque during single phase short circuit fault

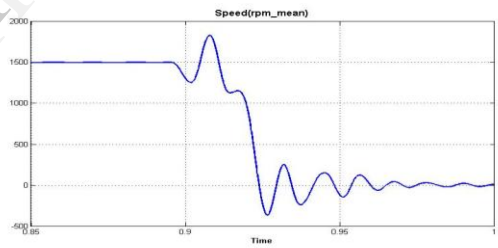

Figure 18 Motor Speed during single phase short circuit fault

In figure 16, 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.THD values for Ia, Ib &Ic are 24.61,13.81 &19.15 percent, which gives an average of about 16%.Torque & speed have THD as 85.21% & 54.44% which shows a considerable decrease compared to the above two conditions. 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].

3.3 Simulation Results Under Two Phase Short Circuit Fault

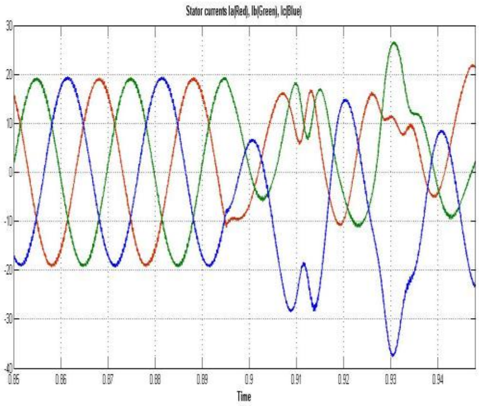

Figure 19 Stator Current during two phase short circuit fault

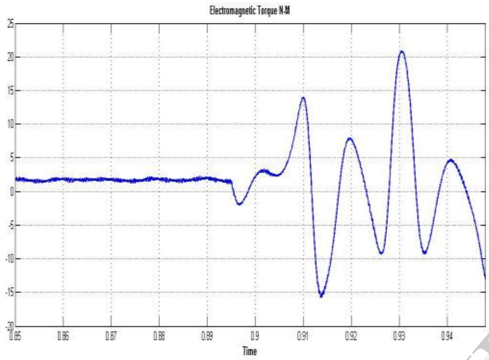

Figure 20 Electromagnetic Torque during two phase short circuit fault

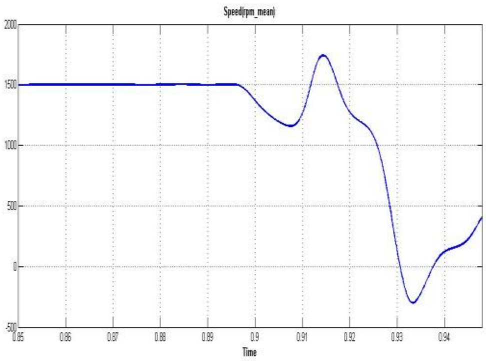

Figure 21 Motor Speed during two phase short circuit fault

. Here in order to introduce two phase short circuit fault gate signals G1,G4 are made '1' during post fault condition.THD of Ia, Ib & Ic are 34.34, 15.46 & 24.67 percent which is near about similar to single phase fault condition. Whereas THD of torque & speed increase with value of 158.81% & 118.34%.

3.4 Simulation Results Under Three Phase Short Circuit Fault

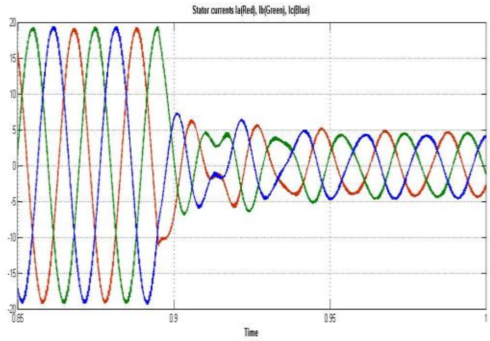

Figure 22 Stator Current during three phase short circuit fault

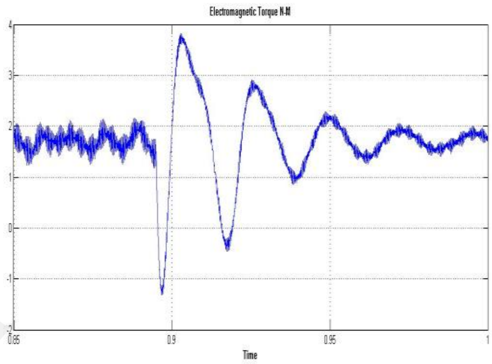

Figure 23 Electromagnetic Torque during two phase short circuit fault

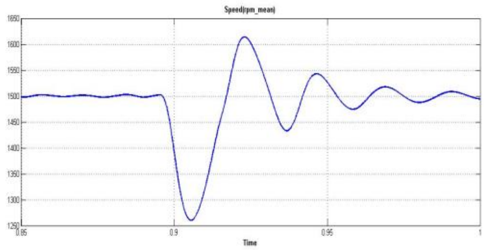

Figure 24 Motor Speed during two phase short circuit fault

. Here in order to introduce two phase short circuit fault gate signals G1,G4 and G6 are made '1' during post fault condition.THD of Ia, Ib & Ic are 11.05,9.03 & 16.41 percent which is least considering the other fault conditions. Whereas THD of torque & speed is the least compared to all the previous conditions, they are 42.91 &35.39 percent. This is even lesser than the healthy conditions

4. Conclusion

As from the result we can see that we get the least THD in case of fault conditions in three phase short circuit fault. If the healthy conditions are considered we get the least THD in the 3phase stator current in the healthy condition. THD in case of electromagnetic torque & speed is high as we get the high frequency and nearly constant amplitude torque & speed & the latter one is desired.

Table 1 THD analysis in various fault conditions of PMSM Motor

Parameter		Motor in healthy condition	Open phase fault	Single phase short circuit	Two phase short circuit	Three phase short circuit
THD in Stator current (%)	Ia	1.72	181.9	24.61	34.34	11.05
	Ib	1.68	16.26	13.81	15.46	9.03
	Ic	1.69	15.48	19.15	24.67	16.41
THD in Electromagnetic torque(%)		333.45	187.51	85.21	158.81	42.91
THD in speed (%)		282.99	130.59	54.44	118.34	35.39

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