Switch Fault Diagnosis using S- Transform on Three Phase Inverter for BLDC Drive

S.Gowtham, Sreenath.G, Sushanth.G,Suba.R And M Balaji

Abstract*: *BLDC drives are highly preferred for electric vehicles application because of its less maintenance, longer life, lower weight and reliability. Normally for electric vehicles the motors are powered by batteries, so three phase inverter is very important in driving the motor. The closed loop system is highly efficient in controlling the parameters of the drive but any fault occurring inside the system may lead to abnormalities which can damage the entire system. So due to this, the fault analysis on the BLDC drive system is very important. As three phase inverter is important in driving the motor, in this project we are going to perform fault diagnosis on three phase inverter in BLDC drive system. The commonly occurring faults in the switches are open circuit and short circuit faults. There are different methods for diagnosing switch open and circuit faults but S-Transform analysis proves to be the best method in providing better results compared to the conventional methods. So in this paper the fault diagnosis on three phase inverter is done using S-Transform method to accurately find where and which type of fault has occurred.

***Index Terms*: Current controller, Hall Effect, S-transform, stator current.**

I. INTRODUCTION

The world is lacking in terms of fossil fuels and at present the rate of pollution is increasing day by day. So to overcome the above situation, the Government of India has made a bold decision that by 2030 most of the vehicles will be electric driven. So the future being electric vehicles, research on the implementation of BLDC drive is becoming very popular. Normally a BLDC drive system consists of power supply, three phase inverter and motor with hall effect sensor embedded to it. If the voltage rating of the motor is more, then a step-up dc-dc converter becomes essential for driving the motor else more number of batteries have to be used which is costlier compared to a step-up dc-dc converter. In this project we are going to use 48V BLDC motor, so we are going to use a system which consists of 24V battery, a boost converter for increasing the voltage level and a three phase inverter for driving the motor which is shown in Fig. 1.

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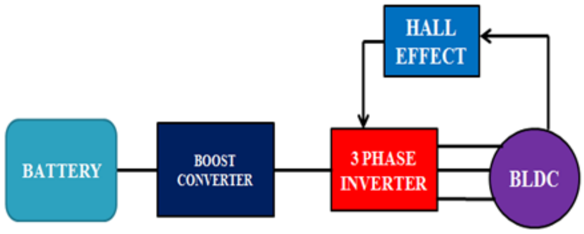

Fig. 1.Block diagram of existing system

The proposed system is tested for conventional drive cycle. Fig.2. shows the drive cycle for the proposed system.

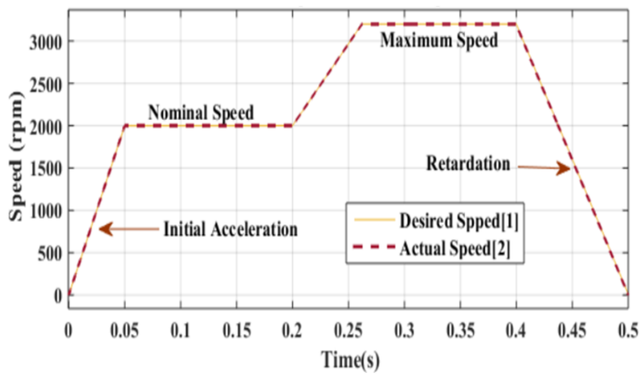

Fig. 2.Conventional drive cycle

For better control of motor speed a hysteresis controller is used which controls the firing pulse of three phase inverter with the signals received from hall sensors. But if there is any fault occurring in the system then it is very difficult to control the motor even in closed loop. So the drive system should be equipped with fault protecting components so that the performance of the system can be maintained better even after the occurrence of the fault. The commonly occurring faults are open and short circuit faults in the power electronic switches. Apart from that, faults can also occur in battery, motor windings and hall sensor of the BLDC drive. Battery and winding faults are not common and they occur because of the faults created in power electronic switches or manual error. Hall sensors faults has become a new concern andseveral fault-tolerant control (FTC) methods have been proposed. However, most of the state-of-the-art FTC methods require sometime to reconstruct the correct Hall sensor signals, which results in significant transient currents and speed dip during fault diagnostic process (FDP).Switch fault diagnosis is an important design aspect for pulse width modulation (PWM) based power converters. It can prevent power converters from further damage, and also make preparations for remedial actions. Few methods are proposed some of them are robust which uses controller and some are fast which uses logic gates to analyze the fault. Some of the techniques like **Discrete Fourier Transform (DFT), Fast Fourier Transform (FFT), Short Time Fourier Transform (STFT)** and **Wavelet Transform** are considered robust. Eventhough they are robust but there are few disadvantages of the above mentioned methods which are shown in table 1 below.

TABLE. 1. COMPARISON BETWEEN TRANSFORMS

Fourier Transform (FT)	Short Time Fourier Transform (STFT)	Wavelet Transform (WT)
It cannot detect the time distribution of different frequencies (time-frequency analysis is unsuitable)	Limitations of fixed window width - cannot track the signal dynamics properly for non-stationary signal	It is good at extracting information from both time and frequency domains, but sensitive to noise

So in this project we used a transform which over comes all the disadvantages present in the above mentioned transforms. STOCKKWELL TRANSFORM(S-TRANSFORM) is derived as the phase correction of the continuous wavelet transform with window being the Gaussian function. It is good in both time and frequency analysis. If the system is operating at low frequency then frequency domain analysis will be suitable and if the system is operating at higher frequency then time domain analysis is more suitable. In our system the step-up dc-dc convertor works at higher frequency so we are going to analyze the drive in time domain.

II. SYSTEM DESCRIPTION

The proposed system is an extension of the existing system shown in Fig. 1. The proposed system has a controller which performs S-Transform analysis. The controller not only controls the drive in closed loop but also takes stator current as input and performs S-Transform analysis. Based on the S-Transform values of stator current the controller can easily predict where and which type of fault has occurred. In time domain analysis there are many features that can be extracted using S-Transform Table. 2 shows the time domain features that can be used for fault analysis.

TABLE.2. TIME DOMAIN FEATURES

Feature extracted	Feature description
F1	The mean of the maximum time amplitude plot
F2	The mean of the standard deviation of the time amplitude plot
F3	The standard deviation of the maximum time amplitude plot
F4	The mean of the minimum time amplitude plot

In this paper we have analyzed Feature F1 alone. Based on the mean of maximum alone we were able to derive conclusion on the type of fault in the drive. The remaining features can also be used for deriving conclusions. The block diagram of the proposed system is shown in Fig. 3. It clearly explains that the controller can provide information about the type of fault i.e;(Single/double switch fault and Open/Short circuit fault). It can also give us the exact information on which switch the fault has occurred.

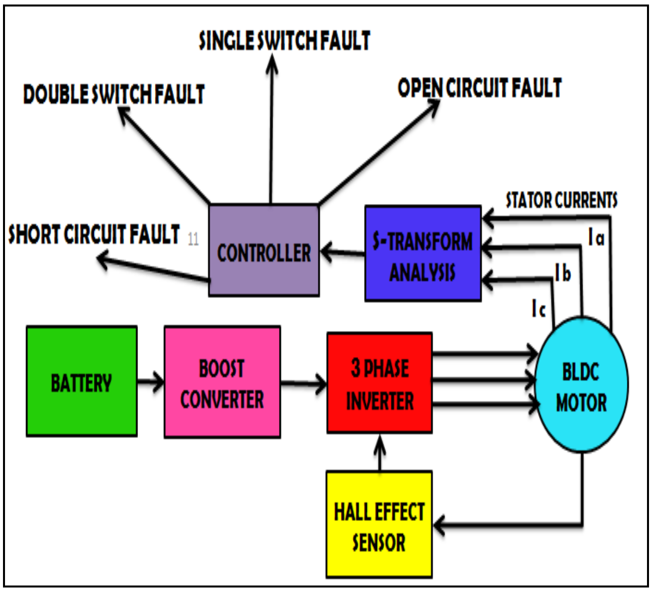

Fig. 3. Block diagram

The specifications for the proposed 250W BLDC drive such as voltage, current, speed, torque and other associated parameters in reference to the converters and motors used, are mentioned in Table.3

TABLE.3. SPECIFICATIONS

S.NO	Parameters	Type	Ratings
1	Motor	BLDC (Brushless dc Motor)	Input Torque-0.63 Nm No. of poles-4 Speed-3200 rpm Power Ratings-250 W Rated current-5.2 A
2	Inverter	Three phase	Input Voltage- 30 V Output Voltage(ph)-48V VL-83.13V Power Ratings- 250 W Output Current -5.2 A
3	Boost Converter	Chopper (DC-DC)	Input Voltage - 24V Output Voltage - 30 V Power Ratings -250 W Input Current -10.41A Output current-8.33A F-1MHz L-0.0002083 H C-0.000625 F
4	Battery	Lithium Ion	24V,65 Ah

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III. SIMULATION RESULTS

The simulation analysis is performed for the proposed 250W BLDC motor drive. The proposed drive is simulated in closed loop under normal condition for conventional drive which is shown in Fig. 2. The electromagnetic torque which is obtained from the motor is shown below in Fig. 4.

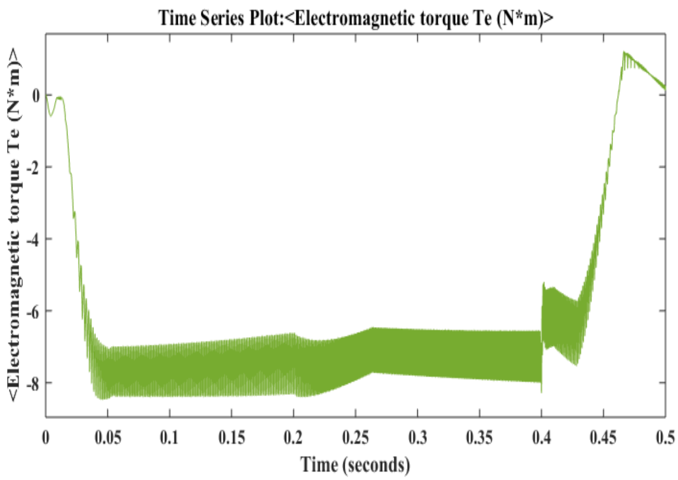


Fig. 4. Electromagnetic Torque

The closed loop implementation is done using hysteresis current controller which is used for precise control of speed. Further the simulations are also performed for abnormal conditions. The abnormal conditions that are going to be tested are open and short circuit faults that occur in the power electronic switches of three phase inverter. We have tested open and short circuit faults for single and double switches. The diagnosing method is S-Transform which gives a clear value to easily identify which type of fault has occurred. Table. 4 shows the S-Transform values for stator current ia, ib, ic under normal condition.

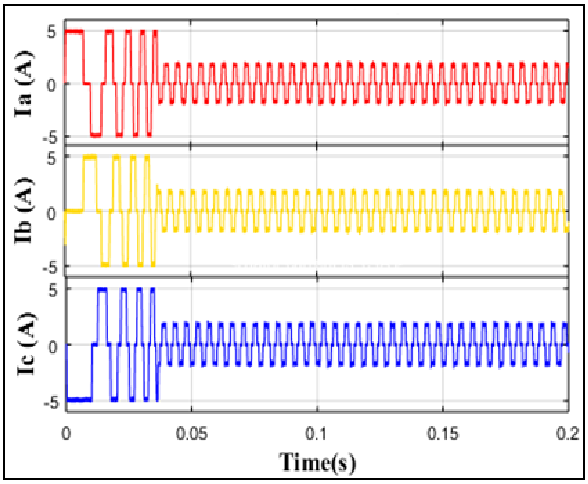


Fig.5. Stator current for ia, ib, ic during normal condition

TABLE. 4. S-TRANSFORM VALUES FOR NORMAL CASE

S-Transform Values(F1)		
Ia	Ib	Ic
1.7314	1.7315	1.7312

A. SINGLE SWITCH FAULT

Single switch is the most commonly occurring fault in three phase inverter. So analysis on the stator current is done using S-Transform. The analysis is done on all the three phase currents ia, ib, &ic. Fig.6, Fig.7 & Fig.8 shows the graphical representation of ia, ib and ic during open circuit single switch fault. The stator current waveform repeats for every 909 points symmetrically (i.e; one cycle covers 909 points in time axis) for every 909 points. We have performed the S-Transform analysis during nominal speed in the drive cycle. The 909 points are also taken during the same nominal speed period. From the graph we can clearly see the amount of distortion from the actual waveform which is show in Fig.5. The motor current loses its shape which makes the motor to lose its stability. This in-turn results in the reduction of speed of the motor, so the hall signals from the motor change which changes the pulse generated for the inverter. So this further reduces the stability of the motor to a greater extent.

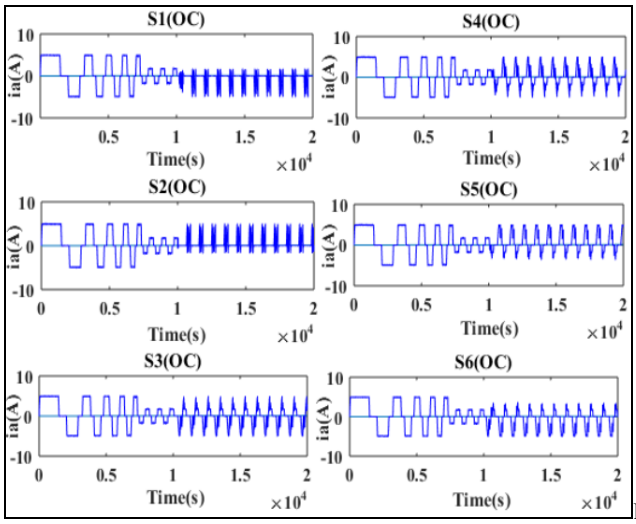


Fig 6. Stator current ia for all single switch O.C faults

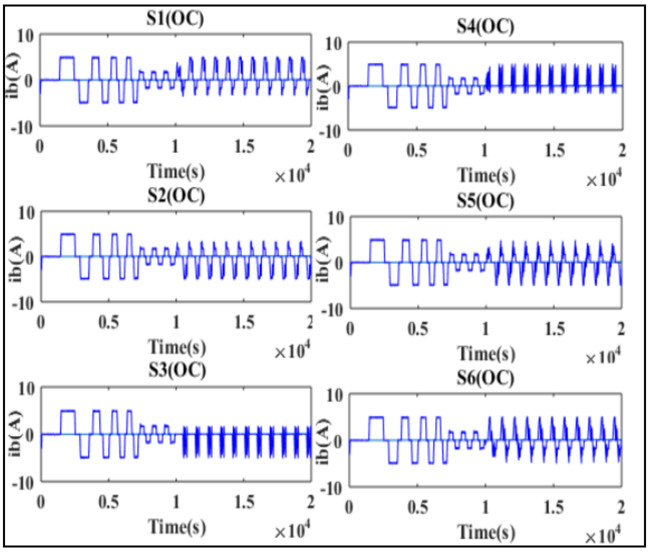


Fig 7. Stator current ib for all single switch O.C faults

TABLE. 5. S-TRANSFORM VALUES FOR SINGLE SWITCH FAULTS

Switch Combinations	Feature Extracted S-Transform values(F1)					
	Open Circuit Fault			Short Circuit Fault		
	ia	ib	ic	ia	ib	ic
S1	0.6745	1.3221	1.2302	1.2411	1.079	1.2383
S2	0.6439	1.3127	1.2332	0.402	0.0378	0.3982
S3	1.2307	0.6565	1.3191	0.0041	5.0003	5.0005
S4	1.2513	0.6505	1.3373	5.001	3.4547	1.5463
S5	1.3339	1.2288	0.6569	0.0068	0.163	0.1619
S6	1.3237	1.2026	0.6569	4.9906	4.3482	0.6224

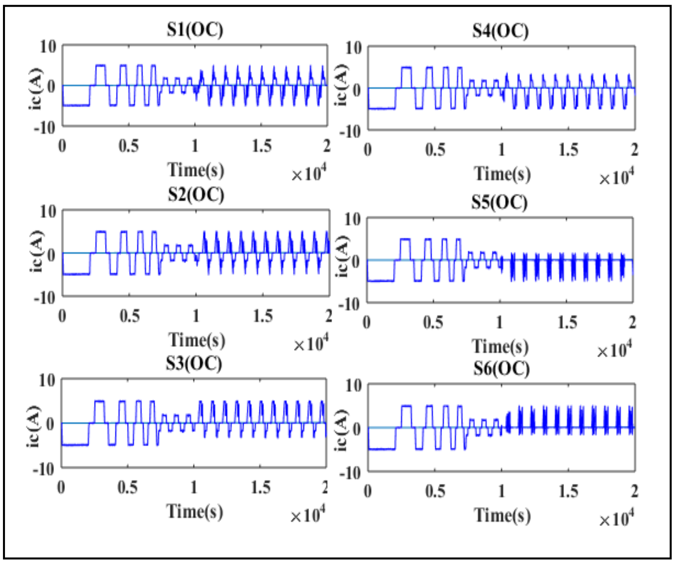


Fig 8. Stator current ic for all single switch O.C faults

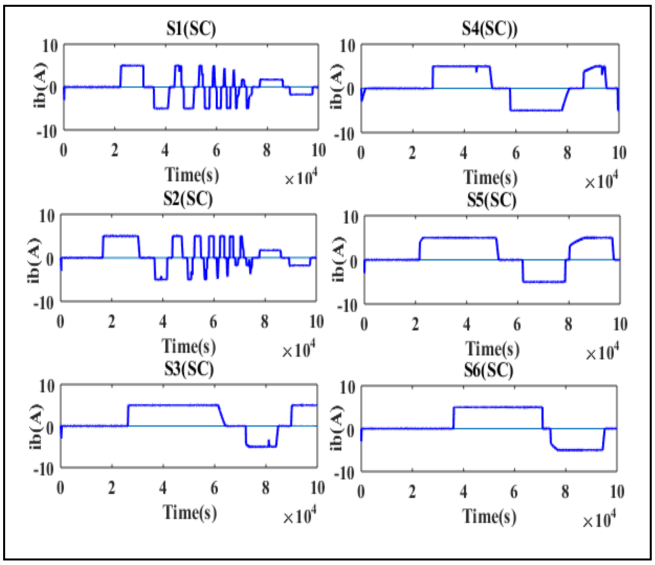
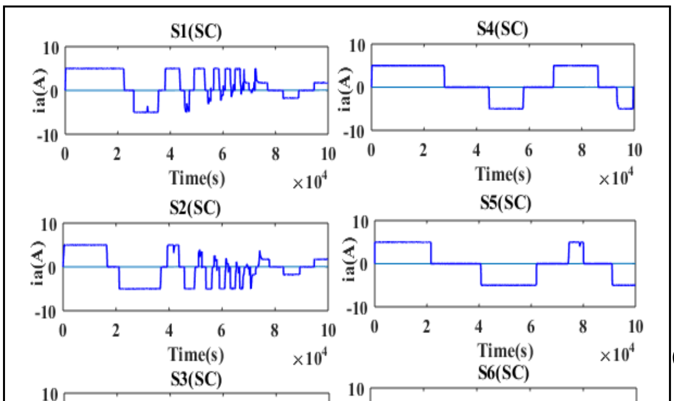


Fig 10. Stator current ib for all single switch S.C faults



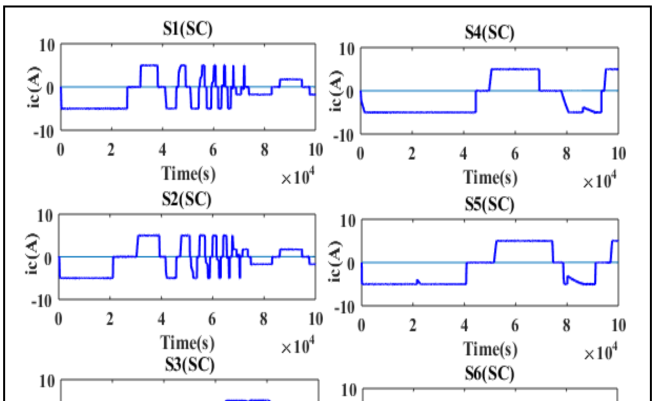


Table. 5 shows the feature extracted values (F1) of S-Transform for stator currents ia, ib&ic during open circuit and short circuit faults. From the table we can see that the values change drastically from the values during normal condition. Using this table we can easily classify the fault as single switch open or short circuit faults. The open circuit faults have less impact on the motor current compared to the short circuit faults. Fig. 9, Fig. 10 & Fig. 11 shows the stator currents ia, ib&ic respectively for single switch short circuit faults. As mentioned earlier the short circuit faults has a completely distorted current compared to the normal stator current which will lead to his malfunction of motor.

B. DOUBLE SWITCH FAULT

The double switch fault can cause great damage to the drive as it can alter the performance of the motor drastically. Fig.12 shows the stator current ia for different combinations of double switch open circuit faults. Comparing the current waveforms for single and double switch faults we can see that the amount of distortion in double switch faults are more compared the single switch faults. As discussed earlier, more distortion changes the performance of the motor to a greater extent. The above Fig.13 & Fig.14 shows the graphical representation of open circuit double switch fault for stator current ib&ic respectively. The stator current waveform can be found with deviations after 1s. The fault for the switches are created at 1s, so till 1s the operation would be normal and after that based on the fault the current and speed of the motor varies.

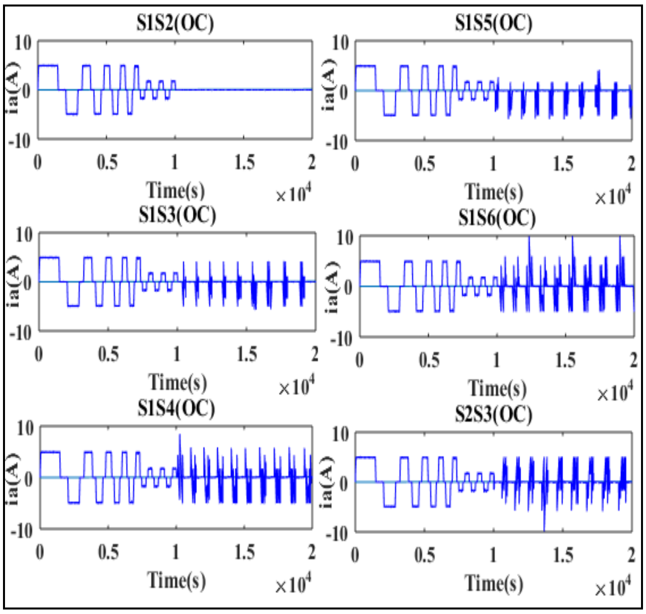


Fig. 12. Stator current ia for few combinations of double switch O.C faults

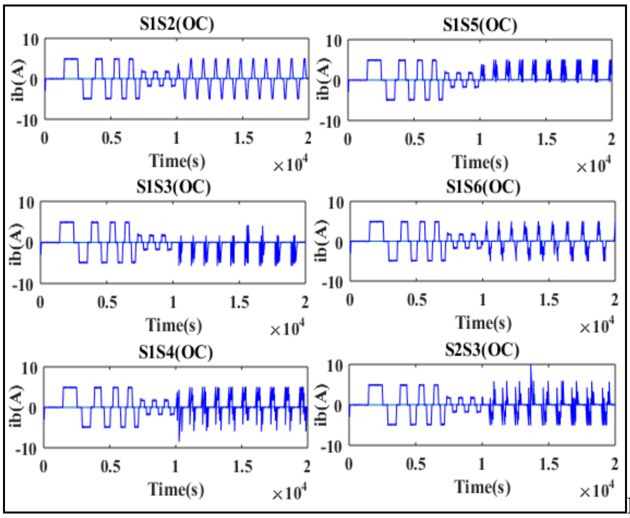


Fig. 13.Stator current ib for few combinations of double switch O.C faults

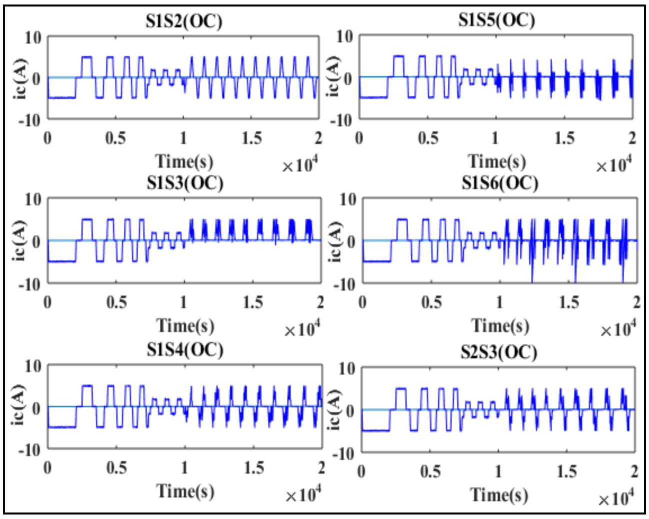


Fig 14. Stator current ic for few combinations of double switch O.C faults

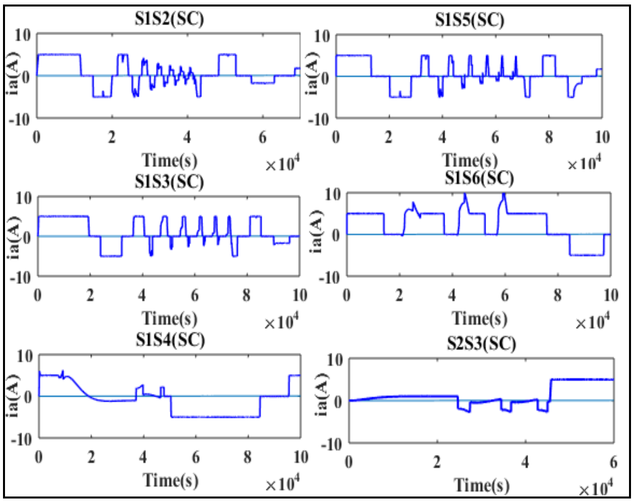


Fig 15. Stator current ib for few combinations of double switch S.C faults

TABLE. 6. S-TRANSFORM VALUES FOR DOUBLE SWITCH FAULTS

Switch Combinations	Feature Extracted S-Transform values(F1)					
	Open Circuit Fault			Short Circuit Fault		
	ia	ib	ic	ia	ib	ic
S1S2	0.006	1.5972	1.5954	1.8565	0.7282	1.1283
S1S3	0.1824	0.3725	0.5108	0.0041	4.2256	5.0025
S1S4	0.7288	0.8997	1.1494	0.031	0.032	0.0389
S1S5	0.9834	1.2778	0.5056	0.3351	0.8237	0.0389
S1S6	0.5487	0.5974	0.5267	0.0068	5.0244	5.0273
S2S3	0.7806	0.6332	0.6023	0.6358	0.9699	1.4392
S2S4	0.4873	1.028	1.4023	0.3227	0.6589	0.3362
S2S5	0.782	1.1526	0.799	0.2635	0.0379	0.2632
S2S6	0.7	0.8703	0.2397	2.8106	5.0098	2.1992
S3S4	1.5138	0.0083	1.5162	0.3399	1.693	1.3531
S3S5	0.9604	0.3238	0.6658	0.0047	2.2577	2.2579
S3S6	1.3149	0.5441	0.5855	5.0009	5.8355	0.8956
S4S5	1.125	0.9427	1.1383	5.0018	2.64	2.3617
S4S6	1.4287	0.5445	0.8929	0.0043	0.9441	0.9441
S5S6	1.5678	1.5679	0.0087	0.0043	1.085	1.085

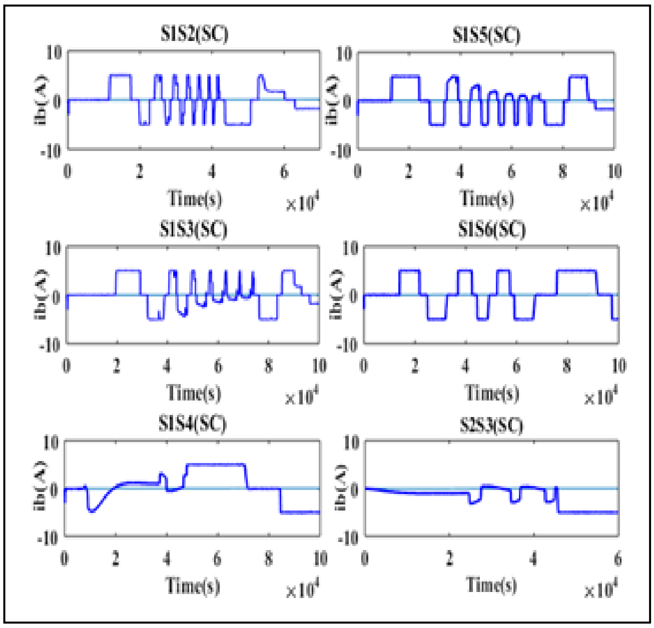


Fig 16. Stator current ib for few combinations of double switch S.C faults

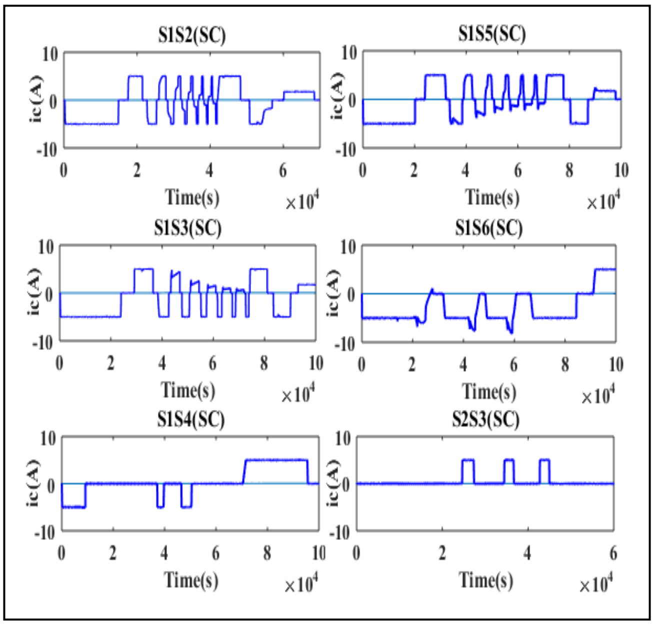


Fig 17. Stator current ic for few combinations of double switch S.C faults

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Fig.15, Fig.16, Fig.17 shows the waveform of stator current for ia, ib, ic during double switch short circuit faults. The waveform clearly gives us a picture that the stator current is misaligned from the original values by a large extent. This can immediately damage the windings of the motor and can cause great damage to the electronic commutator. So diagnosing these faults are of utmost important. The different combinations of double switch faults for feature extracted values (F1) of S-Transform for stator currents ia, ib&ic during open circuit and short circuit faults are shown in Table. 6. There are 15 combinations of double switch open circuit fault. From these values in the table we can clearly see that for few combinations the value have been distorted by a great value. The short circuit values can be easily found as the S-Transform are either very high or very low from the normal value.

IV. Conclusion

Thus single and double switch faults can damage the commutator and the windings of the motor if proper diagnostic measures are not taken at right the time. Single switch faults takes time for creating more problems in the drive where double switch short circuit can cause instant damage. So S-Transform like analysis are needed to immediately identify the faults and isolate them before the fault creates greater problem in the entire drive. Triple switch, four switch and five switch faults can also occur in the system but at very low probability. So we have stopped our analysis only to double switch faults. Further the work can be extended by testing the drive at every phase of the drive cycle during fault conditions and also by comparing the results of S-Transform with some other methods of diagnosis.

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