# Voltage Source Inverter Switches Faults Analysis Using S-Transform

M. Manap
Faculty of Engineering Technology, Universiti Teknikal Malaysia Melaka, Malaysia
Email: mustafa@utem.edu.my

A. R. Abdullah, N. Z. Saharuddin, N. A. Abidullah, N. S. Ahmad, and N. Bahari
Faculty of Electrical Engineering, Universiti Teknikal Malaysia Melaka, Malaysia
Email: {abdulr, nurzawani, hazilina}@utem.edu.my, athira_abidullah@yahoo.com, nursumayyahahmad@gmail.com

***Abstract*—Nowadays, voltage source inverter (VSI) is frequently used in power electronics system. This is due to its ability that can offer higher efficiency, high torque, simpler control system and improved power output. Thus, to ensure safety and reliability of a system, the development of appropriate fault detection technique for faults analysis is a must. This paper proposes S-transform which is time-frequency distribution (TFD) for analyzing VSI signal to detect and identify switches and types of faults. By using the TFD, the faults signal is translated into time-frequency representation (TFR) and then, parameters of the signal are estimated from the TFR. The signal parameters are such as instantaneous of rms current, rms fundamental current, average current, total waveform distortion (TWD), total harmonic distortion (THD) and total non-harmonic distortion (TnHD). Based on the signal parameters, the characteristics of the faults are calculated and used as input for faults detection and classification system. At the end of this research, the results show that the proposed TFD give better analysis for switches faults parameters estimation and suitable for detection and identification system.**

***Index Terms*—switches faults, S-transform, short time fourier transform, voltage source inverter**

## I. Introduction

One of the critical systems that extremely important in electronic system is voltage source inverter (VSI). The structure of VSI have become more complex with additional poles and switches [1] and a study shows that 38% of faults in associated with variable speed ac drive industry are due to the failure of power devices [2]. The most popular power devices in industry are insulated gate bipolar transistors (IGBTs). Designed with high rating of voltage and current capability, the IGBTs are able to withstand short-circuit currents for periods exceeding 10µs [3]. But still, exposing to the electrical excess and thermal stress for a period of time shall degraded the IGBTs performance and lead to the component failure. Therefore, it is vital to develop fault diagnostic and protection methods for preventive maintenance and minimizing downtime schedule for component replacement.

Generally, IGBTs switches fault can be classified as short circuit faults and open circuit faults. Short circuit faults may occur due to a wrong gate voltage, which may be caused by driver circuit malfunction or auxiliary power supply failure. Another short circuit faults is an intrinsic failure, which may be caused by avalanche stress or temperature overshoot [4]. The short-circuit faults are difficult to deal with because the time between the fault initiation and failure is very small. Therefore, most of the existing IGBT short-circuit detection and protection methods are hardware circuit based rather algorithm based. The open circuit faults on the other hand occur due to lifting of bonding wires which caused by thermic cycling. It may be caused by a driver fault or a short-circuit-fault-induced IGBT rupture. The voltages and currents carry the fault signatures and hence can be analyzed to detect and locate the fault. Open circuit faults generally do not cause system shutdown, but reduce its performance in the long run [5].

Conventional techniques that are currently used for switches faults monitoring are based on visual of voltage and current waveforms. The available equipment in the market for the inspection can capture and print the switches faults data only at the current time. Therefore, a real time computerized and automated technique for monitoring and analysis is implemented to improve the switches faults signal. Many techniques were presented by various researchers for analysis, detection and classification VSI switches faults in real time. One of the most widely used in signal processing is spectral analysis using Fourier analysis which is Fourier transform [6]. The Fourier transform is powerful technique for stationary signal because the characteristics of the signal not change with time but it not useful for non-stationary signal because is inadequate to track the changes in the magnitude, frequency or phase [1], [2]. Because of this problem, the time-frequency analysis technique is introduced. The STFT most often used but it cannot track the signal dynamics properly for non-stationary signal due to limitation of fixed window width [7]. Wavelet transform is good to extract the information from both

Manuscript received December 1, 2014; revised July 24, 2015.


doi: 10.18178/ijeee.4.2.157-161

time and frequency domains but wavelet transform is sensitive to noise and cannot identify the sag and swell and also transient condition [8]. S-transform proposed by Stockwell [9] which is time frequency spectral localization method that combine element of wavelet transform and short time Fourier transform (STFT) [9]-[11]. The S-transform has a frequency dependant resolution of time- frequency domain and entirely refers to phase information. The S-transform is required to emphasize the time resolution in the beginning time and frequency resolution in the later of beginning time. The advantage of S-transform offer multi-resolution analysis while retaining the absolute phase of each frequency.

In this paper, S-transform is used to represent the VSI switches faults in jointly time-frequency representation (TFR). From the TFR, parameters of the fault signals are estimated such as instantaneous of rms current, rms fundamental current, average current, total waveform distortion (TWD), total harmonic distortion (THD) and total non-harmonic distortion (TnHD). Then, characteristics of the signals are calculated from the signal parameters and will be used as input for detection and identification system.

## II. VSI Switches Faults

Voltage source inverter (VSI) is an electronic device which converts direct current (DC) to Alternating current (AC). VSI has advantages like higher efficiencies, minimizing installation timing, elimination interconnect power cabling costs and reducing building floor space. The topology of the VSI operation has been discussed in [12]. The switches fault VSI for open circuit fault condition, IGBT falls in the off state and remains in this situation regardless of the gate voltage value. Open circuit fault generally do not cause system shutdown, but degrade its performance. Fig. 1 shows the model of circuit when VSI switches open circuit fault. The short-circuit fault where this faults leads to catastrophic failure of the inverter if the other transistor of the same inverter leg is turned-on, this resulting in a direct short-circuit as shown in Fig. 2, the VSI switches faults have been further discussed in [13].

## III. S-Transform

Time-Frequency analysis techniques present a three-dimensional plot of a signal in terms of the signal energy or magnitude with respect to time and frequency. S-transform is combination a frequency dependent resolution with simultaneous localizing the real and imaginary spectra. The general S-transform is defined by the equation [10].

$$S(\tau, f) = \int_{-\infty}^{\infty} h(t) g(\tau - t, f) e^{-j2\pi ft} dt \qquad (1)$$

where $h(t)$ is the signal, $t$ represent the time, $f$ is the frequency and $g(t)$ is a window function. Windows function is a modulated Gaussian function expressed by

$$g(\tau) = \frac{1}{\sigma\sqrt{2\pi}} e^{-(t^2/2\sigma^2)} \qquad (2)$$

where $\sigma$ is defined as

$$\sigma = \frac{1}{|f|} \qquad (3)$$

## IV. Signal Parameters

Parameters of the signal are estimated from the TFR to identify the signal information in time domain. This information is important to detect and identify the VSI switches faults [12]. The signal parameters have been discussed in [14] to estimate instantaneous of rms current, rms fundamental current, average current, total waveform distortion (TWD), total harmonic distortion (THD) and total non-harmonic distortion (TnHD).

## V. Results

In this section, the results of the switches faults analysis are discussed. Fig. 1 shows the examples of switches faults signals for three phase current for open circuit faults and Fig. 2 shows the examples of switches faults signals for three phase current for short circuit fault. As shown in Fig. 3 when short switch fault occur at S3, the current at phase b (green color) increased whereas the current at phase a (blue color) and c (red color) decreased.

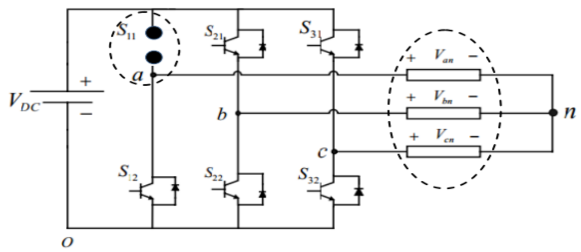


Figure 1. The model of voltage source inverter when switches open circuit fault

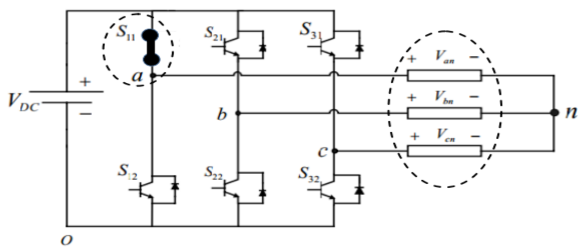


Figure 2. The model of voltage source inverter when switches short circuit fault

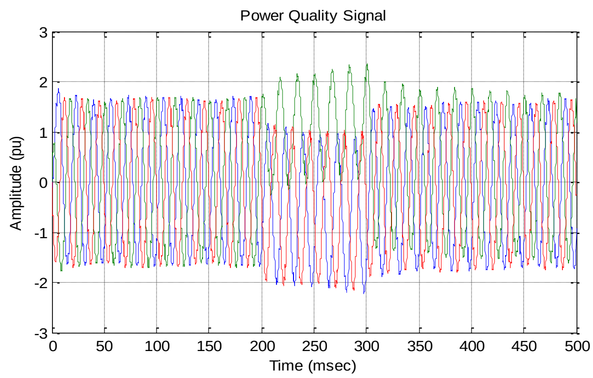


Figure 3. Three phase current of VSI short switch fault at S3 (upper switch)

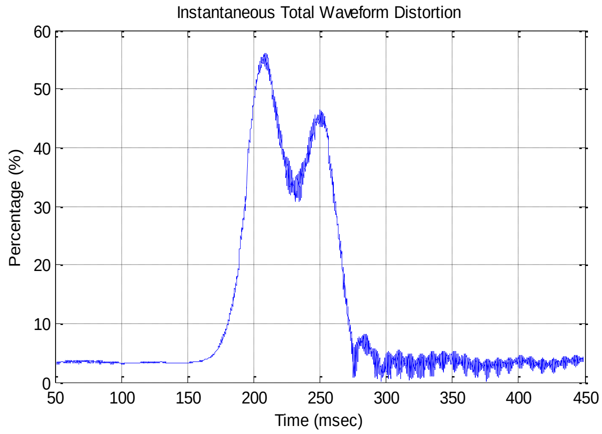


Figure 10. Signal parameter of faults signal using instantaneous total waveform distortion (TWD)

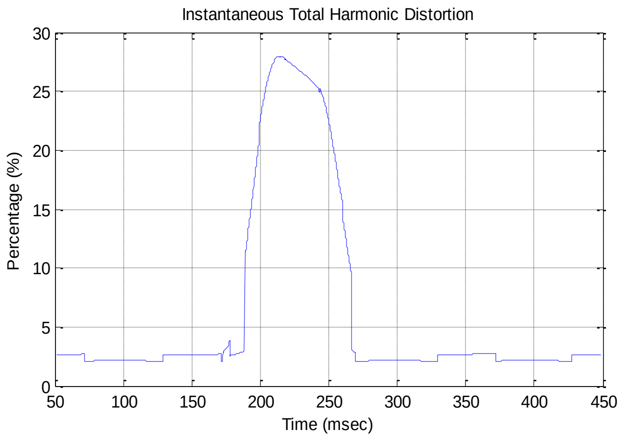


Figure 11. Signal parameter of faults signal using instantaneous total harmonic distortion (THD)

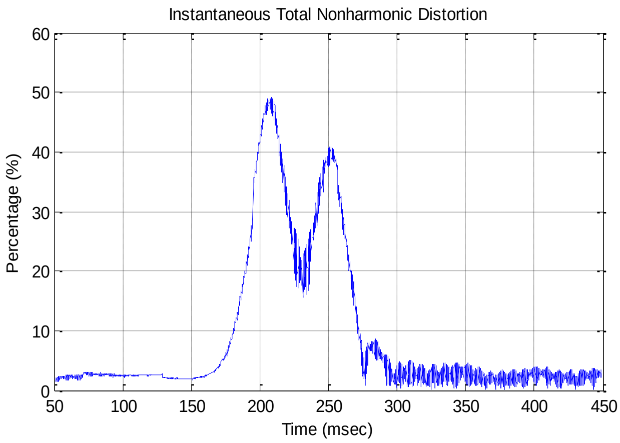


Figure 12. Signal parameter of faults signal using instantaneous total nonharmonic distortion (TnHD)

## VI. Conclusion

This paper presents the analysis and parameters of switches faults signals using S-transform. The observation clearly shows that the TFR can be used to estimate the useful signal parameters to determine the characteristics of the switches faults signals. From the signal characteristics, switches faults can be detect and identify as well as the information of the VSI signal can be demonstrated. The analysis can be implemented to be automated detection and identification system.


## Acknowledgment

The authors would like to thank Universiti Teknikal Malaysia Melaka and the Ministry of Higher Education (MOHE) for providing the research grant RAGS/1/2014/TK03/UTEM//1 for this research.


## References


[1] B. A. Welcko, T. A. Lipo, T. M. Jahns, and S. E. Schulz, "Fault tolerant three-phase AC motor drives topologies: A comparison of features, costs and limitations," *IEEE Trans. Power Electronics*, vol. 19, pp. 1108-1116, Jul. 2004.

[2] F. W. Fuchs, "Some diagnosis methods for voltage source inverters invariable speed drives with induction machines—A survey," in *Proc. IEEE Ind. Electron. Conf.*, 2003, pp. 1378-1385.

[3] B. Lu and S. K. Sharma, "A literature review of IGBT fault diagnostic and protection methods for power inverters," *IEEE Trans. on Industry Applications*, vol. 45, no. 5, Sep. 2009.

[4] M. Trabelsi, M. Boussak, and A. Chaari, "High performance single and multiple faults diagnosis in voltage source inverter fed induction motor drives," in *Proc. International Conference on Electrical Machines (ICEM)*, 2012, pp. 1717-1723.

[5] J. O. Estima and A. J. M. Cardoso, "A new approach for real-time multiple open-circuit fault diagnosis in voltage source inverters," in *Proc. IEEE Energy Conversion Congress and Exposition (ECCE)*, Sep. 2010, pp. 4328-4335.

[6] S. W. Smith, *The Scientist & Engineer's Guide to Digital Signal Processing*, 1st ed., California Technical Pub., 1997.

[7] M. H. Bollen and I. Gu, *Signal Processing of Power Quality Disturbances*, Wiley, 2006.

[8] R. L. Allen and D. Mills, *Signal Analysis: Time, Frequency, Scale, and Structure*, Wiley, 2004.

[9] R. G. Stockwell, L. Mansinha, and R. P. Lowe, "Localization of the complex spectrum: The S transform," *IEEE Transactions on Signal Processing*, vol. 44, pp. 998-1001, 1996.

[10] I. W. C. Lee and P. K. Dash, "S-Transform-Based intelligent system for classification of power quality disturbance signals," *IEEE Trans. on Industrial Electronics*, vol. 50, pp. 800-805, 2003.

[11] A. R. Abdullah, A. Z. Sha'ameri, N. A. M. Said, N. M. Saad, and A. Jidin, "Bilinear time-frequency analysis techniques for power quality signals," in *Proc. International Multiconference of Engineers & Computer Scientists*, 2012.

[12] N. S. Ahmad, A. R. Abdullah, and N. Bahari, "Switches faults analysis of voltage source inverter (VSI) using short time fourier transform (STFT)," *International Review of Modelling and Simulations*, vol. 7, pp. 409-415, 2014.

[13] A. R. Abdullah, A. Z. Sha'ameri, A. R. M. Sidek, and M. R. Shaari, "Detection and classification of switches faults disturbances using time-frequency analysis technique," in *Proc. 5th Student Conference on Research and Development*, 2007, pp. 1-6.

[14] N. S. Ahmad, A. R. Abdullah, and N. Bahari, "Open and short circuit switches fault detection of voltage source inverter using spectrogram," *Journal of International Conference on Electrical Machines and Systems*, vol. 3, no. 2, pp. 190-199, 2014.


**Mustafa Bin Manap** was born in Selangor, Malaysia in 1978. He received his B. Eng. degrees in Electrical Engineering from the Universiti Teknologi Malaysia (UTM). Currently, he is a master degree student researcher in Electrical Engineering at Universiti Teknikal Malaysia Melaka (UTeM).

**Dr. Abdul Rahim Abdullah** was born in Kedah, Malaysia in 1979. He received his B. Eng., Master, PhD Degree from University of Technology Malaysia (UTM) in 2001, 2004 and 2011 in Electrical Engineering and Digital Signal Processing. He is currently a Senior Lecturer and Coordinator of Center of Excellent Robotic and Industrial Automation (CeRiA) in Universiti Teknikal Malaysia Melaka (UTeM).

**Nur Zawani Binti Saharuddin** was born in Negeri Sembilan, Malaysia. She received her Bachelor Engineering degree in Electrical Engineering from Universiti Teknikal Malaysia Melaka (UTeM) and completed her Master Engineering in Electrical Energy and Power System from Universiti Malaya (UM). She is currently a Lecturer in Universiti Teknikal Malaysia Melaka (UTeM).