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An Evaluation of Linear Time Frequency Distribution Analysis for VSI Switch Faults Identification

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ABSTRACT

This paper present an evaluation of linear time frequency distribution analysis for voltage source inverter system (VSI). Power electronic now are highly demand in industrial such as manufacturing, industrial process and semiconductor because of the reliability and sustainability. However, the phenomenon that happened in switch fault has become a critical issue in the development of advanced. This causes problems that occur study on fault switch at voltage source inverter (VSI) must be identified more closely so that problems like this can be prevented. The TFD which is STFT and S-transform method are analyzed the switch fault of VSI. To identify the VSI switches fault, the parameter of fault signal such as instantaneous of average current, RMS current, RMS fundamental current, total waveform distortion, total harmonic distortion and total non-harmonic distortion can be estimated from TFD. The analysis information are useful especially for industrial application in the process for identify the switch fault detection. Then the accuracy of both method, which mean STFT and S-transform are identified by the lowest value of mean absolute percentage error (MAPE). In addition, the S-transform gives a better accuracy compare with STFT and it can be implement for fault detection system.

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1. INTRODUCTION

The vast majority of the electrical drive frameworks in modern process are presented to hash environment which can diminish the life expectancy of the inverter because of regular maturing process. Along these lines, to keep up the execution and dependability, protecting the strength of the inverter is amazingly essential. This issue has pulled in numerous analysts to enhance deficiencies recognition and analysis systems. Statistical information demonstrates that 63% regarding the inverter experience faults inside the preceding a year over operation and 70% of the short circuit happened are identified with power switch which classes into short circuit fault, open circuit fault and gate-misfiring fault [1]. The waveform analysis strategies can be classifications into segment based and framework based. In segment based strategies, standard components of industrial power converter, for example, entryway signal checking and overcurrent plan is utilized to ensure strong state switches. To ascertain the profitable remedial action, this schemes who built-in including an auxiliary analog circuitry for change abnormalities detection have to operate between less than 10μsec to prevent the silicon chip from harms [2]. The algorithmic techniques to identify type of faults and its location while system based technique in other word is focusing on waveform analysis [3]. For waveform fundamental analysis, an open switch short circuits produced undesirable dc segment in yield current waveform. The inverter blame can be followed by recognizing a vast deviation of deficiencies marker from their normal qualities [4]. Algorithmic methods then again connected propelled classifier calculation to distinguish flawed inverter ignores constant yield estimations [5].

In this paper, S transform is utilized to represent to the VSI switches fault in combine with time-frequency representation (TFR). From the TFR, the signal of fault parameters are assessed 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, qualities of the signs are figured from the signal parameters and will be utilized as contribution for recognition and identification system.

2. VOLTAGE SOURCE INVERTER (VSI) SYSTEM FAULT

In this paper, the fault signal of VSI is modeling by using MATLAB that displayed as a part of Figure 1. It is comprise of DC supply of 50V and RLC circuit as estimated load. The Simulink of VSI comprise of gate signal, pulse width modulation modules, fault generation modules. Figure 1 underneath are demonstrated K1 show open circuit and K2 is short out issues. Impede are brought on of over current gate circuit debasement affect ionization and bond wire break. If the fault is happened, the system will automatically shut down, while the open short out will be brought about the system performed degrades.

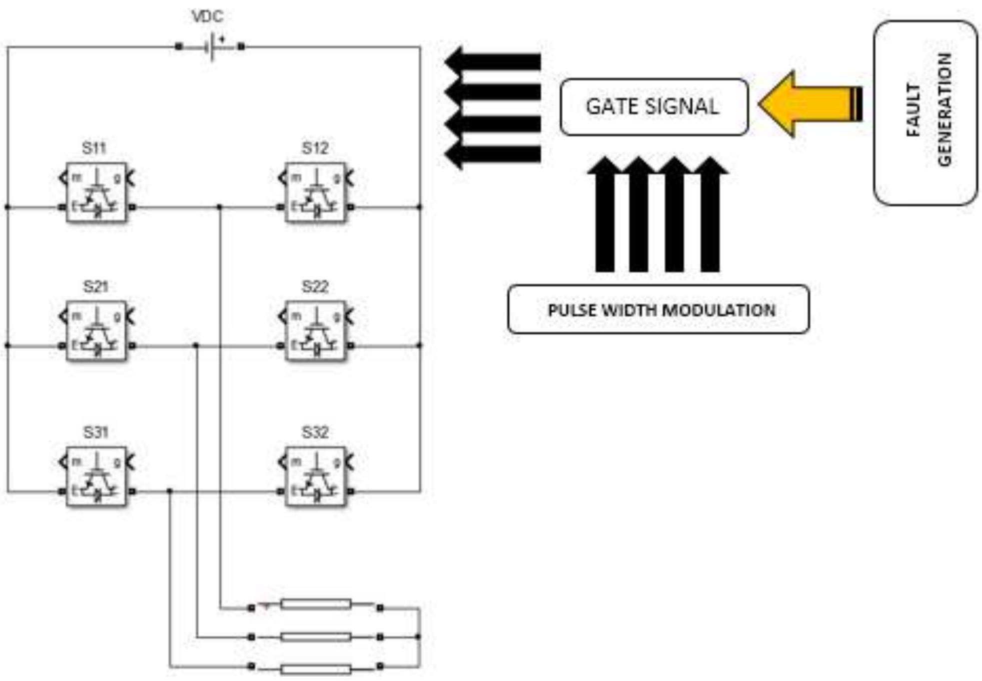

Figure 1. The model of voltage source inverter (VSI)

3. TIME FREQUENCY ANALYSIS TECHNIQUE

The signal can be interpreted into time and frequency domain represented from Time Frequency Represented (TFR) through the effective technique Time Frequency Distribution (TFDs). There are few time frequency distribution technique which is wavelet transform, spectrogram, S-transform, short time Fourier transform (STFT) and Gabor transform [6]-[7].

3.1. Time Frequency Distribution

Time-frequency distributions (TFDs) technique such as Short Time Fourier transform (STFT) and S-Transform are considered as a powerful tool to represent a signal in both time and frequency domain [8]. From the TFR, the spectral information of a signal can be observed in time domain. Therefore, the TFDs are appropriate method for analyze switches faults signals that consist of non-stationary and multi-frequency component signal. The short time Fourier transform (STFT) and S-transform are among the famous or familiar technique and often used in industry such as communication, power electronic and acoustic. From the combination from the best features of short time Fourier transform (STFT) and wavelet transform (WT) [5] the S-Transform is created. S-Transform has produced frequency dependent resolution of time-frequency domain and completely refers to phase information. The benefits of this technique is it offer multi-resolution analysis while maintaining the absolute phase of each frequency.

STFT signal is divided into several minor segments called window and it is assumed as stationary in these segments. This technique which obtained localization of Fourier analysis can perform transformation by selecting appropriate desired window [9]. The resolution of the frequency is inversely proportionate with time resolution but not for size windows. The STFT of a signal x(t), is can be describe as:

$$S_x\,(t,f) = \int_{-\infty}^{\infty} x\,(t)w\,(\tau - t)\,e^{-j2\pi f\tau}d\tau \tag{1}$$

S-transform technique is create from combination of STFT and wavelet transform [6] to overcome the limitation of STFT. It produced a time frequency representation of a time series signal by uniquely combining a frequency-dependent resolution that simultaneously localizes the real and imaginary spectra. It can be viewed as frequency dependent STFT or phase corrected Wavelet transform. The benefit of S-transform is that it offers multi-resolution analysis while maintaining the absolute phase each frequency. It also has capability to detect the disturbance correctly in the present of noise which is very famous in detecting power system and disturbances [7]. The general S-transform is defined by the equation [8].

$$S_x\,(t,f) = \int_{-\infty}^{\infty} x(t)g(\tau - t)e^{-j2\pi f\tau} \tag{2}$$

Where v (t) is the signal and g is a windows function. Windows function is a modulated Gaussian expressed by:

$$g(\boldsymbol{\tau}) = \frac{\mathbf{1}}{\boldsymbol{\sigma}\sqrt{\mathbf{2}\boldsymbol{\pi}}}\,\boldsymbol{e}^{-(\boldsymbol{t}^{\mathbf{2}}/\mathbf{2}\boldsymbol{\sigma}^{\mathbf{2}})} \tag{3}$$

Where $\boldsymbol{\sigma}$ is the function of time and frequency, f defined as:

$$(f) = \frac{1}{|f|} \tag{4}$$

3.2. Signal Parameter

The signal parameter are estimated from the calculated TFR. The signal parameter that list as instantaneous RMS current, I_{rms} (t) instantaneous average current, I_{avg} (t), instantaneous RMS fundamental current, I_{1rms}(t), instantaneous total waveform distortion, TWD(t) instantaneous total harmonic distortion, THD(t), and instantaneous total non-harmonic distortion TnHD(t). The more details about the signal parameter as shows as previous research [10]-[12].

3.3. Signal Characteristic

The signal characteristic present the information of the signal and are used as input for base rule base classifier to classify and identify switches faults signals. By using the instantaneous RMS current, the average of RMS current can be estimated by using (5). While duration of switches fault, $T_{d,fault}$, can be identified from the instantaneous total waveform distortion, TWD(t) as shown in equation (7) where TWD $_{\text{thres fault}}$, is the total waveform distortion threshold for switches faults.

$$I_{\text{rms,mean}} = \frac{1}{T}\int_0^T I_{\text{rms}}\,(t)\,dt \tag{5}$$

$$I_{\text{rms,mean}} = \frac{1}{T}\int_0^T I_{\text{ave}}\,(t)\,dt \tag{6}$$

$$T_{\text{d,fault}} = \int_0^T \begin{cases} 1, & \text{for TWD (t)} \geq TWD_{\text{thres,fault}} \\ \mathbf{0,} & \mathbf{x} \geq \text{ elsewhere} \end{cases} \tag{7}$$

Where TWD thres fault is the total waveform distortion threshold for switches fault and the threshold is set at 0.05 or 5% based on analysis made for this signal as shown in Table 1.

Table 1. Analysis made for this signal

Type Of Fault	Switch	Minimum Threshold
Short Circuit	S_1	3.9%
	S_2	4.0%
	S_3	4.8%
	S_4	4.6%
	S_5	4.1%
	S_6	4.9%
Open Circuit	S_1	4.6%
	S_2	3.8%
	S_3	4.1%
	S_4	4.2%
	S_5	3.5%
	S_6	4.5%

The characteristics and parameter of the signal waveform distortion such as waveform distortion, the instantaneous total harmonic distortion and instantaneous total non-harmonic distortion is analyzed and used to obtain the mean total harmonic distortion and non-harmonic distortion is equation:

$$THD_{\mathrm{mean}} = \frac{1}{T}\int_0^T I_{THD}\,(\mathrm{t})\,\mathrm{dt} \tag{8}$$

$$TnHD_{\mathrm{mean}} = \frac{1}{T}\int_0^T I_{TnHD}\,(\mathrm{t})\,\mathrm{dt} \tag{9}$$

$$TWD_{\mathrm{mean}} = \frac{1}{T}\int_0^T I_{TWD}\,(\mathrm{t})\,\mathrm{dt} \tag{10}$$

3.4. Switch Fault Classification System

In this analysis, since the signal characteristic provide good prior knowledge of the switches fault signal, the rule-based is suitable to be used for the signal classification. To analyze and classify the switches fault based on characteristic of the signal the pseudo code are used.

Function [z]=rule-based classifier ($T_{d,fault}$, $I_{ave,mean}$, $I_{rms,mean}$, $THD_{ave,mean}$, $TnHD_{ave,mean}$, $TWD_{ave,mean}$)

```
If (011011)
    z= Open : S1
else if (100111)
    z= Short : S1
else if (100011)
    z= Open : S2
else if (011111)
    z= Short : S2
else if (101101)
    z= Open : S3
else if (010010)
    z= Short : S3
else if (010101)
    z= Open : S4
else if (101010)
    z= Short : S4
else if (110110)
    z= Open : S5
else if (001011)
    z= Short : S5
else if (001110)
    z= Open : S6
else if (110011)
    z= Short : S6
```

3.5. Performance Measurement Time Frequency Distribution

The prediction performance of both technique which is short time Fourier transform (STFT) and S-transform is analyze by using mean absolute percentage error (MAPE). This analysis required the complexity of computation and memory size. The high accuracy is determined if the value of MAPE get is small. This analysis have already tested in [13]. The expression of MAPE can describe as:

$$MAPE = \frac{100\%}{n}\sum_{t-1}^{n} \left| \frac{At-Ft}{At} \right|$$

4. RESULTS AND ANALYSIS

In this section, the result of switching fault are discussed. The results are obtained from the TFD by using STFT and S-transform. From time-frequency distribution (TFD) the details are extracted in term of frequency and spectral. The instantaneous RMS current, instantaneous average current, instantaneous fundamental RMS current, instantaneous TWD, instantaneous THD and instantaneous TnHD are among parameter that analyzed. The result can be whether negative or positive value rely on the fault switch.

4.1. Short Time Fourier Transform (STFT)

4.1.1. Short Circuit Switches Faults for VSI (Upper Fault)

Figure 2a has shown the short circuit s occur at phase *a* as indicated in red color. The magnitude of signal decreasing from 1.5A to 0A for fault duration of 60ms starting from 200 to 260ms. In other word, for both cases, the TFR present that frequency of 60Hz appear along of time axis but, DC component exist during 200 to 260ms time interval where the frequency is suppress to 0Hz as shown in Figure 2b. Blue color represents the lowest magnitude while the red color represent as highest magnitude which can be observed from the contour plots.

As appeared in Figure 2d, the RMS current for short out, abruptly, increment to 1.3A from its ostensible estimation of 1.17A, while RMS fundamental current then again tumbles to 0.75A for length of 60ms. Comparative trademark with normal current where the signal is falling from 0A to -1.1A as the fault signal exists just on the negative cycle. The parameter of total non-harmonic as appeared in Figure 2h increment from 3% to 56% at 180ms for span of 70ms. For aggregate consonant mutilation, the extent keeps up at 2% as appeared in Figure 2g. Thus, Figure 2f demonstrates the greatness of aggregate waveform contortion around comparable with total nonharmonic bending on account of the entirety of total harmonic distortion and total non-harmonics distortion.

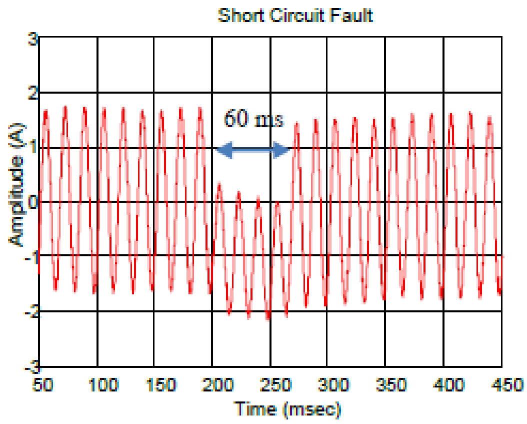

Figure 2a. Signal short circuit switch fault

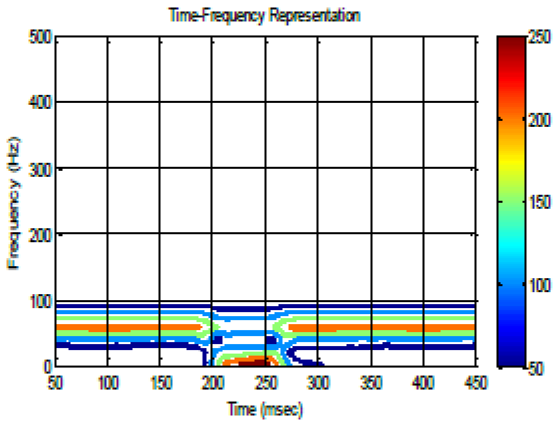

Figure 2b. TFR of short circuit fault using spectrogram

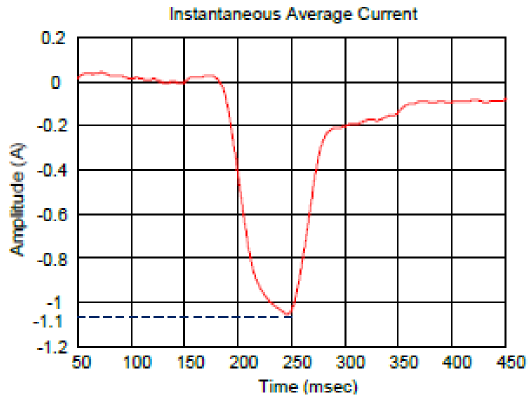

Figure 2c. Characteristic of instantaneous average current for short circuit switch fault

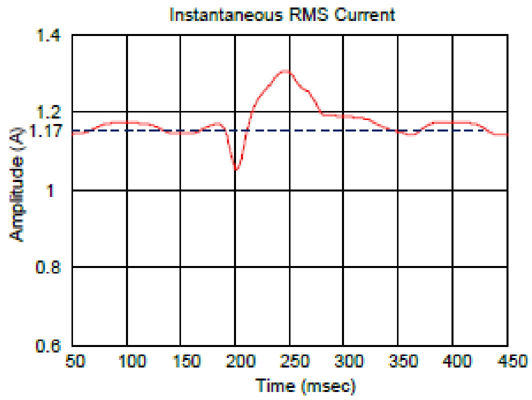

Figure 2d. Instantaneous RMS current of short circuit switch fault

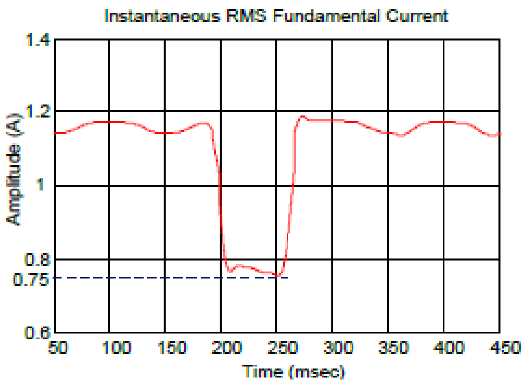

Figure 2e. Instantaneous RMS fundamental current of short circuit switch fault

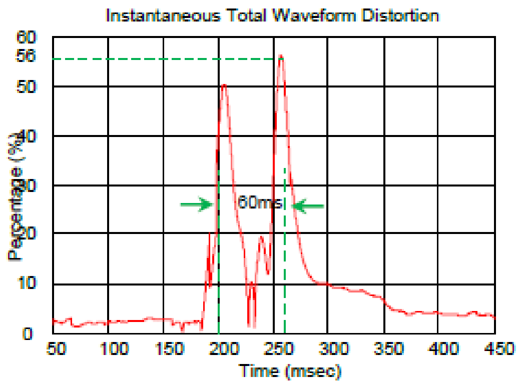

Figure 2f. Instantaneous Total Waveform Distortion

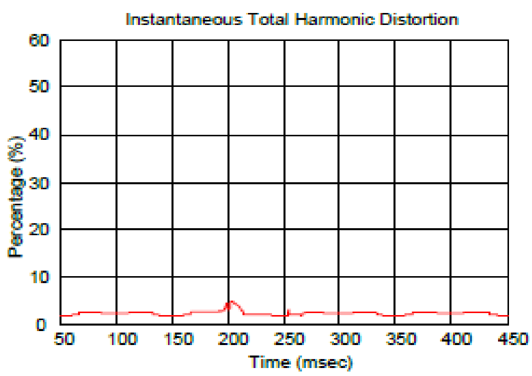

Figure 2g. Instantaneous Total Harmonic Distortion

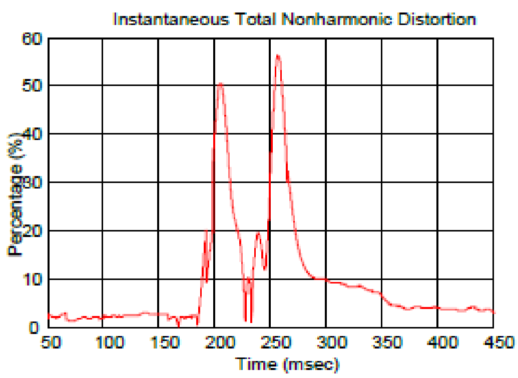

Figure 2h. Instantaneous Total Nonharmonic Distortion

4.2. S-Transform

4.2.1. Open Circuit Switches Faults for VSI

The fault analysis done by using S-transform technique. At S_{32} the open circuit fault is occur and the magnitude value is increase at time 200ms to 260ms is shown in Figure 3a. The fault signal yield the DC component and reduces the signal magnitude at fundamental frequency as indicated by its TFR in red color for highest amplitude and lowest is shown in blue contour color plot using S-transform that presented at 3b.

From TFR the signal parameter for open short fault are analyzed and shown at Figure 3. The parameter like instantaneous of RMS and the RMS fundamental current are slightly lower than the nominal value of 1.18A which are 1.0A and 0.7A as shown in Figure 3 (a) and (b), respectively. However, the instantaneous of average current is 0.7A which is higher from its nominal value, 0A, while the magnitude of total waveform distortion and total nonharmonic distortion increase between 50% and 45% for duration of 60ms while for total harmonic distortion, the magnitude maintains at 28% for open circuit switches fault.

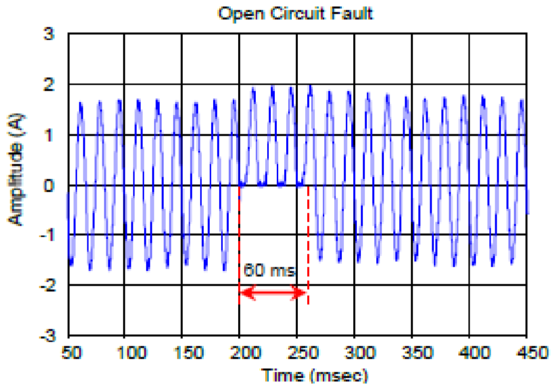

Figure 3a.The signal of phase for open switch fault

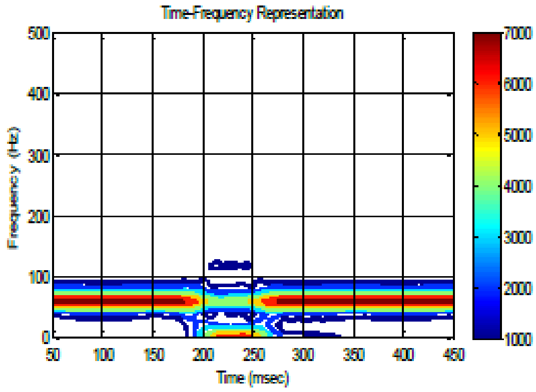

Figure 3b. TFR of open switch fault using S-transform

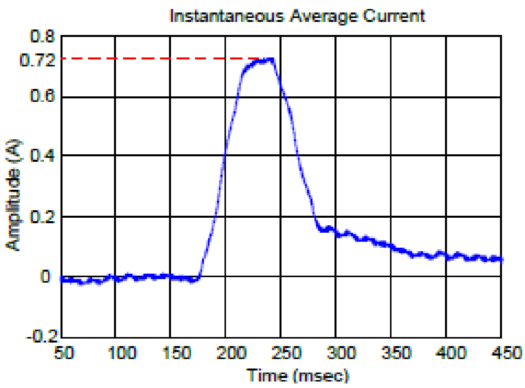

Figure 3c. Characteristic of average current

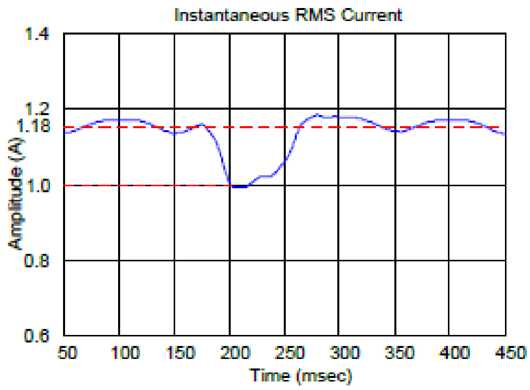

Figure 3d. Instantaneous RMS current

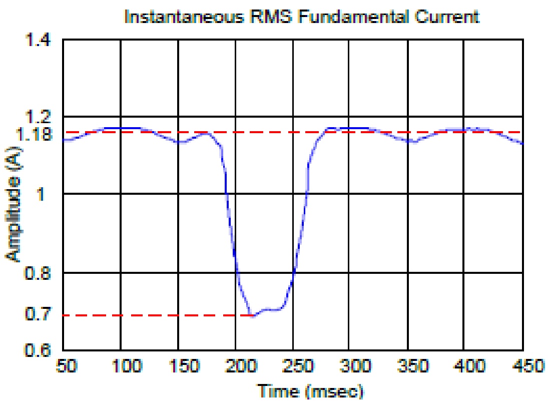

Figure 3e. Instantaneous RMS fundamental current

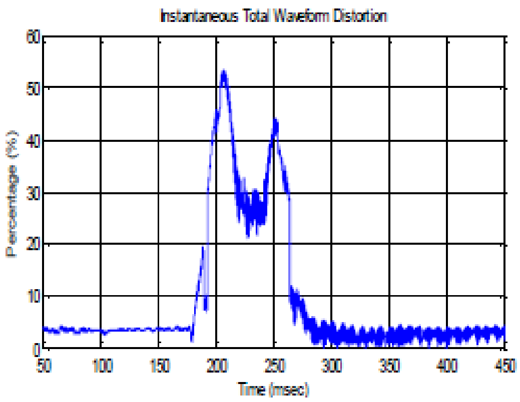

Figure 3f. Instantaneous total waveform distortion

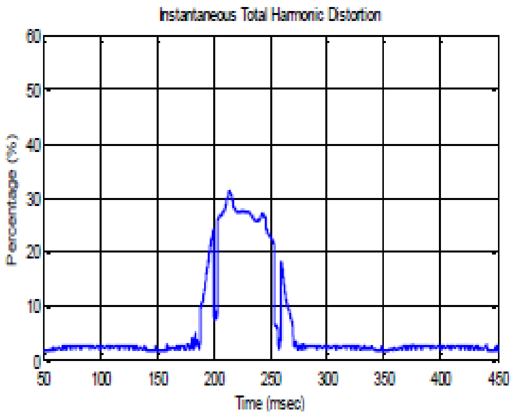

Figure 3g. Instantaneous total harmonic distortion

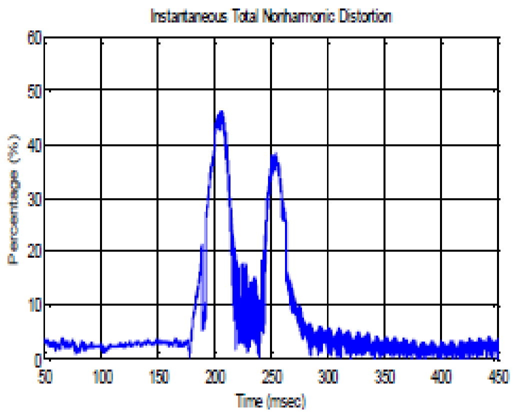

Figure 3h. Instantaneous total non-harmonic distortion

5. CONCLUSION

The evaluation of the performance analysis in this paper is contribute the knowledge and understanding about linear time frequency distribution between two difference technique which is STFT and S-transform. Both technique have been used in open-short circuit fault analysis for VSI system. Based on result, the performance of open-short circuit fault for VSI system have been identified with estimate parameter such as instantaneous RMS current, instantaneous average current, as instantaneous RMS fundamental current, instantaneous TWD, instantaneous THD and instantaneous TnHD. The conclusion that can made is both technique yield comparable signal parameter, but the best technique are S-transform because provide more accuracy than the STFT.

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