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Performance Comparison of VSI Switches Faults Analysis Using STFT and S transform

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Abstract. Switches fault in power converter has become compelling issues over the years. To reduce cost and maintenance downtime, a good fault detection technique is an essential. In this paper, the performance of STFT and S transform techniques are analysed and compared for voltage source inverter (VSI) switches faults. The signal from phase current is represented in jointly time-frequency representation (TFR) to estimate signal parameters and characteristics. Then, the degree of accuracy for both STFT and S transform are determined by the lowest value of mean absolute percentage error (MAPE). The results demonstrate that S transform gives better accuracy compare to STFT and is suitable for VSI switches faults detection and identification system.

Introduction

Most of the electrical drive systems in industrial process are exposed to hash environment which can reduce the lifespan of the inverter due to natural aging process. Therefore, to maintain the performance and reliability, preserving the health of the inverter is extremely crucial. This issue has attracted many researchers to improve faults detection and diagnosis techniques. Statistical data shows that 63% of the inverter experience faults within the first year of operation and 70% of the faults occurred are related to power switch which categories into short circuit faults, open circuit faults and gate-misfiring faults [1]. Generally fault diagnosis techniques can be categories into component based and system based. In component based techniques, standard features of industrial power converter such as gate signal monitoring and overcurrent scheme is used to protected solid state switches. To ensure the successful remedial action, these schemes which integrated with an auxiliary analog circuitry for switch abnormalities detection must operate in less than 10µsec to prevent the silicon chip from damages [2]. System-based techniques on the other hand focusing on waveform analysis and algorithmic techniques to identify type of faults and its location [3]. For waveform analysis, an open switch faults generated unwanted dc component in output current waveform. The inverter fault can be traced by spotting a large deviation of faults indicator from their expected values [4]. Algorithmic techniques on the other hand applied advanced classifier algorithm to identify faulty inverter disregards real time output estimations [5].

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 nonharmonic distortion (TnHD).Then, characteristics of the signals are calculated from the signal parameters and will be used as input for detection and identification system.

VSI Switches Faults

One of the most common failures in semiconductor switches is short circuit faults [6]. This fault occurs when the switch is closed and remains its ON state regardless the signal from gate control. Hence, it may cause catastrophic damages to either load connected or the battery as soon as the other switch of the leg is closed resulting large current flows through the two switches of one phase leg and the dc source [7] and may lead to system shutdown. Open switch faults on the other hand occurred due to overheating causing rupture connections or thermal cycling resulting lifted bonding wire [8]. However, an open switch fault does not cause system shutdown but the performance of the VSI will degrade and potentially lead to secondary faults.

Time Frequency Distribution

A signal can be translated into time and frequency representation (TFR) via powerful techniques called time frequency distributions (TFD) [9]. With TFR, spectral information of a signal can be monitored for a period of time. The limitation of observing non-stationary signals in Fourier transform elevated the advantages of STFT technique for TFR. Extensively used in power quality analysis, STFT technique offer an insight in the time evolution of each signal component by disintegrate the time varying signal into time-frequency domain components [10]. 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 [11]. Frequency resolution is proportional with the size of window but inversely proportional with time resolution. STFT of a signal x(t) is given by:

$$S(t,f) = \int_{-\infty}^{\infty} x(\tau)w(\tau - t)e^{-j2\pi f\tau}dt \quad (1)$$

where *w(t)* is an arbitrarily chosen window function. However, STFT shows drawback when analysing transient signal comprising both high and low frequency components. To overcome this limitation, the S transform technique has been introduced and developed by Stockwell [12], which combines the good features of STFT and wavelet transform (WT). It produces 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 a frequency dependent STFT or a phase corrected Wavelet transform. The advantage of S transform is that it offers multi-resolution analysis while maintaining the absolute phase of each frequency. The general S transform is defined by the equation [13] as

$$S(\tau, f) = \int_{-\infty}^{\infty} h(t)g(\tau - t, f)e^{-j2\pi ft}dt \quad (2)$$

where *h(t)* is the signal and *g(t)* is a window function. Windows function is a modulated Gaussian function expressed by

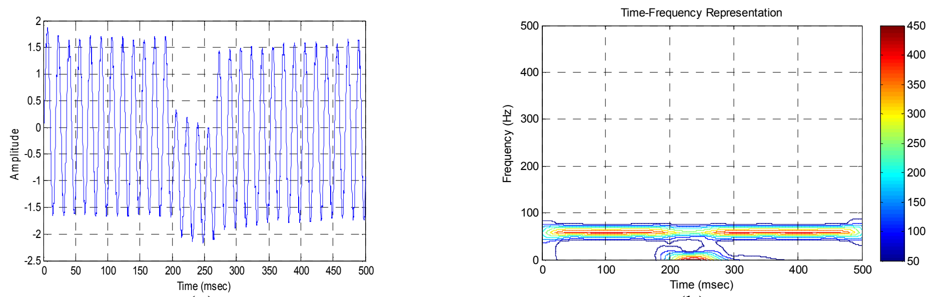
$$g(\tau) = \frac{1}{\sigma\sqrt{2\pi}} e^{-(t^2/2\sigma^2)} \quad (3)$$

Where σ is function of time and frequency, f defined as:

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

Results

The results of the switches faults analysis and comparison using STFT and S transform are discussed in this section. For instance, open switches fault signal at S2 for phase *a* and its TFR using STFT is presented in Fig.1. As shown in Fig.1 (a), there is a momentary magnitude decrease from 200 to 260ms. While, its TFR contour plot indicates that, the faults signal consists of fundamental component at 60Hz as well as produce DC component and their magnitudes are decrease and increase, respectively.



(a) (b)

Fig. 1, (a) Current signal of phase *a* for short switch fault at S2 (lower) and (b) Its TFR using STFT

The parameters of the fault signal estimated from the TFR above are shown in Fig. 2. For the short switches fault at S2, the magnitudes of instantaneous of RMS current, total waveform distortion, total harmonic distortion and total nonharmonic distortion are increase between 200 and 350ms while decrease between 200 and 350ms for instantaneous of RMS fundamental and average current.

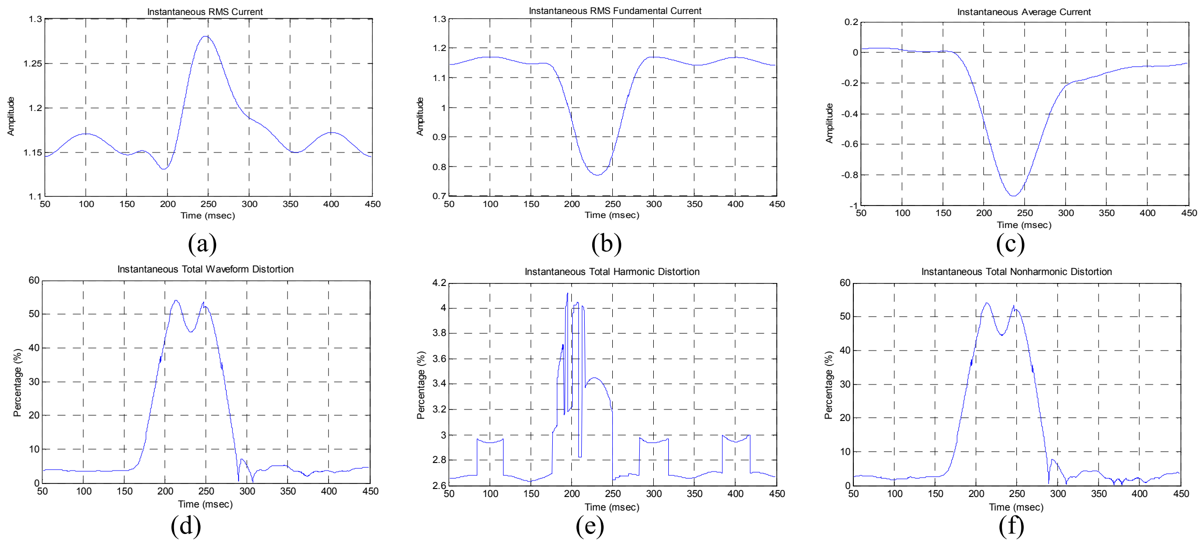
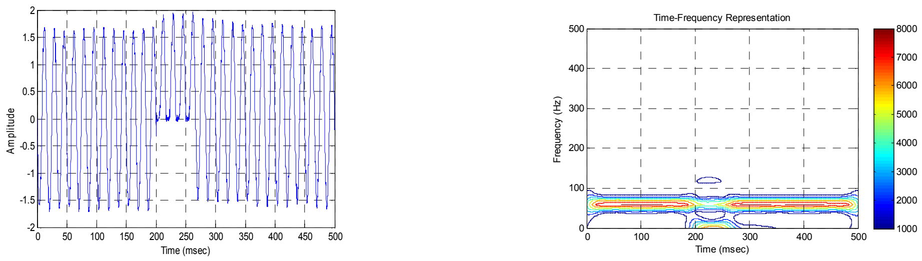


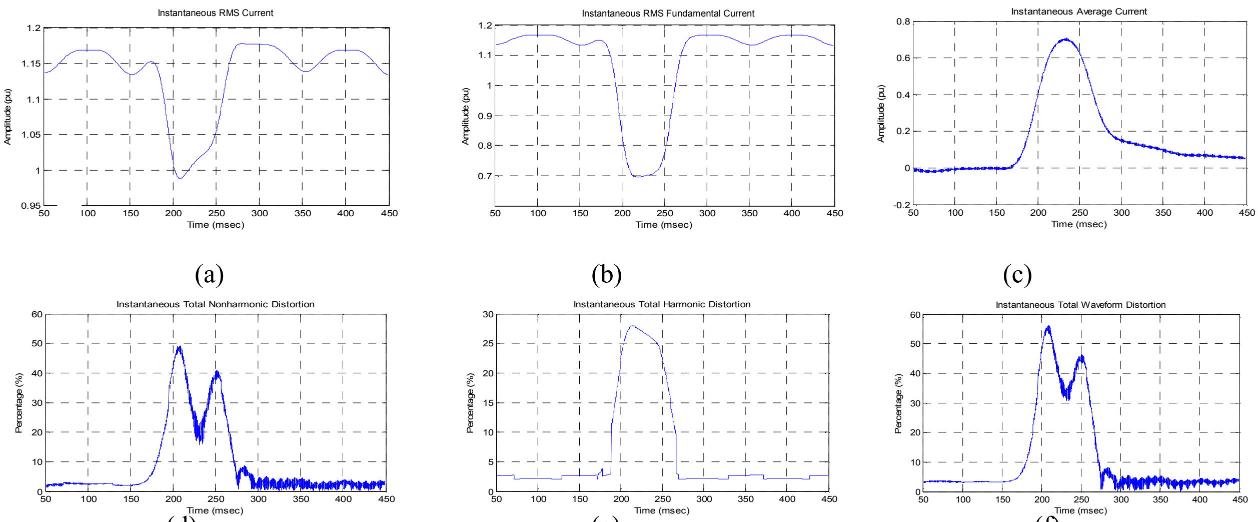
Fig.2. Signal parameter for short circuit fault (*phase a-S2 Lower*)

Open switch fault signal at S6 with magnitude increase from 200 to 270ms is shown in Fig, 3(a). The fault signal produce DC component and reduce the signal magnitude at fundamental frequency as indicated by its TFR contour plot using S transform as presented in Fig. 3(b). From the TFR, signal parameters for the open switch fault are estimated as illustrated in Fig. 4. As shown in Fig. 4(a) and (b), the magnitudes of the instantaneous of RMS and fundamental RMS current are lower the nominal value while higher for instantaneous of average current, total waveform distortion, total harmonic distortion and total nonharmonic distortion.



(a) (b)

Fig. 3, (a) Current signal of phase *c* for open switch fault at S6 (lower) and (b) its TFR using S transform

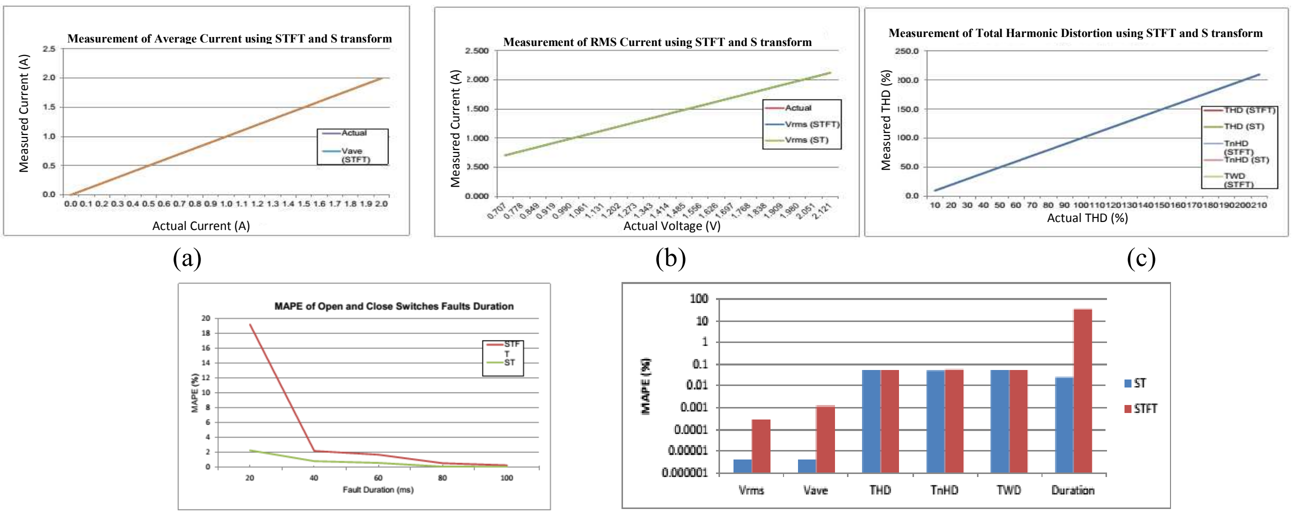


(a) (b) (c)

(d) (e) (f)

Fig.4, Signal parameter for open circuit fault (*phase c-S6 lower*)

Switches faults analysis using STFT and S transform are tested using open and short fault signal for each switch with various durations. Then, signal parameters and duration of the fault are measured and compared as demonstrated in Fig. 5. The results shows that, the measurements of total waveform distortion, total harmonic distortion and total nonharmonic distortion are comparable but for average current, RMS current and duration of faults, S transform gives higher accuracy compare to STFT as indicated lower mean absolute percentage error (MAPE) as shown in Fig. 5(e).



(a) (b) (c)

(d) (e)

Fig.5. Accuracy of signal parameters measurement

Conclusion

The performance comparison of VSI switches faults using STFT and S transform has been analyzed and demonstrated in this paper. 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. Both STFT and S transform techniques produce comparable signal parameters. However, the lower mean absolute percentage error (MAPE) shows that S transform provides better accuracy than STFT and is appropriate for VSI switches faults detection and identification system.

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