Harmonics Source Identification Analysis Using Spectrogram for Rectifier Load

Nabilah Mat Kassim, Abdul Rahim Abdullah, Aida Fazliana Abdul Kadir and Nur Hazahsha Shamsudin
Fakulti Kejuruteraan Elektrik,
Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya,
76100 Durian Tunggal, Melaka, Malaysia.
nabilah.matkassim@gmail.com

***Abstract*— The increasing of power electronics equipment contributes to the poor quality in power system. One of the major issues of power quality problem is harmonics distortion. A poor quality of electrical supply will affect the manufacturing process, malfunction of equipment and economic losses. Thus, it is important to trace and identify the harmonic source in power system so that precaution action can be taken appropriately. This paper aims to identify and analyze the harmonics source in power system using spectrogram technique. The sources of harmonic will be focused in this study is rectifier. The information of the harmonic characteristic obtained from the proposed technique will be presented in the time-frequency representation (TFR). From the TFR the signal parameters such as instantaneous root means square (*rms*) voltage, instantaneous *rms* current, spectrum of voltage and spectrum of current will be extracted. Next, these signal parameters will be used to identify the characteristics of harmonics source by using TFR of impedance. The signification finding of this research shows the harmonic sources location can be identified by referring to the relationship between fundamental impedance (Z_1) and harmonic impedance (Z_h).**

***Index Terms*— Harmonic source identification; Harmonics distortion; Rectifier; Spectrogram; TFR.**

I. Introduction

The widespread use of nonlinear and time-varying devices are produced the waveform distortion in the electrical power supply [1]-[2]. Waveform distortion such as harmonics and inter-harmonics have many negative impact to the power system such as reduce the power factor, poor power quality and resonance problem [3]-[4]. Therefore, the detection of harmonic source is an important issue to determine the harmonic source either from the utility side or customer side.

Several researchers were presented many techniques for analyze harmonic signal and obtain the harmonic sources location [5]-[6]. Recently, the most popular technique is presented in time or frequency or TFR [7]-[8]. TFR is used for non-stationary signals whose spectral characteristics change in time which represents a three-dimensional plot of the signal energy with respect to time and frequency [9].

Harmonic signals usually measured at the point of common coupling (PCC). According to the [10], PCC is located at point in the power system closest to the user where the system owner offer service to another user. This is mean that the measurement is taken on the distribution board (DB) at customer side for capturing the voltage and current harmonic signals.

In this paper, spectrogram is proposed for identifying the harmonic sources location in the power system. The voltage and current signals are captured at PCC. By using spectrogram, the information are presented in TFR. From TFR, the information of signal parameters such as voltage and current frequency marginal are obtained. Then, this signal parameters will be used to calculate harmonic impedance. The harmonic sources location can be identify by referring to the relationship between fundamental impedance and harmonic impedance.

II. Spectrogram

The spectrogram involves a compromise between time resolution and frequency resolution. It is mean that a longer window provides less localization in time and more discrimination in frequency [11]-[12]. The purpose of the window is to obtain a time-slice of the signal during which the spectral characteristics are nearly constant [9]. Equation (1) and Equation (2) shows the spectrogram equation for voltage and current respectively [13]-[14].

$$S_v(t,f) = \left| \int_{-\infty}^{\infty} v(\tau) w(\tau - t) e^{-2j\pi f} dt \right|^2 \quad (1)$$

$$S_I(t,f) = \left| \int_{-\infty}^{\infty} i(\tau) w(\tau - t) e^{-2j\pi f} dt \right|^2 \quad (2)$$

where $v(\tau)$ is the voltage signal, $i(\tau)$ is current signal and $w(t)$ is the window function.

III. Impedance Of Time-Frequency Representation

The TFR of impedance is generated from Equation (1) over Equation (2). It can be define as:

$$Z(t,f) = \frac{S_v(t,f)}{S_I(t,f)} \quad (3)$$

where S_V (t,f) and S_I (t,f) are the TFR of voltage and TFR of current, respectively.

IV. Harmonics Source Analysis

The harmonic source signals are generated by using rectifier load in MATLAB Simulink. The voltage and current signals are measured by oscilloscope at PCC in the test system. The PCC is a separate point between the upstream and downstream side [10]. It is used for monitoring the direction of current flow from electricity sources to the load as shown in Figure 1.

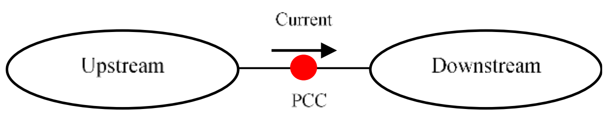


Figure 1: Measurement point at PCC

In order to identify the location of harmonic sources, four case studies were carried out consist of no harmonic sources (N-N) in the test system, harmonic sources at the downstream side (N-H), the harmonics sources at the upstream side (H-N) and harmonic sources at the both side (H-H) of the test system. Where N is for normal signal while H is for harmonic signal.

V. RESULTS AND DISCUSSION

The performance of the proposed technique has been analyzed by using MATLAB simulation program. The simulations with four cases are carried out in order to identify the characteristic of harmonic sources location. The evaluation results are discussed in the following section.

A. *Case 1: No harmonic source (N-N)*

Figure 2 display the voltage and current signals for Case 1. The resistive load are existed at the upstream side and the downstream side of the system. From the Figure 2(a), the peak of voltage is 200.2V and Figure 2(b) shows the peak of current is 1.251A. The voltage and current signals presents sinusoidal waveform because of no harmonic in this system

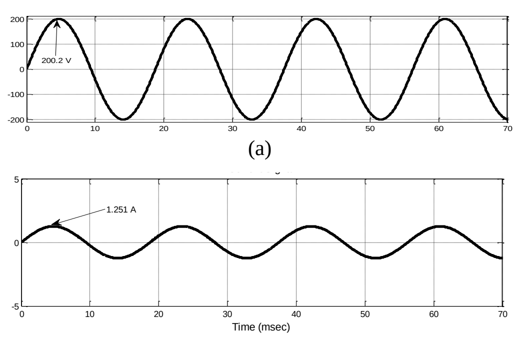


Figure 2: No harmonic source (a) voltage signal (b) current signal

Figure 3 shows the TFR for Case 1. The TFR shows the highest value in red color, while the lowest value is represented in blue color. The TFR of voltage is shown in Figure 3(a) and the TFR of current is shown in Figure 3(b) indicated that the highest magnitude power at 50 Hz, respectively. Therefore, no harmonic sources existed in this system.

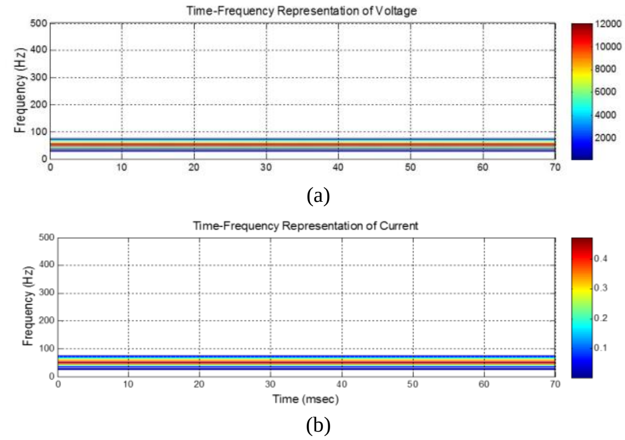


Figure 3: No harmonic source (a) TFR of voltage (b) TFR of current

Figure 4(a) and (b) presents the spectrum of voltage and the spectrum of current that extracted from TFR in Figure 3 with time-slice of the signal at *t*=30ms. Figure 4(a) indicates the fundamental voltage is 142V and Figure 4(b) marks the fundamental current is 0.885A at 50 Hz. The spectrum of impedance are obtained from the Equation (3), as shown in Figure 4(c) is 160Ω. Thus, the spectrum of impedance signifies that no harmonic component obtained in this case.

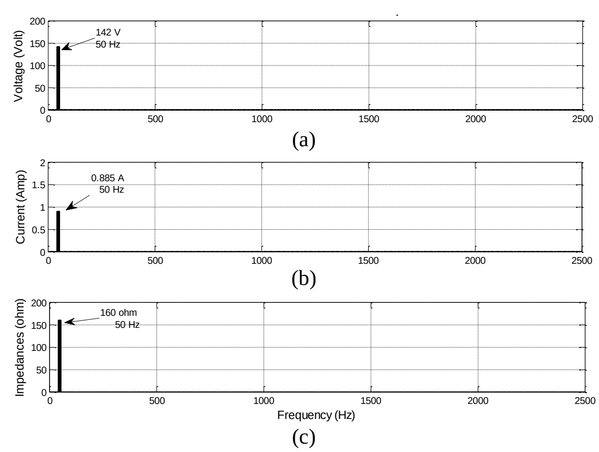


Figure 4: No harmonic source (a) Spectrum of voltage (b) Spectrum of current (c) Spectrum of impedance

Thus, the following equation is obtained from the analysis:

$$Z_1 \neq 0 \tag{4}$$

$$Z_h = 0 \tag{5}$$

B. *Case 2: Harmonic source at downstream (N-H)*

The harmonic source signal are generated at downstream side while the resistive load is located at the upstream side for Case 2. Distorted waveform of voltage and current signals are captured, then presented in Figure 5. From the Figure 5(a), the peak of voltage is 151.7 V and Figure 5(b) shows the peak of current is 2.681A. The peak of voltage drop from 200.2 V to 151.7 V while the current is draw more from 1.251 A to 2.681 A due to rectifier load at downstream.

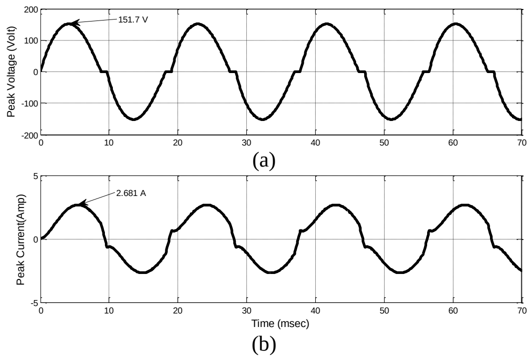


Figure 5: Harmonic source at downstream (a) voltage signal (b) current signal

Figure 6 shows an analysis using spectrogram, then presented in TFR for Case 2. Figure 6(a) presents the TFR of voltage and Figure 6(b) presents the TFR of current with higher magnitude power at 50 Hz, respectively. Moreover, Figure 6(a) and (b) display the low magnitude power at 150 Hz, 250 Hz, 375 Hz, 475Hz, 588Hz and 688 Hz. Therefore, the TFR are able to present the harmonic and non-harmonic component are existed in Case 2.

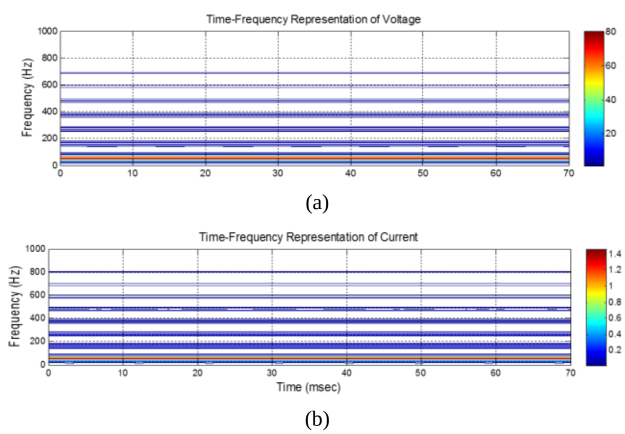


Figure 6: Harmonic source at downstream (a) TFR of voltage, (b) TFR of current

From Figure 6, the spectrum of voltage and the spectrum of current are extracted from TFR with time-slice of the signal at *t*=30ms. Thus, Figure 7(a) indicates the fundamental, harmonic and non-harmonic component of voltage. Moreover, the fundamental, harmonic and non-harmonic component of current are displayed at Figure 7(b). According to equation (3), the spectrum of impedance are obtained and shown in Figure 7(c).

Figure 7 (c) indicate that the fundamental component (50 Hz) of the impedance is large than the harmonic component of impedance.

Therefore, the characteristic of harmonic sources in Case 2 can be concluded as:

$$Z_1 > Z_h \tag{6}$$

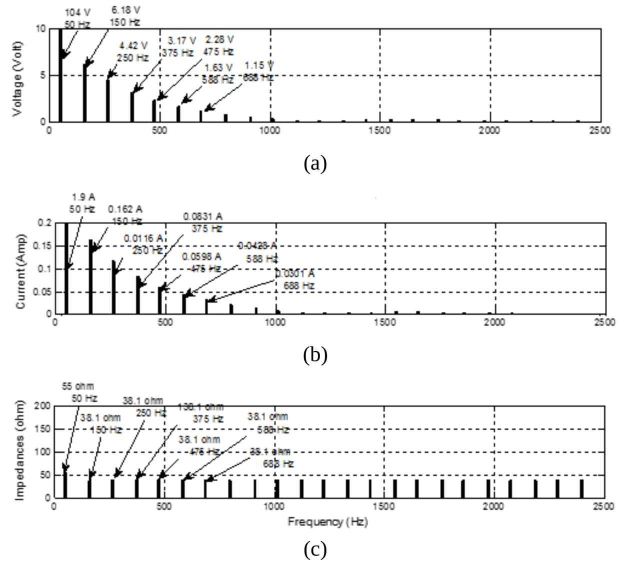


Figure 7: Harmonic source at downstream (a) Spectrum of voltage (b) Spectrum of current (c) Spectrum of impedance

C. Case 3: Harmonic source at upstream (H-N)

In this Case 3, the harmonic source are generated by using rectifier at upstream side while the resistive load is located at the downstream side. Figure 8 shows the distorted waveform of voltage and current signals. From the Figure 8(a), the peak of voltage is 151.7 V and Figure 8(b) shows the peak of current is 0.948 A. The peak of voltage drop from 200.2 V to 151.7 V as same as Case 2, but the current draw less in this Case 3 (0.948 A) compared with Case 2 (2.681A) and Case 1(1.251 A) because the resistive load at the downstream draw less current according to direction of current flow.

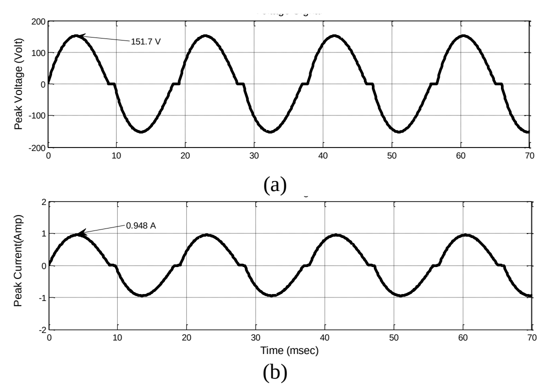
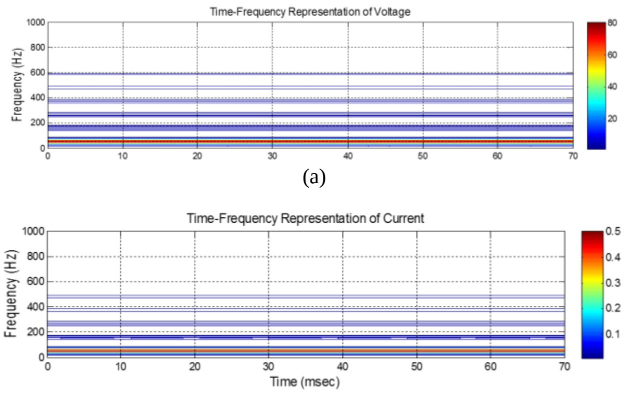


Figure 8: Harmonic source at upstream (a) voltage signal (b) current signal

From the TFR of voltage, the highest magnitude power was founded at 50 Hz, while the low magnitude power of the harmonic and non-harmonic component are located at 150 Hz, 250 Hz, 375 Hz, 475 Hz and 588Hz as shown in Figure 9(a) . Then, from the TFR of current was identified the higher magnitude power at 50 Hz. Thus, the harmonic and non-harmonic component with low magnitude power are presented at 150 Hz, 250 Hz, 375 Hz and 475 Hz as shown in Figure 9(b).

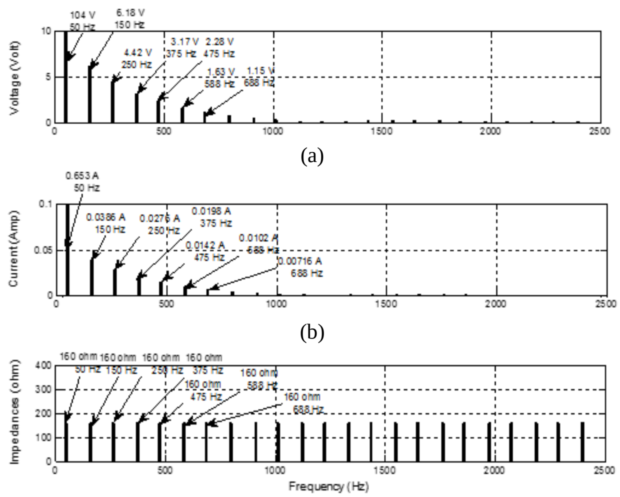


(a)

(b)

Figure 9: Harmonic source at upstream (a) TFR of voltage (b) TFR of current

The power of voltage in Figure 9 are extracted at *t*=30ms to present the fundamental, harmonic and non-harmonic component of voltage as shown in Figure 10(a). Furthermore, the fundamental, harmonic and non-harmonic component of current are extracted at t=30ms and then, are displayed at Figure 10(b). According to equation (3), the spectrum of impedance are obtained and shown in Figure 10(c).



(a)

(b)

(c)

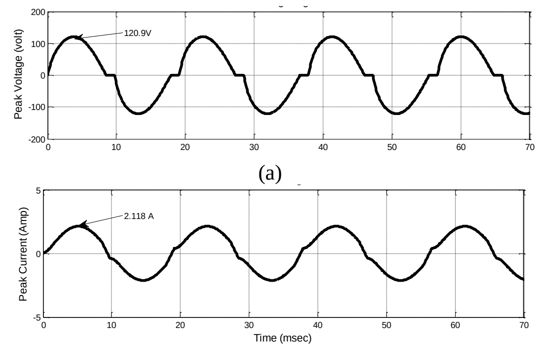
Figure 10: Harmonic source at upstream (a) Spectrum of voltage (b) Spectrum of current (c) Spectrum of impedance

It is apparent from Figure 10(c), that the magnitude impedance of the fundamental component (50Hz) of impedance and the harmonic component of impedance and are equal. Therefore, the characteristic of harmonic sources in Case 3 can be written as:

$$Z_1 = Z_h \tag{7}$$

D. *Case 4: Harmonic disturbances at upstream and downstream (H-H)*

The rectifier load are located at the upstream and downstream for generating distorted waveform at both side. The voltage and current signals are measured at the PCC and presented in Figure 11. The distorted waveform in Figure 11(a) are indicated that the peak of voltage is 120.9 V and the peak of current is 2.118 A as shown in Figure 11(b). The reading of peak voltage is the lowest reading compared with Case 1(200.2 V), Case 2(151.7 V) and Case 3(151.7 V) due to rectifier load at both side. However, the reading current at PCC is more than Case 1(1.251 A) and Case 3(0.948A), but less than Case 2 (2.681A) regarding to the same power draw from both side rectifier.

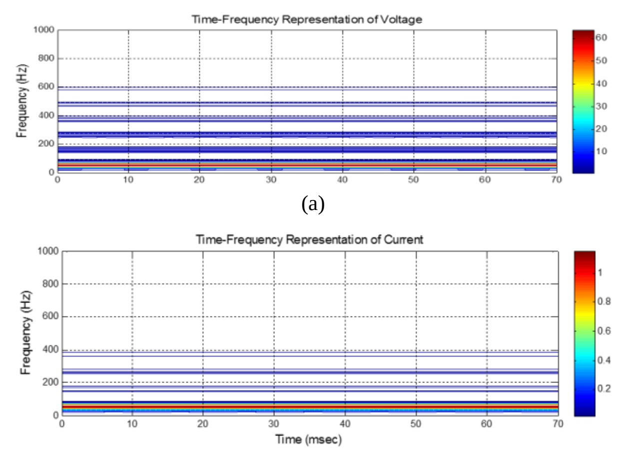


(a)

(b)

Figure 11: Harmonic source at upstream and upstream (a) voltage signal (b) current signal

Figure 12(a) presents the TFR of voltage and indicates the highest magnitude power at 50 Hz. Then, the low magnitude power of the harmonic and non-harmonic component was founded at 150 Hz, 250 Hz, 375 Hz, 475 Hz and 588Hz as shown in Figure 12(a). Then, from the TFR of current was identified the higher magnitude power at 50 Hz and low magnitude power of the harmonic and non-harmonic component are presented at 150 Hz, 250 Hz, 375 Hz and 475 Hz as shown in Figure 12(b).



(a)

(b)

Figure 12: Harmonic source at upstream and upstream (a) TFR of voltage (b) TFR of current

From Figure 12, the spectrum of voltage and the spectrum of current are extracted from TFR with time-slice of the signal at *t*=30ms. Figure 13(a) presents the fundamental, harmonic and non-harmonic component of voltage and Figure 13(b) shows the fundamental, harmonic and non-harmonic component of current. According to equation (3), the spectrum of impedance are obtained and shown in Figure 13(c).

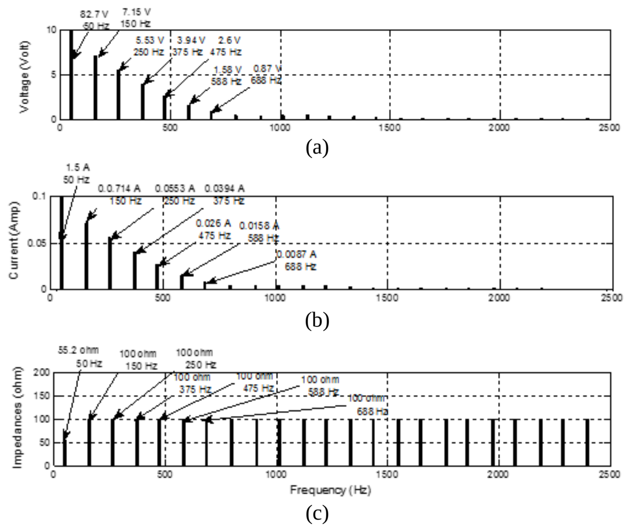


Figure 13: Harmonic source at upstream and upstream (a) Spectrum of voltage (b) Spectrum of current (c) Spectrum of impedance

The result as seen in Figure 13, indicate that the magnitude fundamental component (50Hz) of impedance is lesser than the harmonic component of impedance. Therefore, the characteristic of harmonic sources in Case 3 can be obtained as:

$$Z_1 < Z_h \tag{8}$$

From the case study, the results show that the harmonic sources can be characterized using Spectrogram. Table 1 summarizes the characteristic of harmonic sources that have been tested in four cases. The difference cases can be identified by relationship of the fundamental component of impedance and harmonic component of impedance. The behavior of fundamental impedance and harmonic impedance can be used to identify the harmonic source location. The summary of the characteristic of the harmonic source location is shown in Table 1.

Table 1
Characteristic of harmonic source location

Case	Upstream	Downstream	Characteristic
1	Normal	Normal	Z_h=0
2	Normal	Harmonics	Z_1>Z_h
3	Harmonics	Normal	Z_1=Z_h
4	Harmonics	Harmonics	Z_1<Z_h

where, Z_1 is fundamental, Z_h is harmonic component and h= 3,5,7,9…n

VI. Conclusion

This paper presents the analysis of harmonic signal by using spectrogram in order to identify the harmonics source location. The signal parameters which are the power spectrum of voltage and the power spectrum of current are obtained from TFR. Then, the signal parameters will be used to calculate harmonic impedances by using impedance method. Therefore, the relationship between fundamental impedance and harmonic impedance is used to obtain the location of harmonic sources either at upstream, downstream or both side of the system. Moreover, the voltage and current signals are measured directly in online mode without calculate system impedance and this analysis is more practical for identifying the location of harmonic source. As conclusion, the information of harmonic source by using time-frequency analysis technique which is spectrogram can be used to identify the harmonic source location.

Acknowledgment

This research is supported by the team of this project from Advance Digital Signal Processing Laboratory (ADSP Lab). Special thanks also go to the Faculty of Electrical Engineering of Universiti Teknikal Malaysia Melaka (UTeM) and to the Ministry of Higher Education Malaysia (MOHE) for giving the cooperation and funding to this research who make the research successful which are 06-01-14-SF00119 L00025. Their support is gratefully acknowledged.

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