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An Improved of Multiple Harmonic Sources Identification in Distribution System with Inverter Loads by using Spectrogram

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ABSTRACT

This paper introduces an improved of multiple harmonic sources identification that been produced by inverter loads in power system using time-frequency distribution (TFD) analysis which is spectrogram. The spectrogram is a very applicable method to represent signals in time-frequency representation (TFR) and the main advantages of spectrogram are the accuracy, speed of the algorithm and use low memory size such that it can be computed rapidly. The identification of multiple harmonic sources is based on the significant relationship of spectral impedances which are the fundamental impedance (Z1) and harmonic impedance (Zh) that extracted from TFR. To verify the accuracy of the proposed method, MATLAB simulations carried out several unique cases with different harmonic producing loads on IEEE 4-bus test feeder cases. It is proven that the proposed method is superior with 100% correct identification of multiple harmonic sources. It is envisioned that the method is very accurate, fast and cost efficient to localize harmonic sources in distribution system.

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1. INTRODUCTION

Present day in modern power distribution system, a lot of harmonic producing loads that consist of non-linear loads and electronically switched loads such as inverters, arc furnaces and so on, have injected harmonic into system, which leads to potential threat for standard performance of power system as per discussed in [1]–[3]. Thus, it is a crucial request to reduce or eliminate the harmonic pollution and the detection of harmonic sources is the first step towards enhancing the power quality of the system [4]-[5]. Meanwhile, in power distribution system, multiple harmonic sources can be found at utility side which known as upstream and downstream when harmonic sources located at customer side with a respect to a measurement point of point of common coupling (PCC) [6]– [8].

Previously, diverse methodologies of localizing multiple harmonic sources can be found in many kinds of literature. The earliest technique to localize the harmonic sources is utilizing power direction technique, however, this method cannot give accurate results when some harmonics and phase angle beyond 90° [9], [10]. Moreover, a state estimation method is introduced with the implementation of least square and Kirchhoff current law [11]. However, a study [12], showed that state estimation technique requires numerous measurement devices and unreasonable setup cost for the large power system. Furthermore, in the literature, the identification of harmonic sources using critical impedance technique has also been discussed [13]–[15]. The major drawback of this technique is a pre-requirement of source internal impedances values of utility and customer side, in practical it is hard to obtain those parameters without switching test and it costly [16], [17]. To overcome the limitation of critical impedance method, a harmonic current vector method is introduced [18]–[20]. The assessment customer impedances can be done without any switching testing. However, the measurement long-drawn-out and difficult to examine harmonic impedances at customer side [10].

In the previous studies [21]-[22], the harmonic source estimation has been proposed by utilizing the harmonic state estimation (HSE) and Bayesian estimation. Unfortunately, this technique requires a high multiplicity in the algorithm and very expensive cost to setup the distributed measurement system station [23]. By using an alternate methodology that focuses on two-point measurements strategy, impedances information can be obtained by comparing the data between the supply and incoming of the load utilizing frequency and phase approach [15]. However, this technique gives an accurate impedances information, but then again it still expensive and difficult to practice [17]. In real time, the accuracy, quick estimation and low cost are important and most of the previous studies did not consider those factors. Based on above discussion, the limitation of previous techniques can be overcome using time-frequency distribution (TFD).

This paper proposes a high accuracy, fast estimation and costs efficient of a new multiple harmonic sources identification method with single-point measurement [8] at the PCC utilizing TFD which is spectrogram. The spectrogram is an appropriate technique that represents a signal in time and frequency representation and known as time-frequency representation (TFR) [8]-[15]-[17]. From these the signals, spectral information can be monitored with changes of time. Therefore, the Spectrogram is a very appropriate method to identify harmonics sources. Furthermore, spectral information of the system can be extracted from TFR in order to identify the system characteristic and a common harmonic producing load which is inverter will be used as loads in the system [2]-[3]. From the TFR, spectral impedances which are fundamental impedance, Z_1 and harmonic impedance, Z_h will be estimated and calculated accurately. Finally, utilizing the significant characteristic between Z_1 and Z_h, the identification of multiple harmonic sources location can be realized accurately.

2. METHODOLOGY

A single point-measurement will be implemented in this study, while TFD which is spectrogram is used in order to examine and analyse the signal parameters

2.1. Spectrogram

The spectrogram is a one of the technique in TFD analysis and represented a dispersion of signal energy in time-frequency representation. By windowing the signal at first and after that taking the Fourier transforms the time-localization can be obtained correctly. Furthermore, this will lead to the rise of short time Fourier transform, (STFT) or windowed Fourier transform. Furthermore, the squared value of the STFT is, usually used in the signal analysis which called as a spectrogram and can be defined as in Equation 1 and Equation 2 [17].

$$S_v(t,f) = \left| \int_{-\infty}^{\infty} v(\tau) w(\tau - t) e^{-j2\pi f} dt \right|^2 \tag{1}$$

$$S_i(t,f) = \left| \int_{-\infty}^{\infty} i(\tau) w(\tau - t) e^{-j2\pi f} dt \right|^2 \tag{2}$$

Whereby, w(t) is observation windows. The Hanning window is selected with respect to IEC standard that characterized this window is suitable for analyzing harmonic [3] and also be chosen due to its lower peak side lope which has the narrow effect on other frequencies around fundamental value and other frequency components. The spectrogram is used in numerous applications and generally utilized as an initial investigative instrument as it has the property of non-producing cross-term parameters of TFD [4]-[5].

2.2. Principle of Proposed Methodology

The implementation for multiple harmonic sources identification can be realized as demonstrate in Figure 1 and with IEEE 4-bus test feeder cases as show in Figure 2. There are four condition considered in the simulation with referring to the measurement point at the PCC as follows:

a. No harmonic sources within the distribution system.
b. A downstream, when the harmonic sources located at a customer side
c. Both stream, when the harmonic sources located at utility and customer side. Whereby, this is the common scenario in practice.
d. An upstream, which is means the harmonic sources located at the utility side.

In addition, the source detection is using the single-point measurement approach at PCC [28]. The measurement data will be analyzed by spectrogram and signal parameters of the power system are estimated from the time frequency representation (TFR). Finally, the harmonic sources location are identified based on the significant relationship between fundamental impedance, Z_1 and harmonic impedance, $Z_{h.}$

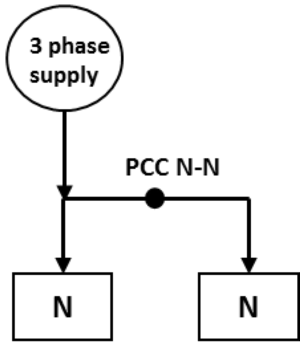


Figure 1. Case 1

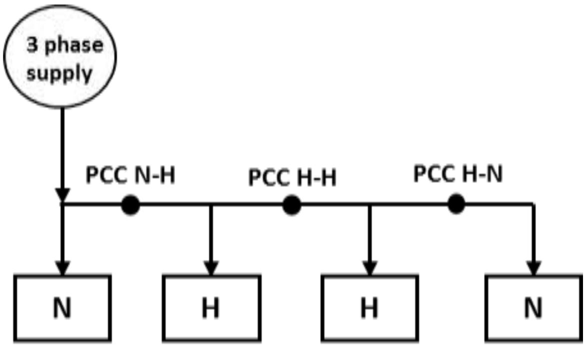


Figure 2. Case 2, 3 and 4

Whereby, N is non-harmonic producing load and H is harmonic producing load.

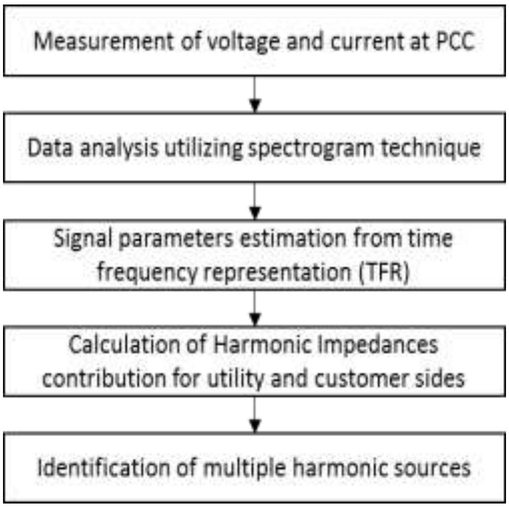


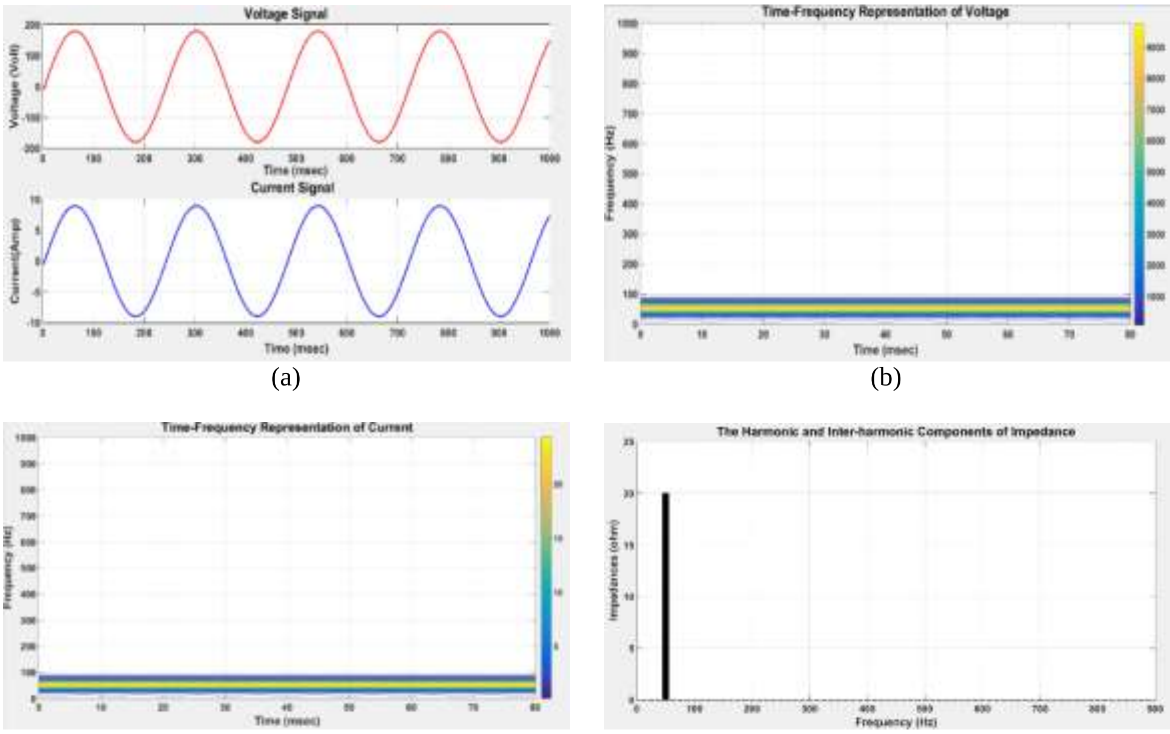
Figure 3. The implementation procedure in identification of multiple harmonic sources at the PCC

The implementation of methodology in executing the proposed approach for distinguishing harmonic sources as can be seen in Figure 3. From the proposed technique, it is demonstrated that the methodology can be effortlessly actualized in the system. This is due to that no requirement for any complex calculation or itemized data of system parameters. The only measurement data required for this method are voltages and current only at the PCC.

3. RESULTS AND DISCUSSION

3.1. Case 1: No Harmonic Sources within the System

The data for this case was measured at PCC N-N as illustrated in Figure 1 and non-harmonic producing loads connected to the system. Figure 4(a) shows the voltage and current signal in time domain. Meanwhile, Figure 4(b) and Figure 4(c) clearly show that only fundamental frequency at 50Hz exists in the system. As can be seen from Figure 4(d), the fundamental impedance is estimated from TFR at a value of 20 ohm as depicts in Figure 4(e) and no harmonic impedance exists.



(a) (b) (c) (d)

Figure 4. No harmonic sources. (a) Voltage and current Signal, (b) TFR of voltage, (c) TFR of current, (d) Harmonic and inter-harmonic components of spectral impedance.

Apparently from Figure 4(d), it is plainly shown that the significant characteristic of spectral impedances for Case 1 can be concluded as:

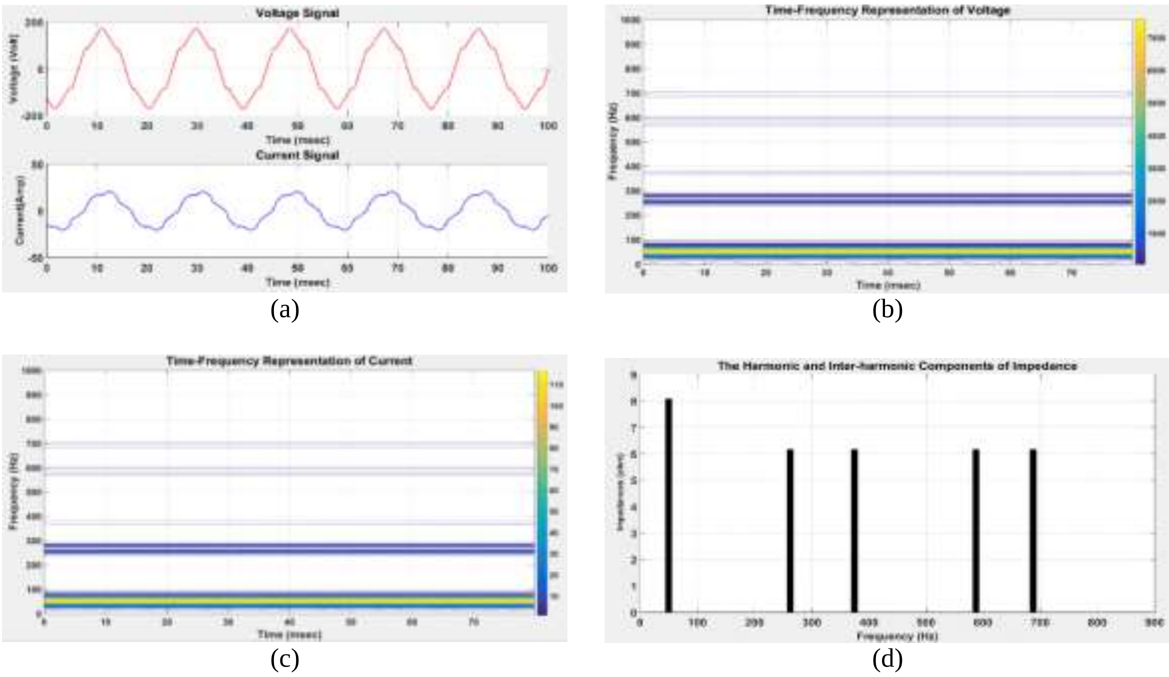
$$Z_h = 0 \text{ ohm} \tag{3}$$

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

3.2. Case 2: Harmonic Sources at Downstream

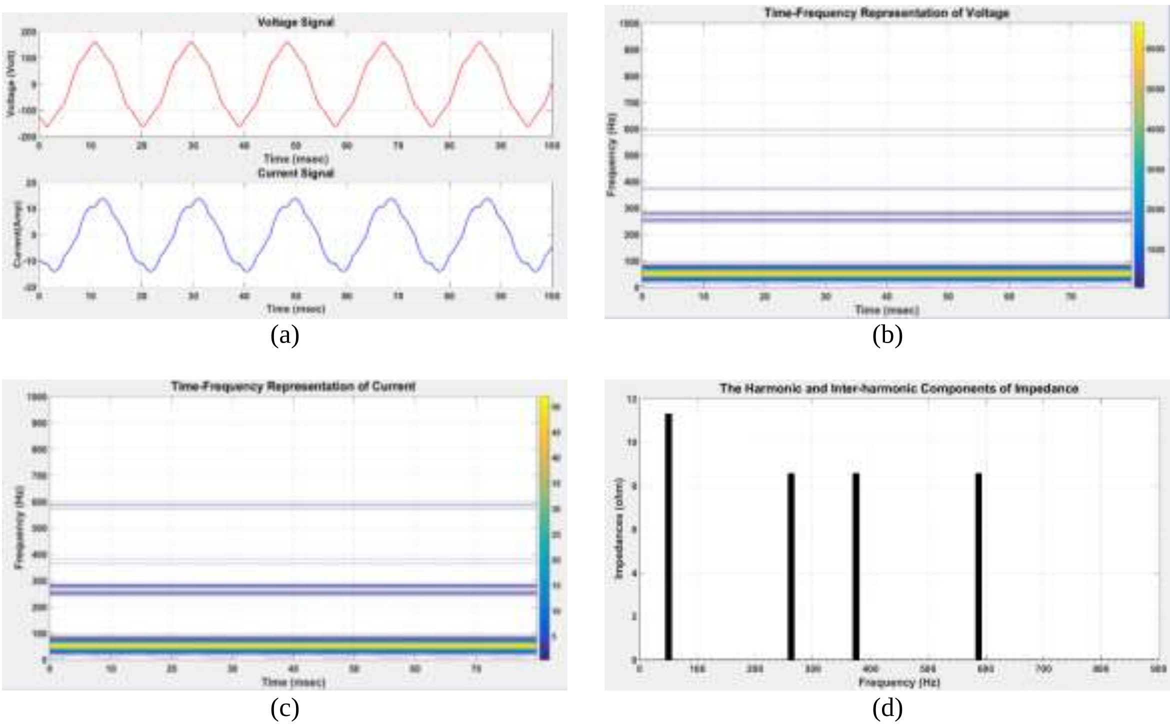
Case 2 was carried out due to identifying harmonic sources when the harmonic producing load located at downstream and the measurement data were taken at PCC N-H. Figure 5(a) shows the harmonic signal in time domain when AC-DC-AC PWM converter was used as a harmonic source at downstream. Furthermore, the TFRs in Figure 5(b) and Figure 5(c) show the signals of five frequency components consist of the fundamental frequency (50Hz) and inter-harmonic components at 262.5Hz, 375Hz, 587.5Hz and 687.5Hz. Figure 5(d) presents the estimated impedances value of fundamental impedance was 8.296 ohm and the average value of harmonic and inter-harmonic impedance was 6.152 ohm respectively.

The voltage and current signal as shown in Figure 6(a) was obtained when three-phase two-level single bridge converter was used as a harmonic source at downstream. Figure 6(b) and Figure 6(c) show the signal parameter of fundamental and inter-harmonic of voltage and current that estimated from TFR. Components consist of fundamental frequency at 50Hz and inter-harmonic components at 262.5Hz, 375Hz and 587.5Hz. Furthermore, from Figure 6(d), it shows that the fundamental impedance is 11.3 ohm while the average value of harmonic and inter-harmonic impedance is 8.569 ohm respectively.



(a) (b) (c) (d)

Figure 5. Three-phase two-level single bridge converter as a harmonic source at upstream. (a) Voltage and current signal, (b) TFR of voltage, (c) TFR of current, (d) Harmonic and inter-harmonic components of spectral impedance



(a) (b) (c) (d)

Figure 6. Three-phase two-level single bridge converter as a harmonic source at upstream. (a) Voltage and current signal, (b) TFR of voltage, (c) TFR of current, (d) Harmonic and inter-harmonic components of spectral impedance

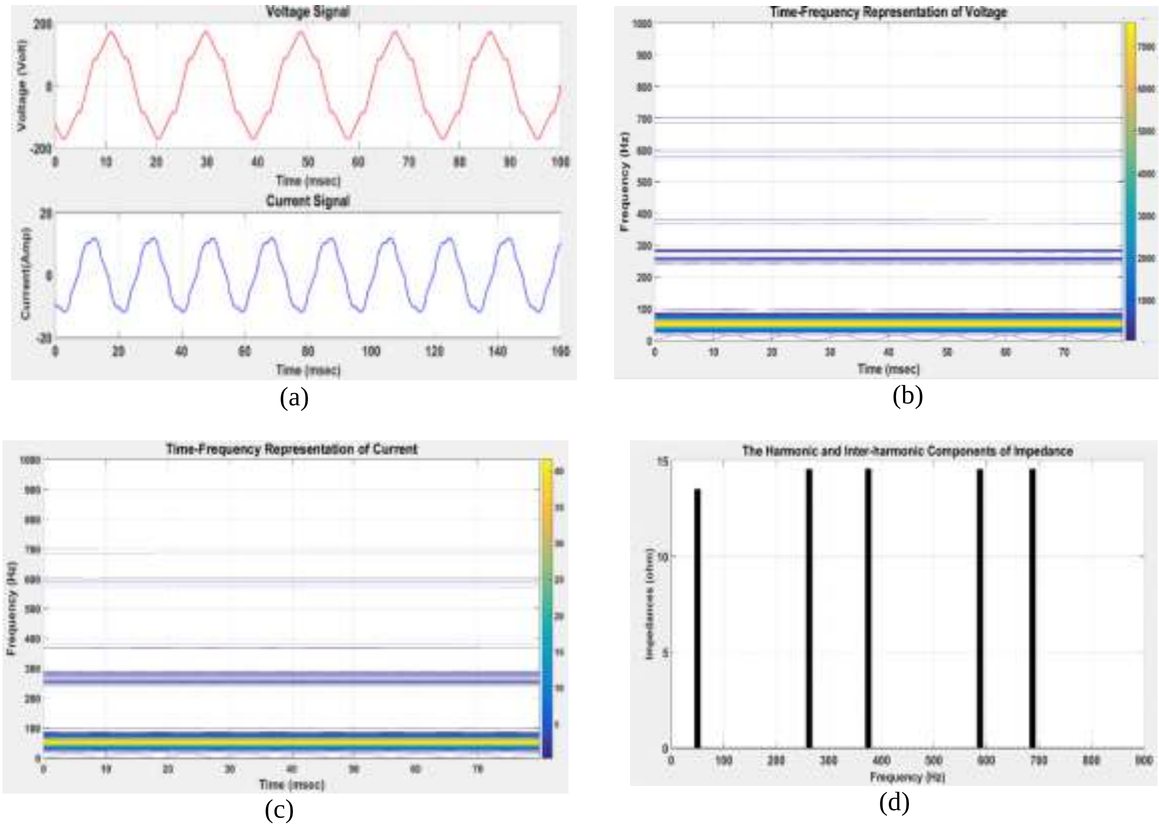
Results that been obtained from Figure 5(d) and Figure 6(d) clearly indicate that the fundamental impedance value is always larger than the harmonic impedance. Therefore, the significant characteristic of spectral impedance for Case 2 can be deduced as

$$Z_1 > Z_h \tag{5}$$

3.3. Case 3: Harmonic Sources at Upstream and Downstream

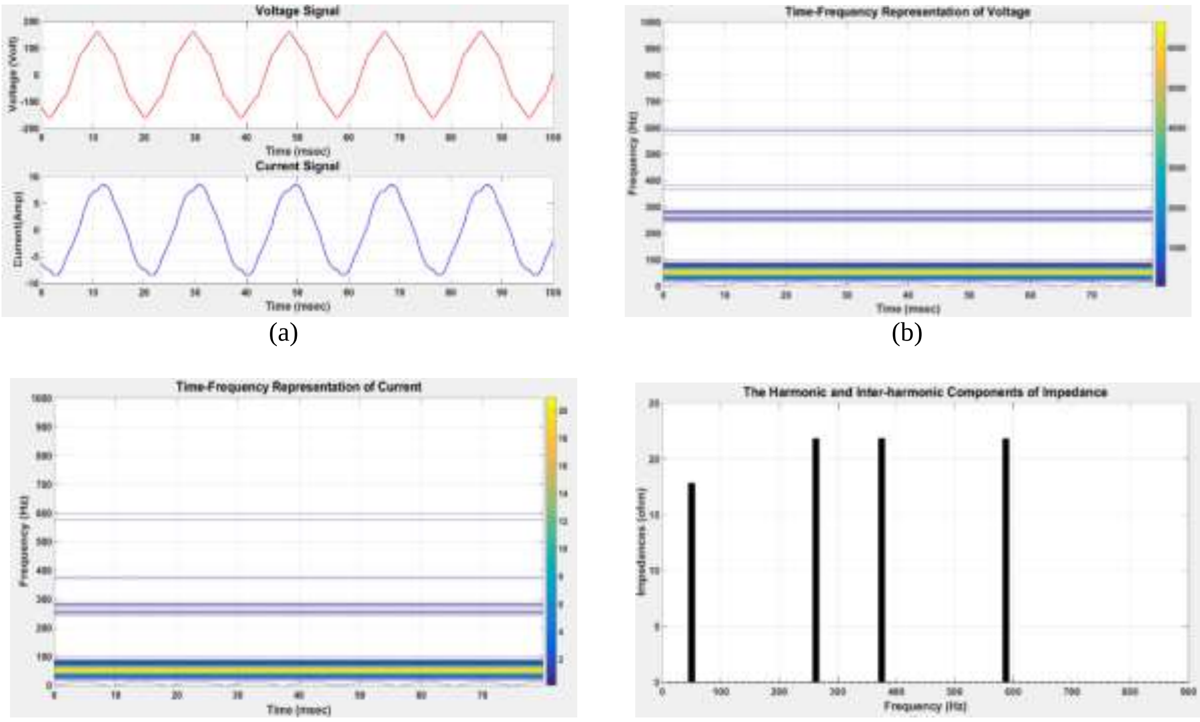
This case studies goals to localize the location of harmonic sources when both streams contain the harmonic producing loads and the measurement of voltage and current was taken at PCC H-H. Current and voltage signals are shown in Figure 7(a) when AC-DC-AC PWM converter acted as harmonic producing loads at upstream and downstream. As can be seen from Figure 7(b) and Figure 7(c), the signals frequency components clearly seen from TFRs and consist of the fundamental frequency (50Hz) and inter-harmonic components at 262.5Hz, 375Hz, 587.5Hz, and 687.5Hz. As shown in Figure 7(d), the TFR estimated the fundamental impedance with a value of 13.49 ohm while the average value of harmonic impedance is 14.55 ohm.

Figure 8(a) shows the voltage and current signal in time domain when three-phase two-level single bridge converter acted as harmonic sources at upstream and downstream. Figure 8(b) and Figure 8(c) show frequency components consist of the fundamental frequency (50Hz) and inter-harmonic components at 262.5Hz, 375Hz and 587.5Hz. As shown in Figure 8(d), the fundamental impedance estimated at a value of 17.82 ohm while the average value of harmonic impedance is 21.81 ohmshown in Figure 8(d), the fundamental impedance estimated at a value of 17.82 ohm while the average value of harmonic impedance is 21.81 ohm.



(a) (b) (c) (d)

Figure 7. AC-DC-AC PWM converter as a harmonic source at upstream and downstream. (a) Voltage and current signal, (b) TFR of voltage, (c) TFR of current, (d) Harmonic and inter-harmonic components of spectral impedance



(a) (b)

(c) (d)

Figure 8. Three-phase two-level single bridge converter as a harmonic source at upstream and downstream. (a) Voltage and current signal, (b) TFR of voltage, (c) TFR of current, (d) Harmonic and inter-harmonic components of spectral impedance

3.4. Case 4: Harmonic Sources at Upstream

With the intention of identifying the location of the harmonic source that located at upstream, case 4 was carried out properly with AC-DC-AC PWM converter as a harmonic producing load at downstream and a measurement was taken at PCC H-N. Figure 9(a) shows the voltage and current signal in time domain. Meanwhile, Figure 9(b) and Figure 9(c) are TFRs that represent the signals of frequency components consist of the fundamental frequency (50Hz) and inter-harmonic components at 262.5Hz, 375Hz, 587.5Hz and 687.5Hz. The analysis of TFR as depicts in Figure 9(d) estimated the fundamental and harmonic impedances are equal with a value of 40.01 ohm.

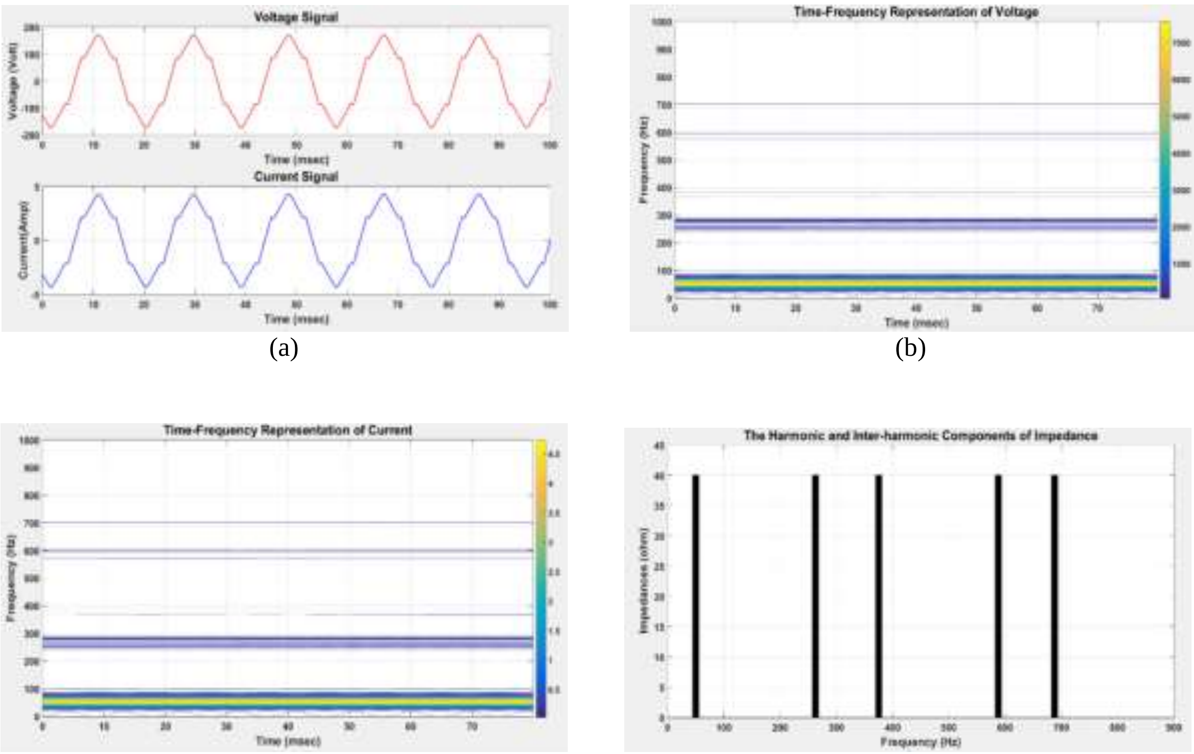
Three-phase two-level single bridge converter alternately used as a harmonic source in the system. The voltage and the current signal at PCC H-N in time domain are shown in Figure 10(a). Meanwhile, the TFRs in Figure 10(b) and Figure 10(c) show the signals of frequency components consist of fundamental frequency at 50Hz and inter-harmonic components at 262.5Hz, 375Hz and 587.5Hz. As can be seen in Figure 10(d), the fundamental, harmonic and inter-harmonic impedances were estimated at 40.01 ohm respectively. It is apparent from the results of Figure 9(d) and Figure 10(d), the magnitude of the fundamental impedance is always equal with harmonic impedances in Case 4. Therefore, the significant characteristic relationship of spectral impedances for Case 4 can be concluded as:

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

Table 1. Spectral impedance characteristic for multiple harmonic sources identification

Case	Upstream	Downstream	Spectral Impedance Characteristic
1	N	N	$Z_h = 0$ ohm
2	N	H	$Z_1 > Z_h$
3	H	H	$Z_1 < Z_h$
4	H	N	$Z_1 = Z_h$

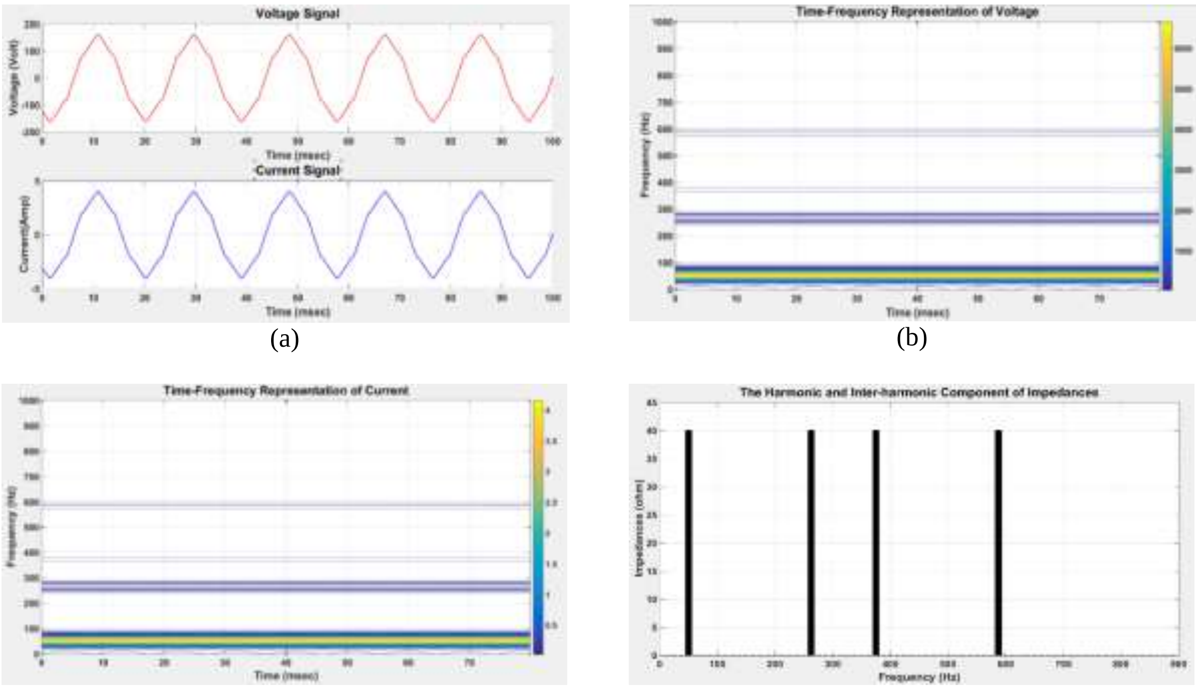
Whereby, N is non-harmonic load, H is harmonic producing load, Z_1 is fundamental impedance and Z_h is harmonic impedance.



(a) (b)

(c) (d)

Figure 9. AC-DC-AC PWM converter as a harmonic source at downstream. (a) Voltage and current signal, (b) TFR of voltage, (c) TFR of current, (d) Harmonic and inter-harmonic components of spectral impedance



(a) (b)

(c) (d)

Figure 10. Three-phase two-level single bridge converter as a harmonic source at downstream. (a) Voltage and current signal, (c) TFR of voltage, (d) TFR of current, (e) Harmonic and inter-harmonic components of spectral impedance

4. CONCLUSION

The main concern of this paper is to identify the location of multiple harmonic sources that been produced by the harmonic producing load which are inverters with a single-point measurement approach by utilizing spectrogram technique. The main contribution of this research is the significant spectral impedances relationship which are Z_1 and Z_h in identifying the location of MHS in distribution systems. Based on Table 1, multiple harmonic sources in the power system can be identified and can be distinguished clearly as follow:

a. If the magnitude of harmonic impedances, Z_h is 0 ohm, there is no harmonic producing load in the system.
b. If the magnitude of the fundamental impedance, Z_1 is greater than harmonic impedances, Z_h there is harmonic producing load at downstream.
c. If the magnitude of fundamental impedance, Z_1 is lower than harmonic impedances, Z_h there are harmonic producing loads at upstream and downstream.
d. If the magnitude of fundamental impedance, Z_1 is equal with harmonic impedances, Z_h there is harmonic producing load at upstream.

Consequently, considering the explanation, the spectrogram technique can be used accurately in obtaining the significant spectral impedances characteristic in order to distinguish the harmonic sources location in the system. In addition, the proposed method can be readily used in practice.

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