Localization of Multiple Harmonic Sources for Inverter Loads Utilizing Periodogram

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***Abstract*— This paper introduces a new technique to localize the multiple harmonic sources that caused by power inverter loads in power distribution system utilizing periodogram technique with single-point measurement approach at the point of common coupling (PCC). The periodogram technique is used to analyzed and distinguish multiple harmonic sources location in power system whether at downstream, upstream or both stream by their impedances characteristics. The proposed localization of multiple harmonic sources method is based on the correlational relationship between fundamental impedance (Z1) and harmonic impedance (Zh) in order to identify the suspected buses. The adequacy of the proposed methodology is tested and verified on distribution system for several different cases.**

***Index Terms*— Harmonic; Localization of multiple harmonic sources; Periodogram.**

I. Introduction

It is crucial in the harmonic study to localize the multiple harmonic sources with a specific objective to deal with the issue related to harmonic distortion [1]. This issue keep extending due to the current development and changes of previous bulky power system loads into minimal size power electronic devices for example, inverter and rectifier devices soon act as harmonic producing loads [2]. In the practical distribution system, multiple harmonic sources can be found at upstream and downstream with respect to a measurement point which is known as point of common coupling (PCC) [3]. Different strategies over the time for localizing multiple harmonic sources have been discussed in many literatures. With regards to least square and law of Kirchhoff current, state estimation method is introduced [4]. However, state estimation technique requires many measurement devices and it too costly for large power system [5]. Meanwhile, the earliest approach to recognize the harmonic sources is using power direction technique, anyhow the power direction method hypothetically not accurate when some harmonic and current phase angle is more than 90° [6]. Then, in the literature, a critical impedance technique for localization of harmonic sources has been discussed [7]. A technique need exact information of internal impedances of sources interpreting of utility and customer side, in the meantime it is difficult to measure these impedances [8]. A harmonic current vector method also been proposed to overcome these problems [9]–[11], whereby the calculation of harmonic contribution without any information of customer impedances. However, it requires long-term measurement of harmonic contributions and not easy to estimate harmonic impedances at customer side in order to localize the harmonic sources. In the literatures [12]–[14], a method known as harmonic source estimation is proposed using Bayesian estimation and harmonic state estimation (HSE). This method implies a high complexity in the algorithm and required highly cost of distributed measurement system station setup [15]. With a different approach with respect to two-points measurement method, the authors had proposed a new method by comparing the data between first measurement point at the incoming of point of common coupling and second measurement at the incoming of the load utilizing spectrogram technique [16]. This approach give a correct information, but costly and not easy to implement [17]. In practical, where accuracy, fast measurement, low cost and real-time performances are required, these techniques do not give acceptable cost and result.

This paper actualized multiple harmonic sources localization using single-point measurement utilizing periodogram analysis based on new method of harmonic source detection with good accuracy, fast and cost efficient. Furthermore, nn inverter will be used as harmonic producing load in the power distribution system. The signal parameters from measurement will be analyzed by periodogram and presented in power spectrum representation. Next, the fundamental impedance, Z1 and harmonic impedance, Zh at the PCC are estimated. Finally, the multiple harmonic sources location can be distinguished utilizing the correlational characteristic between Z1 and Zh.

II. Methodology

Localization of multiple harmonic sources are done with a single-point measurement utilizing perodogram technique.

A. Periodogram

The periodogram power spectrum represents the distribution of power signal over frequency and can be expressed as [10].

$$V_{DC}(t)=\sqrt{\int_{-\frac{\Delta f}{2}}^{\frac{\Delta f}{2}} S_v(f)df} \tag{1}$$

$$V_{DC}(t) = \sqrt{\int_{\frac{\Delta f}{2}}^{\frac{\Delta f}{2}} S_v(f)df} \tag{2}$$

where $Sv(f)$ in frequency domain; $v(t)$ is voltage waveform; V_{DC} is direct current voltage and $\frac{\Delta f}{2}$ is system frequency.

B. *Principles of Proposed Method*

The execution of single-point measurement at PCC for localization of multiple harmonic sources are shown in Figure1 and Figure 2. The position of multiple harmonic sources are categorized into three condition. Firstly, harmonic source at customer side which is known as Downstream. Meanwhile, when harmonic sources from utility side, it is known as upstream and finally when multiple harmonic sources at utility and both stream when multiple harmonic sources at customer and utility side. The measurement data at PCC will be analyzed using periodogram and represented in power spectrum. Furthermore, the parameters of power system will be estimated from power spectrum and finally the localization of multiple harmonic sources are identified based on the relationship between fundamental impedance, Z_1 and harmonic impedance, Z_h.

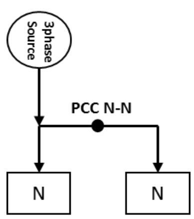


Figure 1: Case 1

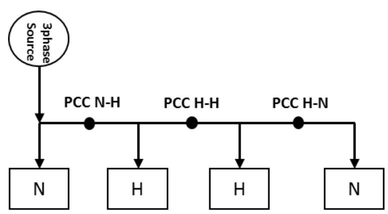


Figure 2: Case 2, 3 and 4

where, *N* is non harmonic load and H is harmonic producing load.

III. Results And Discussion

The adequacy of this methodology is tested and verified on distribution system with non-harmonic load and AC-DC-AC PWM converter was utilized as harmonic producing load. The observation on voltage and current spectrum were done, while the characteristic of impedances will be analyzed and observed.

A. *Case 1: No Harmonic Sources with the System*

Figure 3(a) demonstrate the voltage and current in time domain. The peak voltage and current were measured at 179.7V and 8.982A. Meanwhile, it was observed that the fundamental frequency exists at 50Hz and no harmonic component existed. Figure 3(c) illustrates the power spectrum of power impedance and only fundamental impedance, Z_1 with a value of 20 ohm was existed. It is obviously shown from the

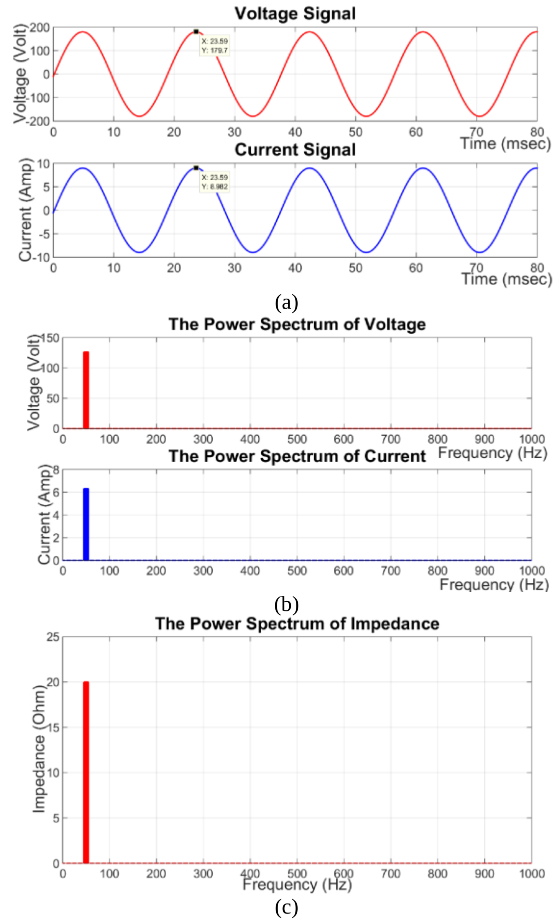


Figure 3: No harmonic sources within the system . (a) Voltage and current signal in time domain, (b) Power spectrum of voltage and current, (c) Power spectrum of impedances.

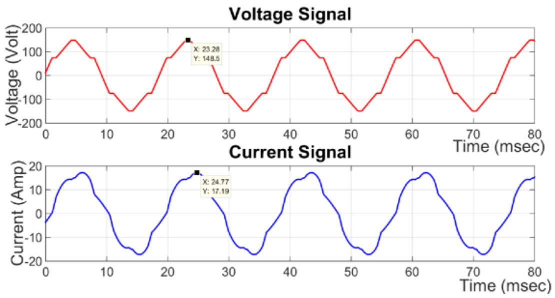
results that no sign of harmonic impedance exist in this case. Thus, the characteristic of power impedance can be finished up as:

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

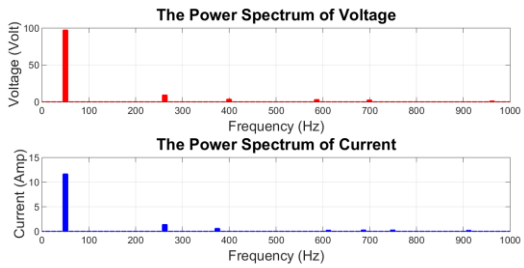
$$Z_1 \neq 0 \text{ ohm} \tag{4}$$

B. *Case 2: Harmonic Sources at Upstream*

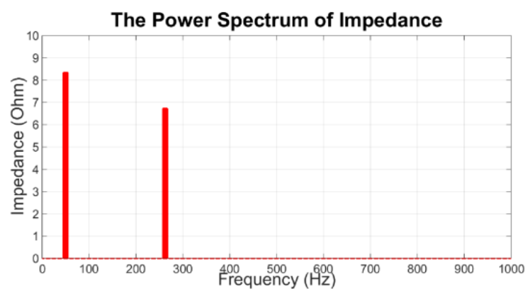
Figure 4(a) shows the voltage and current signal in time domain with a highest peak value of 179.7V and 8.982A respectively. In addition, Figure 4(b) shows the power spectrum of voltage and current. The voltage signal consist of fundamental harmonics at 50Hz with magnitude of 97.23V and inter–harmonics at 262.2Hz, 399.7Hz, 587.5Hz, 699.8Hz and 962Hz with magnitude from 1.15V to 9.281V. In the meantime, current signal comprises of fundamental at 50Hz with value of 11.65A and inter-harmonics at 262.2Hz, 375Hz, 612Hz, 687Hz, 749.8Hz and 912Hz with value from 0.1916 A to 1.379 A. As can be seen in Figure 4(c), subsequently Z_1 is 8.343ohm and Z_H is 6.729ohm.



(a)



(b)



(c)

Figure 4: Harmonic source at upstream. (a) Voltage and current signal in time domain, (b) Power spectrum of voltage and current, (c) Power spectrum of impedances.

Table 1
Power Impedance for Case 2

Power Impedance	Value (Ω)
Z50hz	8.343
Z262.2hz	6.729

The result from Table 1 unmistakably demonstrates that the fundamental impedance is bigger than the harmonic impedance. Thusly, the impedance characteristic for for this case can be concluded as:

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

C. Case 3: Harmonic Sources at Upstream and Downstream

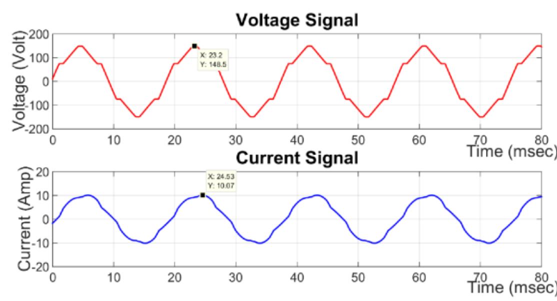
As can be seen from Figure 5(a), the highest peak voltage was measured at 148.5V and 10.07A for current individually. Figure 5(b) depicts the power spectrum of voltage and current. Voltage components were observed, obviously comprise of fundamental voltage with magnitude of 97.23 V and inter-harmonic voltages exist at 262.2Hz, 399.7Hz, 587.5Hz, 699.8Hz and 962Hz with RMS value from 1.15 V to 9.281 V. The current signal comprise of fundamental at 50Hz with magnitude of 7A and odd harmonic at 600Hz and 750Hz. Meanwhile, inter-harmonics were observed at 262.2Hz, 375Hz, 687Hz, and 912Hz with value from 0.1066A to 0.6506A. Additionally, the power impedances were estimated at 13.88 ohm for Z_1 and 14.27 ohm for Z_h as shown in Figure 5(c).

Table 2
Power Impedance for Case 3

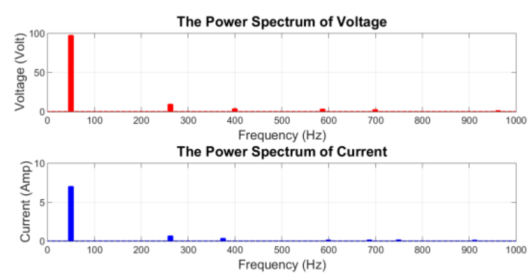
Power Impedance	Value (Ω)
Z50hz	13.88
Z262.2hz	14.27

As shown in Table 2, the outcomes for H-H clarify that the magnitude of fundamental impedance is constantly lesser than the harmonic impedance. Hence, the relationship of impedances in this case can be composed as:

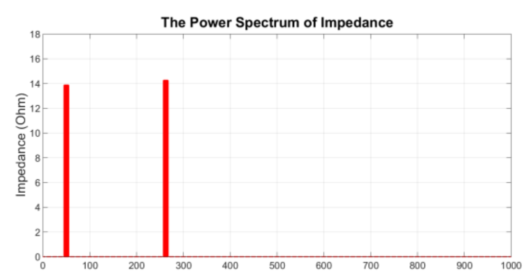
$$Z_1 < Z_H \tag{6}$$



(a)



(b)



(c)

Figure 5: Harmonic source at upstream and downstream. (a) Voltage and current signal in time domain, (b) Power spectrum of voltage and current, (c) Power spectrum of impedances

D. Case 4: Harmonic Sources at Downstream

Figure 6(a) presents the voltage and current signal in time domain with highest peak value of 148.5 V and 3.711 A respectively. Meanwhile, Figure 6(b) shows power spectrum of voltage and current. The current components were discovered at 2.43A for fundamental current while inter-harmonic current at 262.2Hz, 399.7Hz, 582.5Hz, 699.8Hz and 962Hz with magnitude from 0.0287A to 2.43A. In addition, the fundamental voltage was 97.23V and inter-harmonic voltages were observed at 262.2Hz, 399.7Hz, 587.5Hz, 699.8Hz and 962Hz with magnitude from 1.15V to 9.281V. Furthermore Z_1 and Z_h constantly equivalent with a magnitude of 40.01ohm as shown in Figure 6(c).

Table 3
Power Impedance for Case 4

Power Impedance	Value (Ω)
Z50hz	40.01
Z262.2hz	40.01
Z399.7hz	40.01
Z587.5hz	40.01
Z699.8hz	40.01
Z962hz	40.01

It is obviously from Case 4, that the value of fundamental impedances were constantly equivalent with harmonic impedance. Subsequently, the relationship between fundamental and harmonic of this case can be finished up as:

$$Z_1=Z_h \qquad (7)$$

The overall investigation results were tabulated in Table 5 and a clear correlation was observed between fundamental and harmonic impedances. This Impedances characteristic can be utilized plainly as a part of request to distinguish the location of multiple harmonic sources.

Table 5
Conclusion of power impedance characteristic for multiple harmonic sources detection

Upstream	Downstream	Impedance Characteristic
No Harmonic Load	Harmonic Load	Z_h = 0 ohm
No Harmonic Load	Harmonic Load	$Z_1 > Z_h$
Harmonic Load	Harmonic Load	$Z_1 < Z_h$
Harmonic Load	No Harmonic Load	$Z_1=Z_h$

where, Z_1 is fundamental impedance, Z_h is harmonic impedance

IV. Conclusion

The primary intention of this paper is to identify the location of multiple harmonic sources that generated by inverters in the power system, with a single-point measurement approach utilizing periodogram. This is another arrangement to localize the multiple harmonic sources whether at downstream or upstream or both stream by knowing the correlational impedances characteristic. The outcomes acquired demonstrate that the periodogram can be utilized to evaluate the signal parameters in order to localize the multiple harmonic sources. Furthermore, the proposed technique can be promptly utilized as a part of practice.

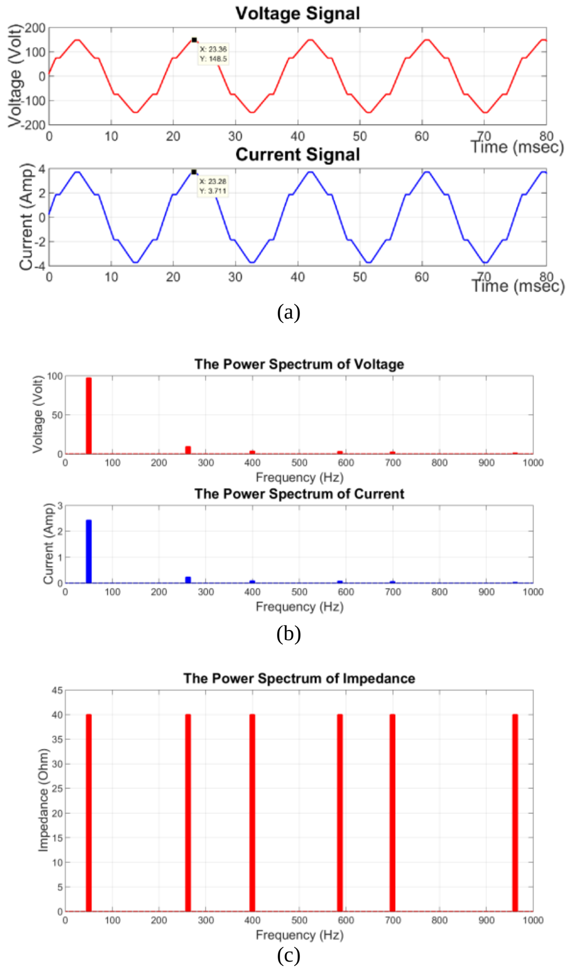


Figure 6: Harmonic source at downstream. (a) Voltage and current signal in time domain, (b) Power spectrum of voltage and current, (c) Power spectrum of impedances.

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