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ANALYSIS OF HARMONIC SOURCE IDENTIFIER USING PERIODOGRAM

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ABSTRACT

The increased use of power electronic controlled equipment, such as variable speed drives, automated production lines, personal computers and non-linear electronic devices in power systems has given rise of voltage and current waveform distortion called as ‘harmonics’. Harmonic disturbances is one of the major issue in the power system. The harmonic source effectively disturb the industrial and customer power utility by changing the property of power stability. In order to determine the causes and sources of harmonic disturbances, it must started with the ability to detect the location of these disturbances. The harmonic source detection by using modelling the equivalent electric network is difficult to get an accurate equivalent circuit model because of loads changing dynamically. Thus, an automated way is required to identify the harmonic source disturbances. The analysis of harmonic sources disturbances using periodogram is presented in this paper. The periodogram is used to analyze the signal and represented the parameter of signals in power spectrum. Hence, the parameter signal are used to calculate the location of harmonic sources disturbances. The signal parameters such as RMS voltage, RMS current and difference angle of current and voltage are estimated from the power spectrum to identify the characteristic of harmonic disturbances. As a result, the characteristic of harmonic disturbances such as harmonic at downstream, upstream and both sides are identified based on harmonic impedances are presented in power spectrum. The difference characteristic of these harmonic source such as the difference magnitude of harmonic impedances are presented in result section. The end of this section, the new technique to identify the harmonic sources disturbances are presented and this technique is suggested to create a system for identify the harmonic sources disturbances.

Keywords: Identify harmonic sources, harmonic analysis, periodogram.

INTRODUCTION

Harmonic disturbance from electrical network is one of the important issues associated with electrical power quality (Zang *et al*., 2014). The increasing use of nonlinear loads such as electronic gadgets and apparatus, making harmonic disturbances in network system. Thus, harmonic disturbances has become an important concern for researchers to identify harmonic source (Shojaie and Mokhtari, 2014). These harmonic disturbances effect the property of power supply network by increasing power losses and damaging system equipment (Stevanović and Petković, 2014). In general, the methods to determine the harmonic source can be single-point methods with is at Point of Common Coupling (PCC). The single-point methods aim to separate the harmonic contribution of the customer and the utility at the customer-utility interface point (Farhoodnea *et al*., 2011). Supply voltage flowing through the harmonic impedances of the network produces a harmonic current and also increase harmonic voltage at the PCC (Hui, Lin and Ye, 2010). The other factor that contribute to harmonic voltage at a PCC is the background voltage supply due to that compose of nonlinear loads. Harmonic voltage at a PCC may turning back to the utility because that other loads, even the load is linear were draw harmonic current (Shojaie *et al*., 2014). Thus, it is important to analyze the harmonic source detection for obtaining the information of harmonic sources disturbances.

Various methods have already been presented in this field. The power direction method has been widely used but it can only give the qualitative conclusion such as which side is the main harmonic source (Timothy, 1991). However, it has been proved that this method does not always provide correct result (Xu, 2000). To quantify the contribution of a specific harmonic source, the model based method is proposed (Xu *et al*., 2003), (Wilsun, Li and Tayjasanant, 2004), (Hamzah, Mohamed and Hussain, 2004), (Wilkosz, 2007), (Moradloo, Tabrizi and Karshenas, 2008). These model-based methods try to establish the equivalent circuit of the system utilizing the measured data. The harmonic source can be estimated from the circuit. The shortcoming of these models are that establishing an equivalent circuit with adequate accuracy is very difficult because of variation of electrical argument in the system. Difference to the model based method, another type of method, called data-based method, (Wen at al., 2011), (Nath, Sinha and Goswami, 2012), (Shojaie *et al*., 2014) are introduced. These data-based methods aimed to find the cause and effect relationship between the harmonic load and the harmonic disturbances at the bus of concern. However, a rigorous assumption that the background harmonic current remains constant is necessary for the method.

In this paper, periodogram technique is implemented for identification of harmonic source disturbances. The harmonic disturbances are analyzed by representing the signals in frequency domain. Then, the parameters such as RMS voltage, RMS current and difference angle are evaluated from power spectrum. The parameters are used to identify the characteristic of harmonic disturbances such as harmonic at downstream, upstream and both sides. The general analysis is shown in Figure-1.

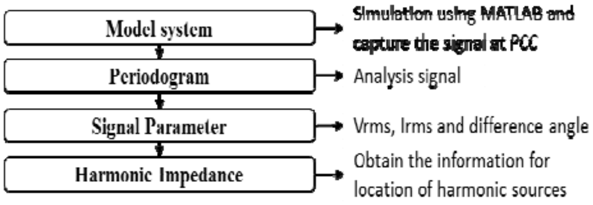


Figure-1. Flowchart of the analysis harmonic source.

PERIODOGRAM

Periodogram is able to obtain the parameters from harmonic signals. The analysis from periodogram is represented in power spectrum that consists of magnitude power against frequency (Abdullah *et al*., 2007). The spectrum will give the direct information based on bar graph representations. The periodogram for the voltage and current waveform can be defined are as follows, respectively.

$$S_V(k) = \frac{1}{N}\left|\sum_{n=0}^{N-1} v(n) e^{-j\frac{2\pi kn}{N}}\right|^2 \tag{1}$$

$$S_I(k) = \frac{1}{N}\left|\sum_{n=0}^{N-1} i(n) e^{-j\frac{2\pi kn}{N}}\right|^2 \tag{2}$$

$$0 \le k \le N-1$$

Where $S_V(k)$ is the frequency representation of the discrete-time voltage waveform, $v(n)$ and $S_I(k)$ is the frequency representation of the discrete-time current waveform, $i(n)$, k is frequency, N is the maximum number of sampling and n is number of sample.

PARAMETERS ESTIMATION

From the power spectrum, the information is used to calculate signal parameters. These signal parameters are root means square voltage and root means square current (Abidullah *et al*., 2014).

Root means square voltage (RMS voltage)

The RMS voltage of the sampled waveform is calculated by the following equation.

$$V_{rms} = \sqrt{\frac{1}{N}\sum_{k=0}^{K-1}\left|S_V(k)\right|^2} \tag{3}$$

Where $S_V(k)$ is the frequency representation of voltage.

Root means square current (*Irms*)

The RMS current of the sampled waveform is calculated by the following equation.

$$I_{rms} = \sqrt{\frac{1}{N}\sum_{k=0}^{K-1}\left|S_I(k)\right|^2} \tag{4}$$

Where $S_I(k)$ is the frequency representation of current.

HARMONIC SOURCES IDENTIFICATION

In this paper we are dealing with method that require only measurement of current and voltage value at point of common coupling (PCC) as shown in Figure-2. PCC is a point located at upstream and downstream relative to a monitoring point (Farhoodnea *et al*., 2010).

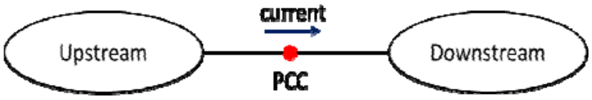


Figure-2. Point of common coupling.

The electrical network connected in parallel and supplies same voltage level to each load (Elmamlouk *et al*., 2013) shown in Figure-3. Moreover, the value of current is depended on load and voltage supply. The voltage supply will be affected when the load producing harmonic to the current (Abdullah *et al*., 2014). The situation became worse when the voltage supply consist of harmonic disturbances moving to other load in parallel connection (Jopri *et al*., 2014). Thus, the harmonic impedance can be defined by capture voltage and current at PCC.

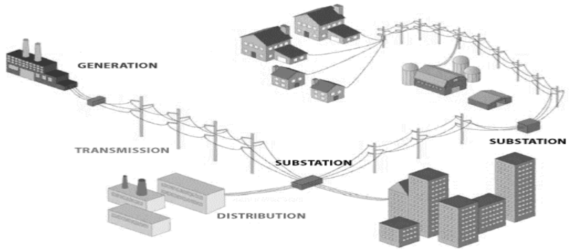


Figure-3. Electrical network.

The harmonic impedance is compared with the fundamental impedance to identify the characteristic of harmonic source either at downstream or upstream or both sides. The impedance method is applied to obtain the fundamental impedance and harmonic impedance respectively, as follows.

The harmonic impedance is compared with the fundamental impedance to identify the characteristic of harmonic source either at downstream or upstream or both sides. The impedance method is applied to obtain the fundamental impedance and harmonic impedance respectively, as follows.

$$Z_{1,pcc} = \frac{V_{1,pcc}\angle\theta_{V_1}}{I_{1,pcc}\angle\theta_{I_1}} \tag{5}$$

$$Z_{h,pcc} = \frac{V_{h,pcc}\angle\theta_{V_h}}{I_{h,pcc}\angle\theta_{I_h}} \tag{6}$$

Where, h=3, 5, 7, 9, …n

The system is designed by using MATLAB Simulink to identify the location of harmonic source disturbances. The location of harmonic source can be upstream or downstream or both sides according to the direction of current flow. There are four types of signals that are tested to identify the location of harmonic disturbance. As shown in Table-1. No harmonic means the system consists of resistive load only while harmonic means rectifier loads.

Table-1. Type of signal.

Case	Upstream	Downstream
1	No harmonic	No harmonic
2	No Harmonics	Harmonics
3	Harmonics	No Harmonics
4	Harmonics	Harmonics

RESULTS

There are four cases that are discussed in this section for no harmonic at the system for case 1, harmonic at downstream for case 2, harmonic at upstream for case 3 and lastly harmonic at both sides of the system for case 4. Firstly, Figure-4(a) shows the system condition for Case 1, no harmonic sources at both sides from the system. The voltage and current signals are captured at PCC and presented in Figure-4(b). These signals are used as the input for periodogram to obtain the power spectrum of voltage, current and difference angle as shown in Figure 4(c).

The diagram of power spectrums show the fundamental voltage and current presented at 50Hz. The impedance method is applied to obtain the fundamental impedance given by equation (7), derived from equation(5).

$$Z_{50Hz} = \frac{V_{50Hz}}{I_{50Hz}} \tag{7}$$

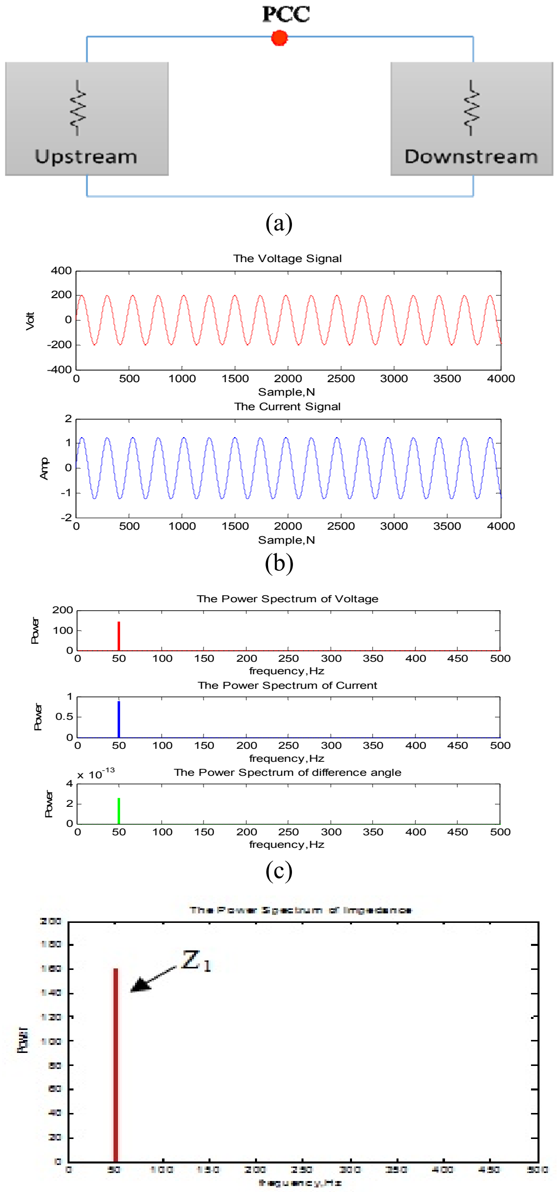
As a result, the fundamental impedance value obtained at 50Hz is 160Ω as shown in Table-2 and no harmonic impedance component exist in spectrum as shown in Figure-4(d). No harmonic signals are produced from this system and harmonic impedance equation can be written as:

$$Z_h = 0 \tag{8}$$

Where, *h*=3, 5, 7, 9,… n

Table-2. The harmonic condition for Case 1.

Frequency (Hz)	Impedance (Ω)
50	160
150	0
250	0
350	0
450	0



(a)

(b)

(c)

(d)

Figure-4. Case 1, a) The system for no harmonic source signal from MATLAB simulation, b) The voltage and current signal waveform capture at PCC c) The spectrum of voltage, current and phase difference analyzes using periodogram, d) The power spectrum of impedance.

Secondly, Figure-5(a) shows the system condition for Case 2, no harmonic source at upstream while harmonic sources located at downstream. The voltage and current signals are captured at PCC and presented in Figure-5(b). The power spectrum of voltage, current and difference angle show that the magnitude power occurs at 150Hz, 250Hz, 350Hz and 450Hz as shown in Figure-5(c). Impedance method is applied to obtain the fundamental impedance as shown in equation

(9) and harmonic impedance as shown in equation (10) and (11).

$$Z_{50Hz} = \frac{V_{50Hz}\angle\theta_{V_{150Hz}}}{I_{50Hz}\angle\theta_{I_{150Hz}}} \tag{9}$$

$$Z_{150Hz} = \frac{V_{150Hz}\angle\theta_{V_{150Hz}}}{I_{150Hz}\angle\theta_{I_{150Hz}}} \tag{10}$$

$$Z_{250Hz} = \frac{V_{250Hz}\angle\theta_{V_{250Hz}}}{I_{250Hz}\angle\theta_{I_{250Hz}}} \tag{11}$$

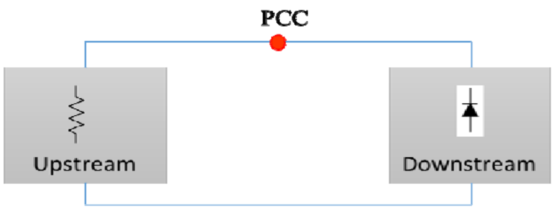
From the equation (9), (10) and (11), the power spectrum of impedance at 50Hz obtained is 58Ω while at 150Hz, 250Hz, 350Hz and 450Hz are obtained as 38Ω as shown in Figure-5(d). Therefore, the fundamental, Z_{50Hz} is more than harmonic component (Z_{150Hz}, Z_{250Hz}, Z_{350Hz} and Z_{450Hz}) as shown in Table-3. In view of that, when downstream side produced harmonic disturbances to voltage supply, then the upstream side voltage will not affect from downstream due to the direction of current flow. Harmonic signals produced from this system and harmonic impedance equation at downstream can be written as:

$$Z_h < Z_1 \tag{12}$$

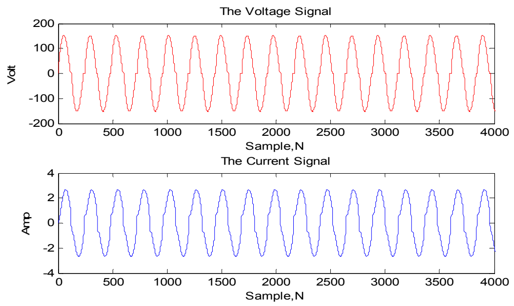
Where, *h*=3, 5, 7, 9, …n

Table-3. The harmonic condition for case 2.

Frequency (Hz)	Impedance (Ω)
50	58
150	38
250	38
350	38
450	38



(a)



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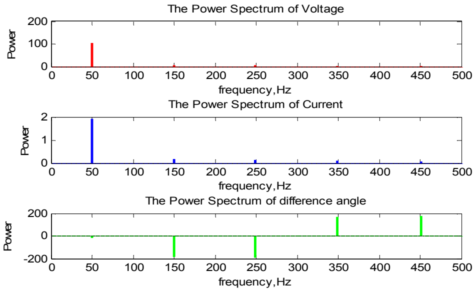

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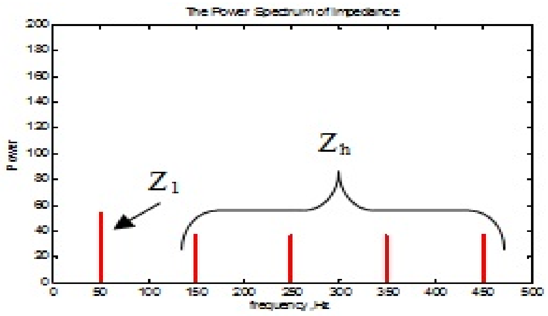


(d)

Figure-5. Case 2, a) The system for harmonic source signal at downstream from MATLAB simulation, b) The voltage and current signal waveform capture at PCC c) The spectrum of voltage, current and phase difference analyzes using periodogram, d) The power spectrum of impedance.

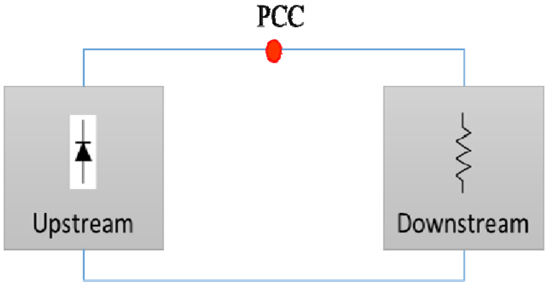
Furthermore, Figure-6(a) shows the system condition for Case 3, harmonic sources at upstream while no harmonic source at downstream. The waveforms of voltage and current signals are presented in Figure-6(b) and the power spectrums of voltage, current and difference of angle are presented in Figure-6(c). The power spectrum of voltage, current and difference of angle show that the harmonic components are existing at 150Hz, 250Hz, 350Hz and 450Hz. Moreover, equation (5) and (6) are applied to obtain the power spectrum of impedance. As a result, the power spectrum of impedance for 50Hz, 150Hz, 250Hz, 350Hz and 450Hz are 160Ω shown in Figure-6 (d). Therefore, the fundamental, Z_{50Hz} are similar to harmonic component (Z_{150Hz}, Z_{250Hz}, Z_{350Hz} and Z_{450Hz}) as shown in Table-4. Hence, when upstream side produced harmonic disturbs the supply voltage then it affects the lower side also due to the direction of current flow. Harmonic impedance equation at upstream can be written as:

$$Z_1 = Z_h \tag{13}$$

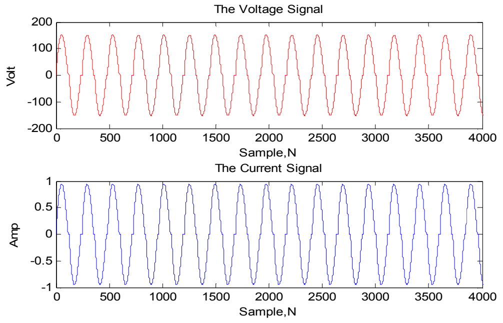
Where, h=3, 5, 7, 9,… n

Table-4. The harmonic condition for case 3.

Frequency (Hz)	Impedance (Ω)
50	160
150	160
250	160
350	160
450	160



(a)



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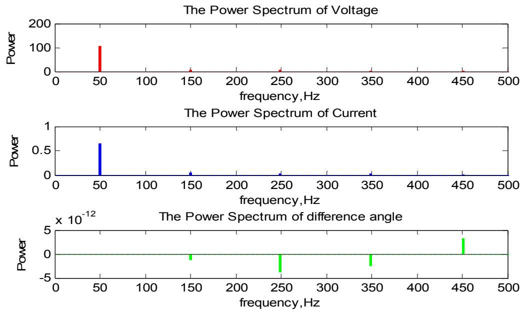

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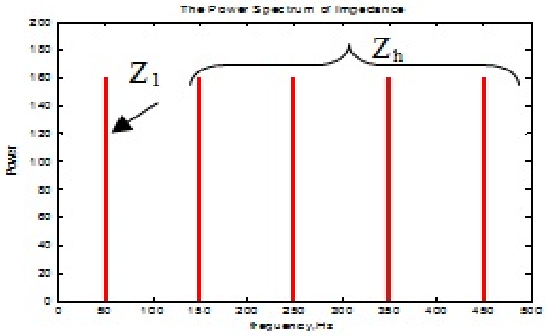


(d)

Figure-6. Case 3, a) The system for harmonic source signal at upstream from MATLAB simulation, b) The voltage and current signal waveform capture at PCC c) The spectrum of voltage, current and phase difference analyzes using periodogram, d) The power spectrum of impedance.

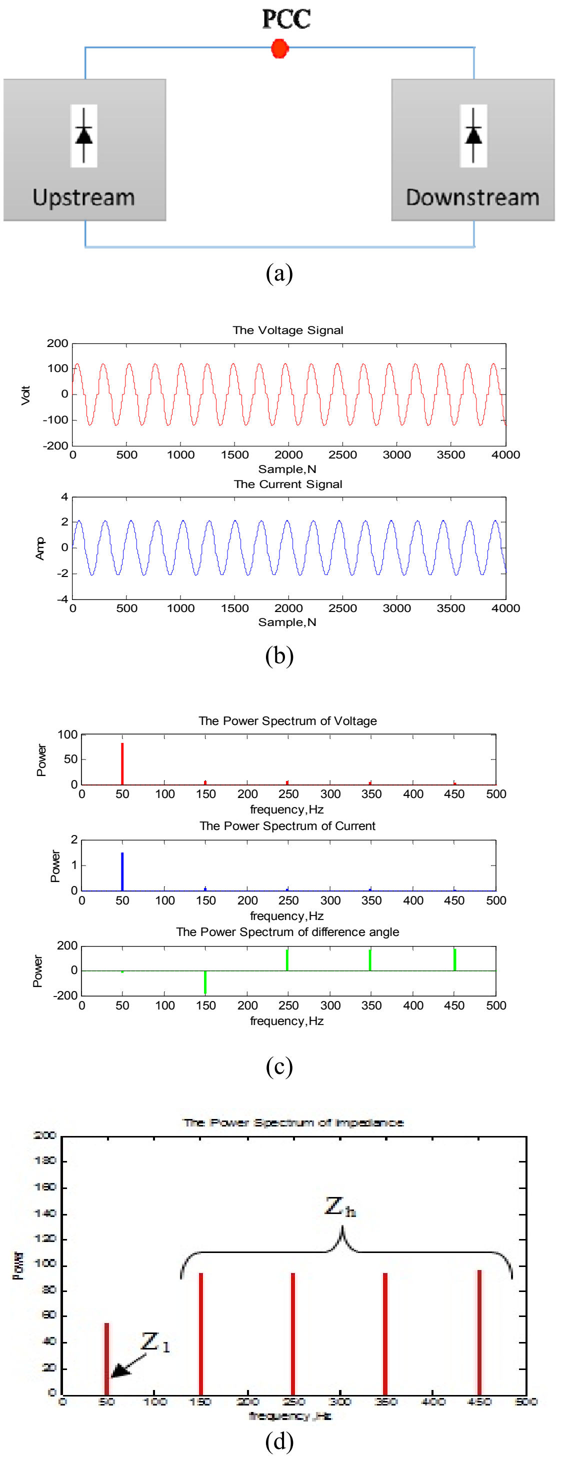
Figure-7(a) shows the system condition for Case 4, harmonic sources at both sides which are upstream and downstream. The waveform of voltage and current signals are presented in Figure-7(b) and the power spectrum of voltage, current and difference angle are shown in Figure-7(c). The power spectrum of impedance show the harmonic component at 150Hz, 250Hz, 350Hz and 450Hz. Besides, equation (5) and (6) are applied to the spectrum of voltage and current to identify the power spectrum of impedance. As a result, the power spectrum of impedance obtained at 50Hz is 58Ω while for 150Hz, 250Hz, 350Hz and 450Hz are 98Ω as shown in Figure-7(d). Therefore, the fundamental, Z_{50Hz} is less than harmonic component (Z_{150Hz}, Z_{250Hz}, Z_{350Hz} and Z_{450Hz}) as shown in Table-5. In view of that, when both streams produced harmonic disturbances to voltage supply the impedance of spectrum, Z will accumulate and will resulting to greater harmonic component at the lower side. Harmonic signals produced from this system and harmonic impedance equation at both sides can be written as:

(14)

Where, h=3, 5, 7, 9, …n

Table-5. The harmonic condition for case 4.

Frequency (Hz)	Impedance (Ω)
50	58
150	160
250	160
350	160
450	160



(a)

(b)

(c)

(d)

Figure-7. Case 4, a) The system for harmonic source signal at upstream and downstream from MATLAB simulation, b) Voltage and current signal waveform capture at PCC c) The spectrum of voltage, current and phase difference analyzes using periodogram, d) The spectrum of impedance, Z.

Table-6 shows the summary of the new technique of harmonic source identification. Where, Z_1 represents fundamental impedance and Z_h represent each impedance harmonic component. This new identification method is suggested for the automated harmonic source monitoring system and easy to be implemented in the harmonic source identification system by measuring in single point at PCC.

Table-6. New technique for identification of harmonic sources.

Identification method (Ω)	Upstream	Downstream
$Z_h=0$	No harmonic	No harmonic
$Z_h<Z_1$	No Harmonics	Harmonics
$Z_1=Z_h$	Harmonics	No Harmonics
$Z_h>Z_1$	Harmonics	Harmonics

Where, *h*=3, 5, 7, 9,... *n*

CONCLUSIONS

As a conclusion, the signal are captured at the PCC that consist harmonic disturbances are used to estimate the parameter signals are analyze using periodogram technique. The information of signal parameter are represented in power spectrum. The parameters such as RMS voltage, RMS current and difference angle between voltage and current are evaluated from power spectrum. The parameters signals are used to identify the characteristics of harmonic disturbances such as harmonic at downstream, upstream and both sides are identified based on harmonic impedances are presented in power spectrum. The difference characteristic of these harmonic source such as the difference magnitude of harmonic impedances are presented as well. In future, these new technique for identification of harmonic sources are suggested to create a system for identify the harmonic sources disturbances automatically.

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