A New Vector Draft Method for Harmonic Source Detection at Point of Common Coupling

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Abstract- **In modern power networks, the issue of power quality (PQ) is becoming very important because of the increasing of load which sensitive to current disturbances. This is mainly due to the increasing use of non-linear power electronic devices draws non-sinusoidal current and creating a current distortion. As a result there is increasing need for PQ to be monitored to establish the type, sources and locations of PQ disturbances, allowing remedial measures to be taken. Consequently, harmonic is one of the most concerned power quality disturbances. The detection of harmonic source is necessary for power quality strategy development. This paper introduces a new single-point measurement method to estimate the harmonic source by using phase spectrogram (PS) and frequency spectrogram (FS) based on a vector draft method. A measurement at the point of common coupling (PCC) with harmonic distortion is done by simulation via PSCAD. Then PSCAD's data are analyzed by using spectrogram in MATLAB. To be precise, voltage and current waveforms are normalized with fundamental magnitude respectively. Next, the normalized voltage and current are plotted on the vector draft to estimate the perpendicular point between the vectors. The center point of the normalized voltage is the boundary between downstream and upstream. The harmonic source can be detected base on the perpendicular point's location that fall on the particular region. The comparison between actual and power direction result have been conducted. Finally, the proposed method is similar with the actual result and more truthful than power direction method.**

I. INTRODUCTION

In recent years, along with continual development of market economy and extension of industrial scale, more and more control equipments based on computer system and electrical equipment are used in many fields in order to improve work productivity and automation level [1]. These equipments have better performance and higher efficiency, but very sensitive response on variation of power supply quality. On the other hands, low power supply quality can induced many economy losses. Especially widely using of nonlinear equipments (e.g. electrical commutate equipment, arc welding, electromotor, electric power engine) in power system, and the power quality are seriously polluted. The limitation of harmonics pollution present at the point of common coupling had been control by IEEE Std. 519 [2] which is widely accepted in industry. Accidents often occur because of bad power supply quality, for example the wire can become very hot when the wire conducts with high frequency current due to skin depth concept. In a nutshell, it is the important task for power department and electricity consumer to improve the power quality.

In the process of improving the power quality, two major technical challenges need to be faced. The first challenge is the need to separate the harmonics contribution of a customer side from the supply system [2]. The other is to isolate the effect of utility impedance variation on customer's harmonics injection levels. Before improving the power quality, it needs a power quality diagnosis system to identify source of the power quality disturbance. This paper focus on identified the source of the harmonic disturbance.

Many methods have been proposed in the previous paper. The power direction method is the earliest method to detect the harmonic source [3]. The negative P_h value means the harmonic source is downstream and vice versa. But the power direction method founded theoretically incorrect [3]. However, the voltage magnitude method can be used to detect the harmonic source, but the procedure is not practical because need to do switching test on the site [4]. Multipoint method report correct information but such method is very difficult to implement and require expensive instrument setup [5]. A current vector method is proposed, but it requires the knowledge of utility and customer impedance [6]. Moreover the current vector method did not take into account impedance change [6]. In order to overcome the shortages of previous method, harmonic source detection are implemented by using phase spectrogram (PS) and frequency spectrogram (FS) based on new method of harmonic source detection.

This paper introduces a new single-point measurement method to estimate the harmonic source by using PS and FS based on a vector draft method. A measurement at the point of common coupling (PCC) with harmonic distortion is done by PSCAD's simulation and the data are analyzed by using spectrogram in MATLAB. To be precise, voltage and current waveforms are normalized with fundamental magnitude respectively. Next, normalized voltage and current are plotted on the vector draft and estimate the perpendicular point between the vectors. The location of the perpendicular point can estimate the harmonic source. Finally, the comparison between actual and power direction result have been conducted.

II. TIME-FREQUENCY ANALYSIS TECHNIQUE

Time frequency analysis technique is used in this research. In this part, the theory of time-frequency analysis is discussed. The amplitude of the waveform can be computed by FS. However the phase angle of the waveform can be defined by using PS.

A. Frequency Spectrogram

In this project, the spectrogram is categorized in to two parts which are FS and PS. The FS provides a distribution of energy of the signal in a time-frequency plane [7] and defined as equations below.

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

$$S_x(\tau,f) = |STFT_x(\tau,f)|^2 \qquad (2)$$

Where x(t) is the input signal and w(t) is the observation window which is hanning window. The standard IEC defined that the hanning window can perform better in analyzing harmonic [8]. The parameter instantaneous root means square value is defined by [9].

B. Phase Spectrogram

To obtain PS, the signal is processed with short-time Fourier transform (STFT) at first. Where $x(t)$ is the input signal and w(t) is the observation window which is rectangular window. The t (Eq.3) is 0.02s (1/fundamental frequency where by the fundamental frequency is 50Hz) [10]. The result of STFT is a complex-valued function allowing the representation of both the phase and magnitude parts of the signal [10]. The phase angle is obtained by apply trigonometry concept on the STFT's result (Eq.4). The n (Eq.6) is indicated the total number of phase angle of the STFT result [10]. The PS result obtained by average the phase angle of the STFT result. The PS is taken into accounts and expressed as:

$$STFT_y(\tau,f) = \int_{-\infty}^{\infty} x(t)w(\tau-t)e^{-j2\pi ft}dt \qquad (3)$$

$$\phi_{STFT_y}(\tau,f) = A\tan\left(\frac{Imag(STFT_y(\tau,f))}{Real(STFT_y(\tau,f))}\right) \qquad (4)$$

$$\theta_y(\tau,f) = \frac{\delta\phi_{STFT_y}(\tau,f)}{dt} \qquad (5)$$

$$PS(\tau,f) = (\Sigma\theta_y(\tau,f))/n \qquad (6)$$

III. HARMONIC SOURCE DETECTION

The basic concept of harmonic is shown in Fig.1. The concept of harmonic is started with the harmonic current source that generated by non-linear load. The source impedance is depending on the network impedance [11]. The harmonic voltage is depended on the source impedance and harmonic current. Then, the harmonic impedance is opposite direction of the source impedance because the harmonic current flow from the source back to the load.
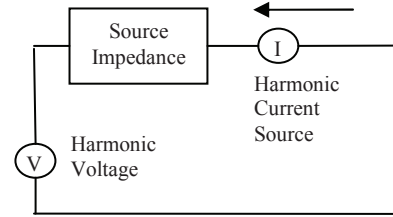

Fig.1 The concept of harmonic

The harmonic's and ohm's laws are shows in Fig.2. The relation between voltage and current is depended on the resistance which is the resistance is a fix variable for ohm's law (Fig.2(a)). However, the relation between harmonic voltage and harmonic impedance is depended on the harmonic current which is the harmonic current is a fix variable in the harmonic circuit (Fig.2(b)).

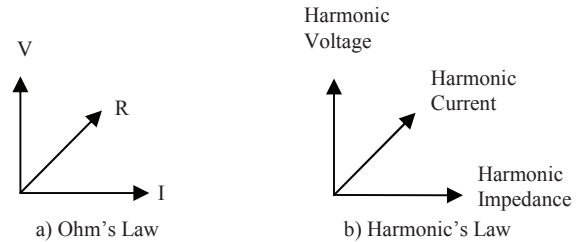a) Ohm's Law   b) Harmonic's Law

Fig.2 Relation of ohm's and harmonic's laws

Fig.3 shows the implementation for harmonic source detection. Generally, harmonic source is categorized to 3 types. Upstream source means the harmonic source from the utility side. However, downstream source means the harmonic source from the customer side. Finally, both streams mean the harmonic produce by utility and customer side at the same time which is the usual occurrence. In the both streams case, the harmonic current from the both streams can add up when the harmonic current have the same magnitude direction and the harmonic currents cancel each other when the current with opposite magnitude direction each other [12].
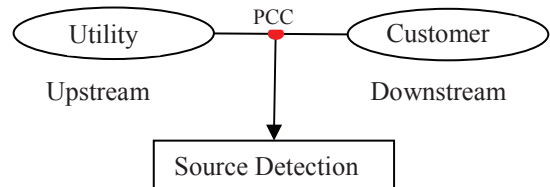

Fig.3 Block diagram for harmonic source detection

Block diagram for the harmonic source detection as shown in Fig.4. The source detection is the measurement value from the PCC. After that, the voltage and current waveform is

processed with time frequency representation to estimate the magnitude and phase shift information for voltage and current for every order respectively. The PS and FS are suitable for non-stationary waveform [9]. Then the harmonic voltage and current are normalized with particular fundamental magnitude. After that, plot the normalized vector and find the perpendicular point between current and voltage vectors.
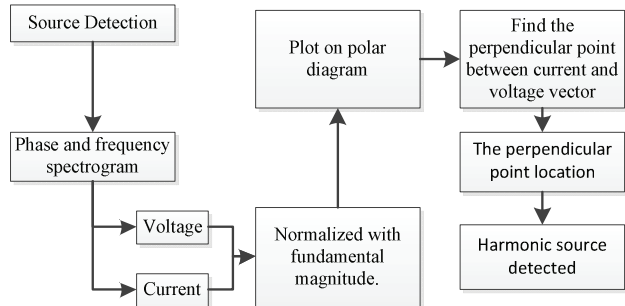

Fig.4 Block diagram for the harmonic source detection

Finally the harmonic source is detected based on the location of the perpendicular point (Fig.5). The perpendicular point located at the right side is considered upstream and vice versa. The reference center line is perpendicular with the center point of v(t). The harmonic voltage vector is pointed from left to right because the harmonic voltage is produced from the load back to the source as shown in Fig.1.
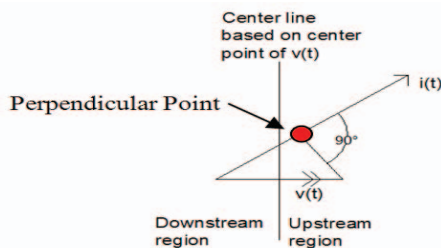

Fig.5 Perpendicular point identification method.

The harmonic simulation is done by PSCAD. Fig.6 shows the concept for upstream and downstream for harmonic source detection. Generally, the circuit consists of two loads. The source impedance is 0.4+0.25j which is recommended by standard Malaysia [13]. The rectifier load and motor driver load are measured by measurement point 1 and measurement point, respectively. In the measurement point 2, the harmonic source is considered downstream if the particular order amplitude harmonic generated by the motor is higher than the rectifier load. However, if the particular amplitude harmonic generated by the motor is lower than the rectifier load is consider upstream at the measurement point 2. Two cases of simulation is done in this simulation. Case 1 is simulate about rectifier load as downstream. However, simulate about motor driver load as downstream for case 2.
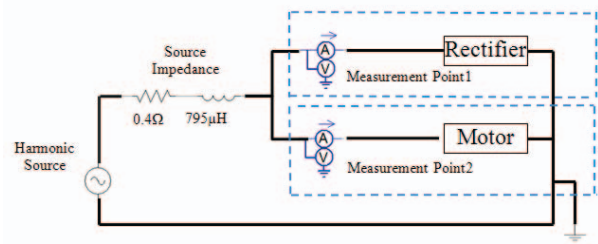

Fig.6 The concept of upstream and downstream harmonic source.

IV. RESULT AND ANALYSIS

In this research, the simulation result is done by PSCAD and analyzed the PSCAD's data by spectrogram via MATLAB. In this part, result and analysis is discussed.

A. Simulation Result with Rectifier load as Downstream (Case 1)

Generally, the circuit simulation for case 1 is connected as shown in Fig.6. The rectifier load and motor driver load is measured by measurement point 1 and measurement point 2 respectively. After that, the voltage and current waveform is analyzed by spectrogram (done by MATLAB). Hence, the output of the spectrogram is considered as actual value as shown in Table 1.The actual value is normalized with the particular fundamental magnitude which is considered as normalized value in Table 1. The actual result is the result with comparing the magnitude current for both of the loads. For 5th harmonic current, the rectifier load is produced 20.35A while the motor driver load is produced 12.41A. The rectifier load is downstream for the actual result because the rectifier load produced higher harmonic current than motor driver load. However, the power direction result is done by calculation. The harmonic power in negative means the harmonic source at the downstream and vice versa. Example the 5th harmonic voltage is 19.35< -78 and the 5th harmonic current for measurement 1 is 20.35< -6, 5th harmonic power is 121W which is positive (upstream).

TABLE 1
SIMULATION RESULT FOR CASE 1

Label	H. Order	Actual Value	Normalized Value	Harmonic Source	Power Direction	Harmonic Detection
Voltage	1	153.26< -95°	1.000			
	5	19.35< -78°	0.126			
	7	8.94< -122°	0.058			
Current Measu. 1	1	90.03< -109°	1.000			
	5	20.35< -6°	0.226	Down	Up	Down
	7	6.71< -58°	0.075	Down	Up	Down
Current Measu. 2	1	97.23< -116°	1.000			
	5	12.41< 129°	0.127	Up	Down	Up
	7	4.33< 76°	0.045	Up	Down	Up

Fig.7 shows the clarification for harmonic source for the rectifier load. The 5th and 7th perpendicular points are fallen in

the downstream region for rectifier load. However, the 5th and 7th perpendicular points are fallen in upstream region for the motor driver load (Fig.8). In the nutshell, the simulation result for case 1 shows that the new proposed for harmonic source detection is more accurate than power direction method.
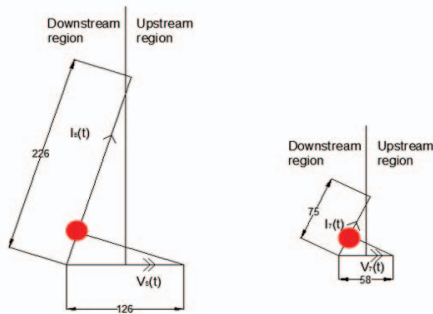

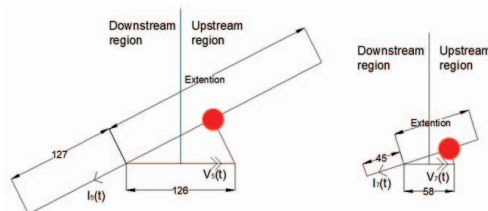Fig.7 5th and 7th harmonics source detection calculation for case 1 measurement 1

Fig.8 5th and 7th harmonics source detection calculation for case 1 measurement 2

B. Simulation Result with Motor Driver as Downstream (Case 2)

The circuit simulation for case 2 is connected as shown in Fig.6. As usual, the rectifier load and motor driver load is measured by measurement point 1 and measurement point 2 respectively. Then, the voltage and current waveform is analyzed by spectrogram via MATLAB. Hence, the output of the spectrogram is considered as actual value as shown in Table 2. The actual value is normalized with the particular fundamental magnitude which is considered as normalized value in Table 2. The result with comparing the magnitude current for both of the loads is considered actual result. For 7th harmonic current, the rectifier load is produced 1.77A while the motor driver load is produced 4.46A. The motor driver load is downstream for the actual result because the motor driver load produced higher harmonic current than rectifier load. However, the power direction result is done by calculation via formula power direction. The harmonic power in negative means the harmonic source at the downstream and vice versa. Example the 7th harmonic voltage is 7.71< -50 and the 7th harmonic current for measurement 2 is 4.46< 78, 7th harmonic power is -21.17W which is negative (downstream).

Fig.9 shows the solution harmonic source for the rectifier load for case 2. The 5th and 7th perpendicular points are fallen in the upstream region for case 2 rectifier load. However, the 5th and 7th perpendicular points are fallen in downstream region for the case 2 motor driver load (Fig.10). The simulation result for case 2 shows that the new proposed for

harmonic source detection is same with power direction method.

TABLE 2
SIMULATION RESULT FOR CASE 2

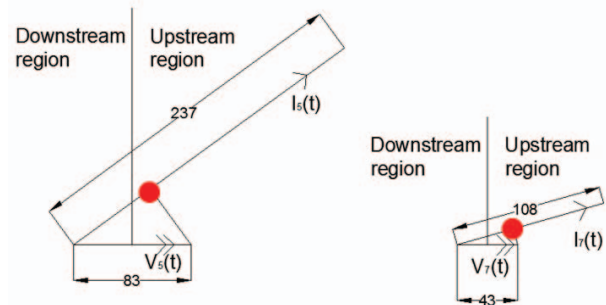| Label	H. Order	Actual Value	Normalized Value	Harmonic Source	Power Direction	Harmonic Detection
Voltage	1	180.22.< -92°	1.000			
	5	15.55< -14°	0.083			
	7	7.71< -50°	0.043			
Current Measu. 1	1	16.43< -104°	1.000			
	5	3.89< 22°	0.237	Up	Up	Up
	7	1.77< -34°	0.108	Up	Up	Up
Current Measu. 2	1	111< -116°	1.000			
	5	11.27< 113°	0.101	Down	Down	Down
	7	4.46< 78°	0.040	Down	Down	Down

Fig.9 5th and 7th harmonics source detection calculation for case 2 measurement 1
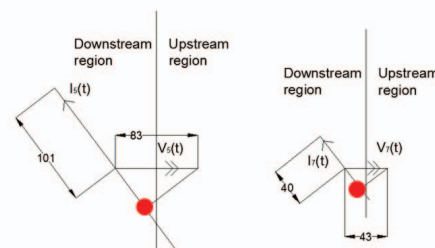

Fig.10 5th and 7th harmonics source detection calculation for case 2 measurement 2

V. CONCLUSION

In this paper, a new single point method is proposed for the harmonic source detection at the PCC. Based on the result in Table 1 and 2, the proposed new method for harmonic source detection is more accurate than the power direction method. The main advantage of the proposed method is that it does not require any data other than the voltage and current waveforms at the measuring point. Consequently, the cost of instrument setup required for proposed method is minimal. Taking into account on the advantages, the method can be considered as practical, easy to implement and compatible.

VI. ACKNOWLEDGMENTS

VII. REFERENCES

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VIII. BIOGRAPHIES

Dr. Abdul Rahim Abdullah was born in Kedah, Malaysia on 1979. He received his B. Eng., Master, PhD Degree from University of Technology Malaysia in 2001, 2004 and 2011 in Electrical Engineering and Digital Signal Processing. He is currently a Senior Lecturer and Coordinator of Center of Excellent Robotic and Industrial Automation (CeRiA) in Universiti Teknikal Malaysia Melaka (UTeM)

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