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# A verification of periodogram technique for harmonic source diagnostic analytic by using logistic regression

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***Abstract***

*A harmonic source diagnostic analytic is vital to identify the root causes and type of harmonic source in power system. This paper introduces a verification of periodogram technique to diagnose harmonic sources by using logistic regression classifier. A periodogram gives a correct and accurate classification of harmonic signals. Signature recognition pattern is used to distinguish the harmonic sources accurately by obtaining the distribution of harmonic and interharmonic components and the harmonic contribution changes. This is achieved by using the significant signature recognition of harmonic producing load obtained from the harmonic contribution changes. To verify the performance of the propose method, a logistic regression classifier will analyse the result and give the accuracy and positive rate percentage of the propose method. The adequacy of the proposed methodology is tested and verified on distribution system for several rectifier and inverter-based loads.*

***Keywords**: harmonic source diagnostic analytic, logistic regression, periodogram, signature recognition pattern*



## 1. Introduction

The widely used of nonlinear loads in power system have inject harmonics into the system and give rise to non-sinusoidal voltages and currents [1]. The varying supply of these loads can malfunctions the control system equipment in the devices [2]. As far as the harmonic distortion is concerned, the number and size of polluting loads continuously increase which poses a potential threat to the performance of power system. As a result, the harmonic distortion has increased losses and decreased life expectancy of the power system equipment [1], [3, 4]. Therefore, it is important to define suitable methodologies to attribute the responsibilities for the deterioration of the power quality [5, 6].

There are few approaches have been proposed by researchers to localize the harmonic producing loads based on different theoretical principles, features, advantages and limitations. However, a high level of engineering expertise are required to properly diagnose the harmonic signals [7-9]. The real power direction method is one of the earliest single point method proposed in locating harmonic sources [4], [10]. However, the real power direction method has been found to be only 50 percent reliable and therefore the accuracy of the method is questionable [11, 12]. To overcome this problem, a State Estimation (HSE) technique was introduced. Heydt, first proposed the idea of using state estimation procedure to identify the harmonic sources [11], [13]. But, a study in [12] showed that state estimation technique requires numerous measurement devices and unreasonable setup cost for the large power system [13-15].

An improvement of HSE method involves the principle of critical impedance method (CIM). However, the major drawback of this technique is a pre-requirement of source internal impedances values of utility and customer side and in practical it is hard to obtain those parameters without switching test [16-18]. To overcome the problem of accuracy related to the solutions of the estimation problem by CIM, Bayesian approach is proposed [19]. This technique requires a high multiplicity in the algorithm and very expensive cost to setup the distributed

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measurement system station [20]. The harmonic Norton equivalent circuit model is used in [21] to determine the harmonic current contributions of loads based on time-synchronized field measurements of load current and PCC voltages signals. However, the voltage harmonic deduced form this measurements need to be either calibrated or need to be recorded using the harmonic measurement infrastructure for transmission system [22]. In [23], a harmonic measurement devices (HMDs) are placed in a power system to identify the multiple harmonic sources and their harmonic injection levels. However, this is only relevant for a small interconnected transmission system [23, 24].

Researchers has been used several machine learning method based on statistical learning theory (SLT) for pattern recognition [25, 26]. Vapnik use support vector machine (SVM) to analyse data and recognized patterns for classification and regression analysis as a load forecasting technique [27]. In [28], Kumar used neural network based classification algorithm for detecting and identifying disturbance signals. However, this method is not suitable to construct frequency spectrum thus results in the loss of frequency components that has low energy components [29]. Fuzzy logic and adjusted probabilistic neural network are used in [30] to identify the location, level and type of harmonic sources however the total accuracy of this method is decrease whenever new type of load is introduced. The power electronics equipment, such as three-phase rectifiers and three-phase inverter with pulse width modulation (PWM) switching are widely used and lead to the disturbances of the utility and the end-user's equipment [31-33]. The widespread use of non-linear loads and integration of inverter connected to PV also have led to the harmonic problem in power system [34, 35]. The nature of inverter which is converting DC to AC is resulting an injection of low order harmonic in power system [36, 37]. Static PV and DC storage and dynamic distributed generation systems that are connected to converter can reduce the traditional line losses. However, it added the harmonic losses due to asynchronous THD voltage [38]. One of the major source of harmonics in homes, offices and industries is the rectifier based device like laptops, televisions, computers and a wide range of consumer electronic devices which can cause waveform distortion [39-41]. No researchers has found any standard on defining the method of identifying the dominant harmonic disturbance [42].Thus, in order to identify the root cause and to mitigate the harmonic disturbance, a diagnostic analytics of harmonic sources is necessary to do so.The predictive models are widely used in variety of sector for diagnostic and predictive tasks. Researchers have proposed quite a number of sophisticated method for classification algorithm [43]. Logistic regression is one the popular classification algorithms from the machine learning field [44]. The logistic regression is widely used for classification compared to linear regression because its outcome on one sample is the probability that it is positive or negative and depends on a linear measure of sample [28]. According to Dreiseit, details on model building are often given for logistic regression rather than artificial neural networks because in a standard logistic regression software, forward, backward and stepwise variable scheme are implemented so it is easily used and reported [27].

This paper proposes a high accuracy, fast estimation and costs efficient technique to identify and diagnose the type of multiple harmonic sources in the distribution system with single point measurement at the point of common coupling by utilizing periodogram. The logistic regression method is used to classify and validate the accuracy of the data from the periodogram technique to diagnose type of harmonic sources. This approach can overcome the limitations on the existing diagnostic analysis method. Logistic regression is a multivariate statistical method and a representative discriminant analysis approach that can be used as a classifications for a set of data into predefined classes with respect to several parameters [45, 46]. For this research, we analysed two type of non-linear load which is inverter and rectifier. The parameters chosen for this classification are the total harmonic distortion (THD) voltage and current and the response will be either inverter or a rectifier.

## 2. Methodology

A single point-measurement of voltage and current is implemented in this research, while the Periodogram is utilised for analysing the signal parameters.

### 2.1. Periodogram

A harmonic spectrum of non-linear loads power analyser which characterizes the behaviour of harmonic sources to provide preliminary data on the severity of the distortion problem is widely employed by the utilities. The periodogram spectral represents the distribution of power signal over frequency and it is based on a Fourier series model of the data, that is, specifically designed for determining harmonic components in power signals [33-35]. It can be formulated as (1):

$$S_V(f) = \left(\frac{1}{T}\int_{-T/2}^{T/2} v(t)e^{-j2\pi ft}dt\right)^2 \quad (1)$$

where, $(f)$ in frequency domain and $(t)$ is voltage waveform

### 2.2. Implementation of Proposed Technique

The execution of proposed technique can be realised as shown in Figure 1 and Figure 2. Two types of common and widely used harmonic sources which are the three-phase rectifier and three-phase inverter with pulse width modulation (PWM) switching [45] are used in this research.

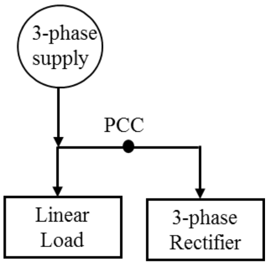



Figure 1. A rectifier based load.

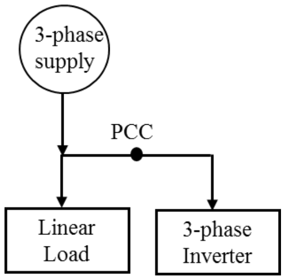



Figure 2. An inverter based load.

Meanwhile, the measurement data are analysed by using periodogram and frequency spectrum. Furthermore, the harmonic indices which are instantaneous total harmonic distortion, *THD (t)* and instantaneous total non-harmonic distortion, *TnHD (t)* are calculated. The contribution changes and distribution of harmonic and interharmonic components are obtained from the diagnostic analytic process. Finally, the distinguishment of harmonic sources can be obtained by observing the signature recognition pattern.

The implementation of the methodology in executing the proposed approach as shown in Figure 3. From the proposed technique, it is demonstrated that the methodology can be effortlessly actualized in the system. This is due to the fact that there is no requirement for any complex calculation of signal parameters.

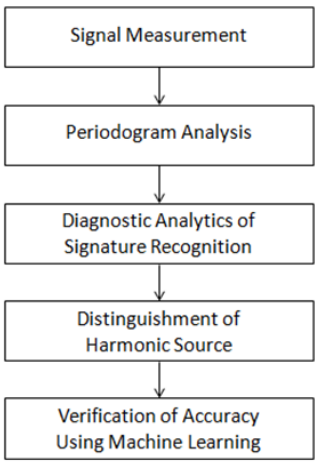



Figure 3. An implementation of harmonic source diagnostic analytics

### 2.3. Signal Parameters

Parameters of power quality signals are estimated from the TFR in order to provide the information of the signal in time. Meanwhile, the minimum width of the measurement window is ten cycles [27].

#### 2.3.1. Instantaneous RMS Voltage

The RMS voltage, $V_{rms}$, can also be derived from the TFR in time and referred to as instantaneous RMS voltage, $V_{rms}(t)$ and written as (2) [36]:

$$V_{rms}(t) = \sqrt{\int_0^{f_s} P_x(t,f)\,df} \tag{2}$$

where $Px\ (t, f)$ is the TFR of the signal and fs is the sampling frequency of the system.

#### 2.3.2. Instantaneous RMS Fundamental Voltage

Instantaneous RMS fundamental voltage, $V_{1rms}\ (t)$, is defined as the RMS voltage at power system frequency [34-36]. From the TFR, the $V_{1,\ rms}\ (t)$, can be calculated as shown in (3):

$$V_{1rms}(t) = \sqrt{2\int_{f_{lo}}^{f_{hi}} P_x(t,f)\,df} \tag{3}$$

$$f_{hi} = f_0 + 25$$
$$f_{hi} = f_0 + 25$$

where $P_x\ (t,f)$ is the time-frequency representation of the signal and $f_0$ is the fundamental frequency that corresponds to the power system frequency. 25 Hz is chosen for $f_{hi}$ and $f_{lo}$ since it can cover the fundamental frequency component to calculate the magnitude of the frequency component.

#### 2.3.3. Instantaneous Total Harmonic Distortion

The instantaneous total harmonic distortion, $THD(t)$, is used to measure how much harmonic content is in a waveform and expressed as shown in (4) [37]

$$THD(t) = \frac{\sqrt{\sum_{h=2}^{H} V_{h,rms}(t)^2}}{V_{1rms(t)}} \tag{4}$$

where $V_{h,\ rms}\ (t)$ is RMS harmonic voltage from $2^{nd}$ to $50^{th}$ harmonic.

#### 2.3.4. Instantaneous Total Nonharmonic Distortion

Besides harmonic, a signal also contains interharmonic components that are not multiple integers and can be quantified by using the instantaneous total nonharmonic distortion, $TnHD(t)$, index which is defined in (5) [38]

$$TnHD(t) = \frac{\sqrt{V_{rms}(t)^2 - \sum_{h=0}^{H} V_{h,rms}(t)^2}}{V_{1rms}(t)} \tag{5}$$

where $V_{h,\ rms}\ (t)$ is RMS harmonic voltage from $2^{nd}$ to $50^{th}$ harmonic.

### 2.4. Logistic Regression

The logistic regression is known as a standard probabilistic statistical classification model. It is extensively used across multiple disciplines. A classification function is derived and the information describing this function is stored. It represents the boundary between the secure and insecure classes. Logistic regression model is a linear model for a binary classification.

Figure 4 shows the description of supervised learning problem slightly formally. Given a training set to learn a function h(x), so it becomes a "good" predictor for the corresponding value of y. In this research, it will focus on the binary classification problem in which the predicted y can take only two values, inverter and rectifier. The logistic function h(x) function can be written as (6):

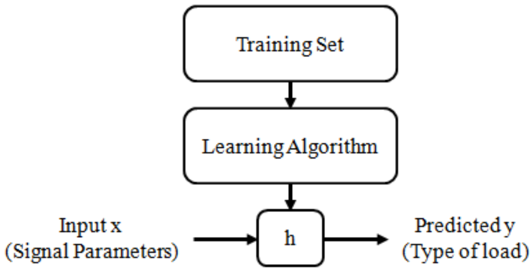



Figure 4. The process of supervised learning

$$h(t) = \frac{1}{1 + e^{-t}} \tag{6}$$

is called the logistic function of the sigmoid function. The logistic regression can be used to find the β parameters that best fit

$$y = \begin{cases} 1 & \beta_0 + \beta_1 x + \varepsilon > 0 \\ 0 & else \end{cases} \tag{7}$$

where the $\varepsilon$ is an error distributed by the standard logistic distribution. Therefore, the logistic regression function [32] can be written as (8)

$$p(x) = \frac{1}{1 + e^{-(\beta_0 + \beta_1 x)}} \tag{8}$$

## 3. Results and Discussion

The results of an analysis of harmonic indices, harmonic contribution changes and signature recognition pattern of harmonic sources which are rectifier based load and inverter-based load presented in this section.

### 3.1. Rectifier based Load

In this case study, the signature recognition of rectifier based load is observed due to perform the harmonic source diagnostic. A six-pulse three-phase rectifier with Pulse Width Modulation (PWM) switching technique is selected to be the rectifier-based load. The voltage and current signal in time domain when this rectifier based load utilized as the harmonic producing load shown in Figure 5 (a). Clearly shown that the voltage and current signals are not a pure sinusoidal form. As shown in Figure 5 (b), the harmonic indices which are *THD (t)* and *TnHD (t)* in the range of 1.093% to 1.098% and 1.295% to 1.3%, respectively. These harmonic indices show that the voltage signal consist of harmonic and interharmonic components. Nevertheless, the harmonic distortion level still in the permitted range of IEEE Standard 519-2014, where the total harmonic distortion cannot more than 8%.

The current spectrum of signal shown in Figure 5 (c). Whereas the harmonic current exist at 250 Hz, 900 Hz and 1000 Hz, respectively. In the meantime, the interharmonic components discovered at 375 Hz, 425 Hz, 575 Hz, and 675 Hz, respectively. As this 6-pulses rectifier, the harmonic order starts at 5th whiles the 3rd harmonic and below are eliminated. As shown in Figure 4 (d), the voltage signal comprising four harmonic and two interharmonic components, individually. Next, to have a good understanding of inverter based load, a diagnostic analytic of inverter based load is performed and explain in next section.

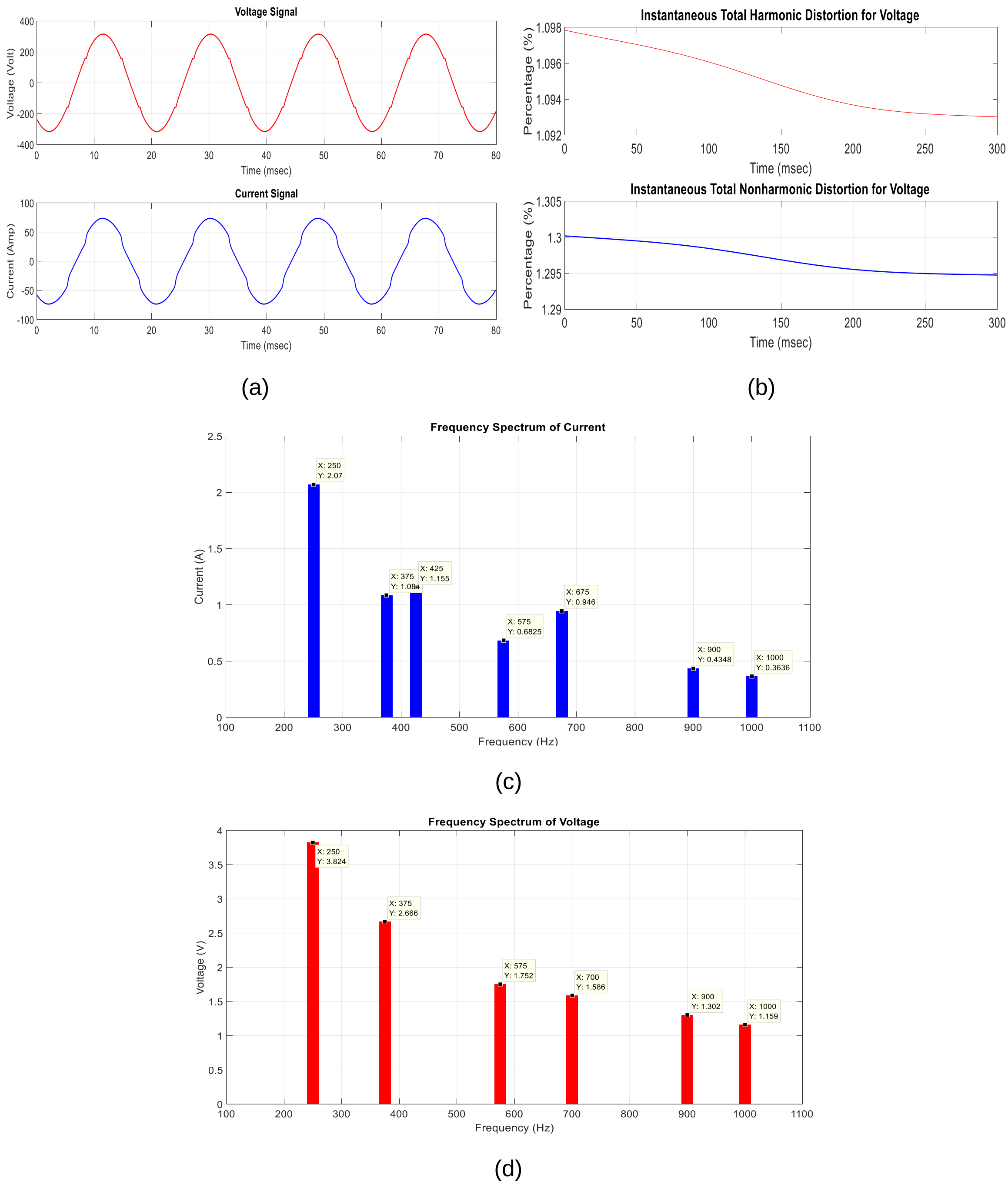
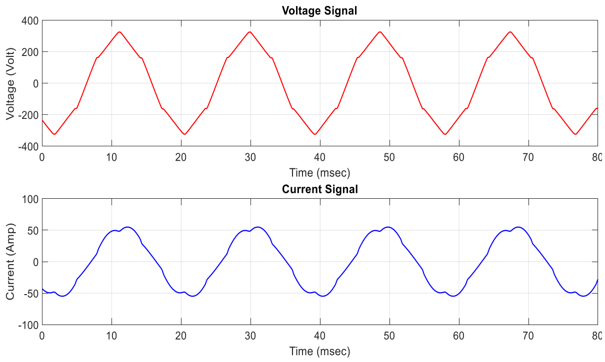



Figure 5. Six-pulses three-phase rectifier (a) voltage and current signal (b) THD(t) and TnHD(t) for voltage and current (c) current frequency spectrum (d) voltage frequency spectrum

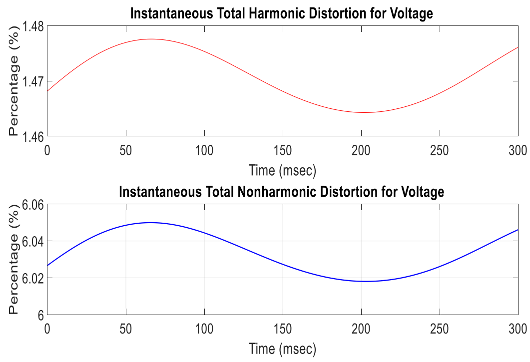
### 3.2. Inverter based Load

This case study seeks to address the signature recognition of inverter-based load and the finding should make an important contribution to the harmonic source diagnostic. The three-phase AC-DC-AC inverter with Pulse Width Modulation (PWM) switching technique was selected to be the inverter-based load. Figure 6 (a) presents the voltage and current signal in time domain when the three-phase inverter was utilized as the harmonic producing load. Furthermore, Figure 6 (b) shows the harmonic indices which are *THD (t)* and *TnHD (t)* in the range of 1.465% to 1.475% and 6.01% to 6.05%, respectively. These harmonic indices shows that the harmonic and interharmonic components are exist in the signal. However, the harmonic distortion level still in the permitted range of IEEE Standard 519-2014, where the total harmonic distortion cannot more than 8%.

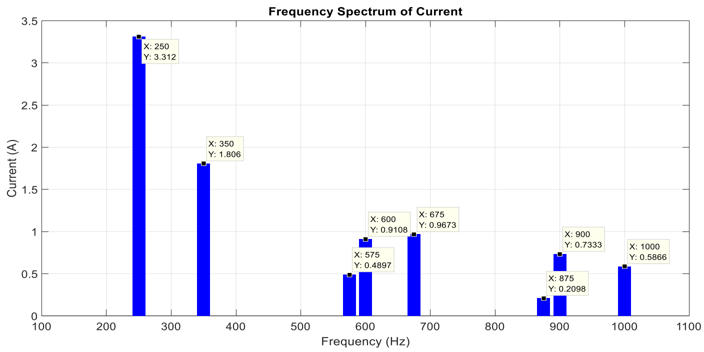
The spectrum of current drawn by the inverter shown in Figure 6 (c). Where by the harmonic current exist at 250 Hz, 350 Hz, 600 Hz, 900 Hz and 1000 Hz, respectively. Meanwhile, the interharmonic components discovered at 575Hz, 675Hz and 875 Hz, respectively. Figure 6 (d) shows the frequency spectrum of voltage and it was distinguished four harmonic and six interharmonic components in the voltage signal, respectively. Previous analysis of harmonic and interharmonic contribution of rectifier based load is done and further analysis on inverter based load is necessary due to conclude the hypothesis of signature recognition of HPL. In addition, no previous research distinguished the HPL based on harmonic and interharmonic contribution of voltage and current.



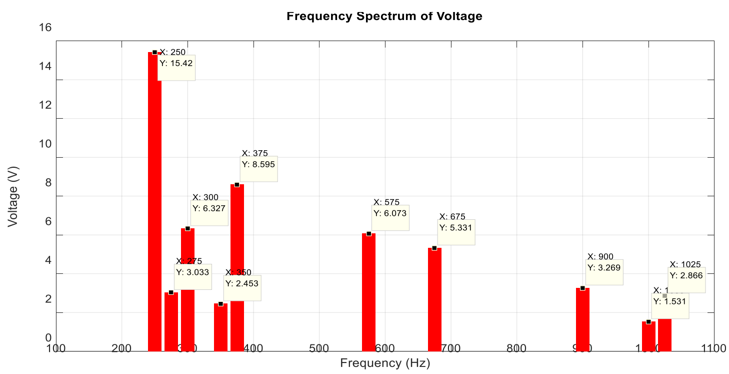

(a)




(b)




(c)




(d)

Figure 6. AC-DC-AC PWM Inverter (a) a instantaneous voltage and current signal at PCC (b) *THD(t)* and *TnHD(t)* of voltage signal (c) frequency spectrum of harmonic and interharmonic of current signal (d) frequency spectrum of harmonic and interharmonic of voltage signal

### 3.3. Voltage and Current Signature Analysis

Although extensive research has been carried out on harmonic source diagnostic, no single study exists which adequately study the relationship of contribution impact of harmonic and interharmonic and the HPL that in the power distribution system. The signature analysis of voltage and current is performed due to study the impact of the contribution to the system. Furthemore, this analysis enhances our understanding on voltage and current signature pattern towards the diagnostic analysis of HPLs. As shown in Figure 7, the harmonic contribution changes (HCC) clearly shows that the voltage contribution changes of inverter-based load are dominant at most of frequencies comparing to the rectifier based load. Interestingly, at 275 Hz, 300 Hz, 350 Hz, 675 Hz and 1025 Hz, only harmonic and interharmonic voltage components of inverter based load were exist with 100% rate of HCC. Turning now to the voltage signature of rectifier based load that only has a dominant harmonic component at 700 Hz and 900 Hz, respectively. Meanwhile at 700 Hz, the HCC rate was 100%. This paragraph has analysed the voltage signature, while the next paragraph will explain the analysis of current signature of HPLs.

What follows is an explanation of current signature of rectifier based load and inverter based load. One of the signature components that contribute in the development of HPL's signature recognition is current signature. Figure 8 shows the most striking result to emerge from the result are that the HCC of inverter-based load have become so dominant. The HCC rate for inverter based load were 100% at 350 Hz, 600Hz and 875 Hz. These are: 250 Hz, 350 Hz, 600 Hz, 875 Hz, 900 Hz and 1000 Hz. Comparing the current signature of inverter based load, it can be seen that the HCC for rectifier based load with rate of 100% at 375 Hz and 425 Hz. In the meantime, it was dominant too at 575 Hz and yielded a 58% of HCC.

A strong relationship of voltage and current signature versus HCC is interesting because this significant relationship can be utilized in diagnostic the above said HPLs. In this section, it is explained that the HCC for voltage and current signature of inverter based load are so dominant compare to rectifier based load.

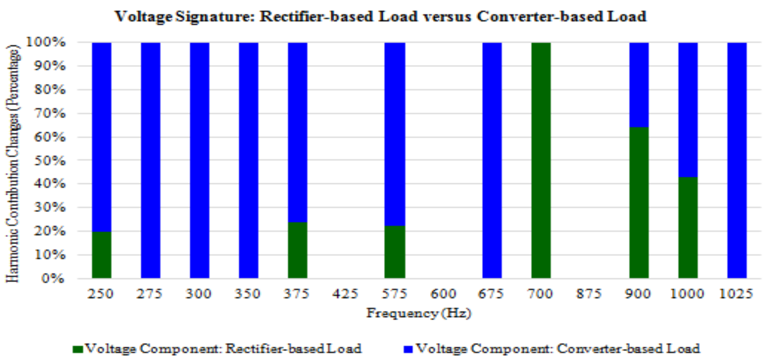



Figure 7. Voltage signature analysis

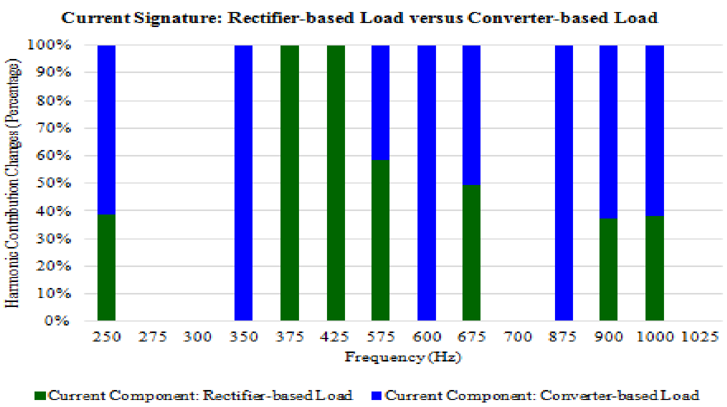



Figure 8. Current signature analysis

### 3.4. Signature Recognition of Harmonic Producing Load using Logistic Regression

The results obtained from the preliminary analysis will be analysed and the significant signature recognition of harmonic producing load will be obtain using machine learning classification model. Logistic Regression classifier will be used in this research because it is suitable for a two-class classification. Table 1 shows the accuracy of the Periodogram technique to diagnose the harmonic source by using the logistic regression as the classifier.

Table 1. The Training Results from the Analysis Data using the Logistic Regression Classifier

| Training Result | Logistic Regression | |
|---|---|---|
| | Inverter | Rectifier |
| Accuracy (%) | 56.7 | 57.4 |
| True Positive Rate (%) | 60.0 | 55.0 |

## 4. Conclusion

The diagnostic analytic. A periodogram technique gives a correct and accurate classification of harmonic signals. By using a signature recognition pattern, the distinguishment of harmonic sources successfully done. A logistic regression classifier is used due to verify the accuracy of current findings in this study indicate the significant relationship and noteworthy contributions of harmonic source the proposed method. 56.7% and 57.4% of accuracy in diagnosing the rectifier and inverter-based load. Meanwhile, the true positive rate is 60% and 55%, respectively. The result show that the propose method does not give high accuracy in diagnostic analytics process. Thus, a better technique such as time-frequency distribution should be considered for future research.

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