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Real-Time Power Quality Disturbances Detection and Classification System

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Abstract: Power quality disturbances present noteworthy ramifications on electricity consumers, which can affect manufacturing process, causing malfunction of equipment and inducing economic losses. Thus, an automated system is required to identify and classify the signals for diagnosis purposes. The development of power quality disturbances detection and classification system using linear time-frequency distribution (TFD) technique which is spectrogram is presented in this paper. The TFD is used to represent the signals in time-frequency representation (TFR), hence it is handy for analyzing power quality disturbances. The signal parameters such as instantaneous of RMS voltage, RMS fundamental voltage, total waveform distortion (TWD), total harmonic distortion (THD) and total non-harmonic distortion (TnHD) are estimated from the TFR to identify the characteristic of the signals. The signal characteristics are then served as the input for signal classifier to classify power quality disturbances. Referring to IEEE Std. 1159-2009, the power quality disturbances such as swell, sag, interruption, harmonic and interharmonic are discussed. Standard power line measurements, like voltage and current in RMS, active power, reactive power, apparent power, power factor and frequency are also calculated. To verify the performance of the system, power quality disturbances with various characteristics will be generated and tested. The system has been classified with 100 data at SNR from 0dB to 40dB and the outcomes imply that the system gives 100 percent accuracy of power quality disturbances classification at 34dB of SNR. Since the low absolute percentage error present, the system achieves highly accurate system and suitable for power quality detection and classification purpose.

Key words: Real-Time · Power Quality Disturbances · Time-Frequency Distribution · Time-Frequency Representation · Spectrogram

INTRODUCTION

The quality of power system has become a vital concern to electricity users at all levels of usage. The ability to maintain the constant amplitude and fundamental frequency of voltage and current signals presents the quality of electrical power supplied to customers [1]. The power quality disturbances can cause failure or disoperation of equipment and economic problem. Thus, it is essential to establish a real-time power quality disturbances detection and classification system for providing plenty exposure of the overall system, understanding the causes of these disturbances, resolving existing problems and predicting future problems [2].

To ensure the quality of electrical power and diminish the risk of failure, a prompt and accurate diagnosis of the disturbances can reduce the time to diagnose and rectify failures [3]. The difficulty of power quality disturbances diagnosis requires an engineering expertise and proficient knowledge in many areas of electrical power [4]. A poor power quality can cause problems like diminishing the lifetime of the load, erroneous of protection devices, instabilities and interruptions in production as well as significant costs due to lost production and downtime.

Power quality disturbances analysis is carried out using transformation technique. There are several techniques for identifying or classifying power quality disturbances that presented by other researchers [5]. The most widely adopted approach in signal processing is spectral analysis using Fourier analysis which is Fourier transform where it is a tremendous technique for analyzing stationary signal because the characteristics of the signal do not change with time but it is unfavorable for non-stationary signal because of its inadequacy in tracking the changes in the magnitude, frequency or

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phase [6, 7]. The time-frequency representation is introduced to vanquish the limitation of this technique. There are numerous time frequency distributions techniques namely short time Fourier transform (STFT), spectrogram, Gabor transform, S-transform and wavelet transform [5-10]. However, this paper focuses on spectrogram which is time frequency analysis technique for distinguishing the signals in time frequency domain. Spectrogram which is squared magnitude of STFT gives the time waveform energy distribution in joint-time frequency domain where this technique is used in many applications and widely used as an initial investigative tool as it has the property of being a cross-term free TFD[11].

In this paper, spectrogram technique is implemented in the power quality disturbances detection and classification system. The disturbances are analyzed by representing the signals in time frequency representation (TFR). Then, the parameters such as RMS and fundamental value, total harmonic distortion (THD), total non-harmonic distortion (TnHD) and total waveform distortion (TWD) for voltage and current are evaluated from TFR and used for the classification of power quality disturbances such as voltage swell, sag, interruption, harmonic, interharmonic and transient. The general system design based on IEEE Std. 1159-2009 is shown in flow chart in Fig. To verify its performance and classification, the system has been tested with 100 signals at SNR from 0dB to 40dB. The percentage of accuracy for classification system is presented.

Power Quality Disturbances: In International Electrotechnical Commission (IEC) standard, the information regarding magnitude, duration and typical spectral for each of electromagnetic phenomenon are classified into several groups as categorized in Table 1 [12]. Common types of disturbance occur in power system are voltage sag, swell, overvoltage, undervoltage, harmonic, interharmonic, transient, notching and interruption based on IEEE Std. 1159-2009.

Signal Model: The power quality disturbances can be categorized into three types of signals which are voltage variation, waveform distortion and transient signal. Voltage variation consists of interruption, voltage swell and sag while harmonic and interharmonic are categorized as waveform distortion. The signal models of the categories according to IEEE Std. 1159-2009 are formed and written as a complex exponential signal as [8, 9, 13]:

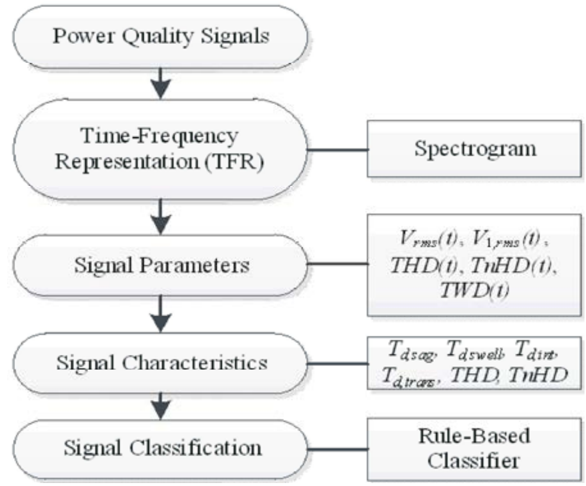


Fig. 1: Flow chart of the general system design

$$z_{vv}(t) = e^{j2\pi f_1 t}\sum_{k=1}^{3} A_k \Pi_k(t - t_{k-1}) \quad (1)$$

$$z_{wd}(t) = e^{j2\pi f_1 t} + Ae^{j2\pi f_2 t} \quad (2)$$

$$z_{trans}(t) = e^{j2\pi f_1 t}\sum_{k=1}^{3} \Pi_k(t - t_{k-1}) + Ae^{-1.25(t-t_1)/(t_2-t_1)}e^{j2\pi f_2(t-t_1)}\Pi_2(t-t_1) \quad (3)$$

$$\Pi_k(t) = \begin{cases} 1, \text{for } 0 \le t \le t_k - t_{k-1}, \\ 0, \quad elsewhere, \end{cases} \quad (4)$$

where, $z_{vv}(t)$ represents voltage variation, $z_{wd}(t)$ represents waveform distortion, $z_{trans}(t)$ represents transient signal, A_k is the signal component amplitude, k is the signal component sequence, f_1 and f_2 are the signal frequency, $\Pi(t)$ is a box function of the signal, t is the time,

In this analysis, f_1, t_0 and t_3 are set at 50 Hz, 0 ms and 200 ms, respectively and other parameters are defined as below:

1. Sag : $A_1 = A_3 = 1$, $A_2 = 0.8$, $t_1 = 100$ms, $t_2 = 140$ms
2. Swell : $A_1 = A_3 = 1$, $A_2 = 1.4$, $t_1 = 20$ms, $t_2 = 80$ms
3. Interruption : $A_1 = A_3 = 1$, $A_2 = 0$, $t_1 = 100$ ms, $t_2 = 140$ms
4. Harmonic : $A = 0.5$, $f_2 = 200$ Hz
5. Non-harmonic : $A = 0.25$, $f_2 = 275$ Hz
6. Transient : $A = 0.5$, $f_2 = 1000$ Hz, $t_1 = 100$ms, $t_2 = 115$ms

Table 1: Categories and Typical Characteristics of Power System Electromagnetic Phenomena

Categories	Typical spectral content	Typical duration	Typical voltage magnitude
1.0 Transients			
1.1 Impulsive			
1.1.1 Nanosecond	5ns rise	< 50 ns	
1.1.2 Microsecond	1 µs rise	50 ns-1ms	
1.1.3 Millisecond	0.1 ms rise	> 1 ms	
1.2 Oscillatory			
1.2.1 Low frequency	< 5 kHz	0.3-50ms	0-4 pu[a]
1.2.2 Medium frequency	5-500 kHz	20 µs	0-8 pu
1.2.3 High frequency	0.5-5 MHz	5 µs	0-4 pu
2.0 Short duration variations			
2.1 Instantaneous			
2.1.1 Sag		0.5-30 cycles	0.1-0.9 pu
2.1.2 Swell		0.5-30 cycles	1.1-1.8 pu
2.2 Momentary			
2.2.1 Interruption		0.5 cycles-3s	< 0.1 pu
2.2.2 Sag		30 cycles-3s	0.1-0.9 pu
2.2.3 Swell		30 cycles-3s	1.1-1.4 pu
2.3 Temporary			
2.3.1 Interruption		3s-1min	< 0.1 pu
2.3.2 Sag		3s-1min	0.1-0.9 pu
2.3.3 Swell		3s-1min	1.1-1.2 pu
3.0 Long duration variations			
3.1 Interruption, sustained		> 1 min	0.0 pu
3.2 Undervoltages		> 1 min	0.8-0.9 pu
3.3 Overvoltages		> 1 min	1.1-1.2 pu
4.0 Voltage imbalance		Steady state	0.5-2%
5.0 Waveform distortion			
5.1 DC offset		steady state	0-0.1%
5.2 Harmonics	0-9 kHz	steady state	0-20%
5.3 Interharmonics	0-9kHz	steady state	0-2%
5.4 Notching		steady state	
5.5 Noise	broad-band	steady state	0-1%
6.0 Voltage fluctuations	< 25 Hz	intermittent	0.1-7%
7.0 Power frequency variations		< 10 s	

Power Quality Analysis Techniques

Spectral Analysis: The determination of the frequency content of signal is acquired through the conversion of the signal from time domain to frequency domain is known as spectral analysis as discussed in equation (5).

$$x(f) = \int_{-\infty}^{\infty} x(t)e^{-j2\pi ft}dt \tag{5}$$

where, f is the frequency to be analyzed.

Time-Frequency Distribution: Instead of using spectral analysis, spectrogram is one of the time-frequency distribution (TFD) that portrays the signal in both time and frequency domain. It displays square magnitude of STFT and the analysis technique is an improvement from limitation of Fast Fourier Transform (FFT) to cater non-stationary signals whose spectral characteristics change with time. It is the result of calculating the frequency spectrum of windowed frames of a compound signal [11]. This technique can be expressed as:

$$P_x(t,f) = \left| \int_{-\infty}^{\infty} x(\tau)w(\tau - t)e^{-j2\pi f}d\tau \right|^2 \tag{6}$$

where, $x(\tau)$ is the input signal, $w(t)$ is the observation window.

Power Quality Measurements: The measurement of power qualities such as voltage, current, active power, reactive power, apparent power, power factor and frequency are executed by the system.

Voltage Measurement: Voltage is measured in the range from 0 to 300volts. Voltage transducer is connected to the system to step down the voltage and acts as isolation between power line and the system that will interface using DAQ card. It will sample the signal and calculate the voltage in RMS value by using the following equation:

$$Vrms = \sqrt{\frac{1}{T}\int_{t=0}^{T} |v(t)|^2 \, dt} \tag{7}$$

Current Measurement: The range of current measured between 0 to 100A. The current transducer, which is connected to the input of DAQ card will sampled the current signal and calculated in RMS value using this equation:

$$Irms = \sqrt{\frac{1}{T}\int_{t=0}^{T} |i(t)|^2 \, dt} \tag{8}$$

Power Measurement: Power measurements consist of active power, reactive power, apparent power and power factor. These can be calculated as follows:

$$P = \frac{1}{T}\int_{t=0}^{T} v(t)i(t)dt \tag{9}$$

$$Q = \sqrt{S^2 - P^2} \tag{10}$$

$$S = |Vrms||Irms| \tag{11}$$

$$pf = \frac{P}{S} \tag{12}$$

Power Quality Parameters: From the time-frequency representation (TFR), the signal parameters are estimated to identify characteristics of the signal. Instantaneous root mean square (RMS) voltage, instantaneous RMS fundamental voltage, instantaneous total waveform distortion, instantaneous total harmonic distortion and instantaneous total interharmonic distortion are the list of signal parameters that used for detection of power quality disturbances [8].

Instantaneous RMS Voltage: The RMS voltage, V_{rms} can also be derived from TFR in time and referred as instantaneous RMS voltage, V_{rms} is mentioned by [8] as:

$$V_{rms}(t) = \sqrt{\int_{0}^{f_{\max}} P_x(t,f)df} \tag{13}$$

where, $P_x(t,f)$ is the time-frequency distribution, $f_{\max}$ is the maximum frequency of interest.

Instantaneous RMS Fundamental Voltage: Instantaneous RMS fundamental voltage is defined as the RMS voltage at power system frequency and can be calculated as:

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

$$f_{hi} = f_1 + \frac{\Delta f}{2}, \quad f_{lo} = f_1 - \frac{\Delta f}{2} \tag{14}$$

where, f_1 is the fundamental frequency that corresponds to the power system frequency, Δf is the bandwidth. Δf is set to 50Hz.

Instantaneous Total Waveform Distortion: Instantaneous Total Waveform Distortion (TWD) can be expressed as sum of harmonic distortion and non-harmonic distortion. It can be obtained by:

$$TWD(t) = \frac{\sqrt{V_{rms}(t)^2 - V_{1rms}(t)^2}}{V_{1rms}(t)} \tag{15}$$

where, V_{rms} is the instantaneous RMS voltage, V_{rms} is the instantaneous RMS fundamental voltage.

Instantaneous Total Harmonic Distortion: Total harmonic distortion is used to identify harmonic content in a signal and can be expressed as:

$$THD(t) = \frac{\sqrt{\sum_{h=2}^{H} V_{h,rms}(t)^2}}{V_{1rms}(t)} \tag{16}$$

where, $V_{h,rms}(t)$ is the RMS harmonic voltage, H is the highest measured harmonic component.

Instantaneous Total Non-Harmonic Distortion: Non-harmonics contain frequency components which are not multiple integer of the power system frequency and it can be written as:

$$TnHD(t) = \frac{\sqrt{V(t)_{rms}{}^2 - \sum_{h=0}^{H} V_{h,rms}(t)^2}}{V_{1rms}(t)} \tag{17}$$

Signal Characteristics: Signal characteristics are calculated from the signal parameters. The characteristics, which contain the information of the signal such as duration of swell, sag, interruption and average of RMS voltage, are used as the input for signal classifier to classify power quality disturbances.

The signal characteristics of voltage variation are calculated from the instantaneous RMS voltage [8]. The other characteristics of the signal can also be estimated and defined as follows:

$$T_{d,swell} = \int_0^T \begin{cases} 1, \mathit{for}\ \mathrm{V}_{rms}(\mathrm{t}) \geq 1.1 \\ 0, \quad \mathit{elsewhere} \end{cases} dt \tag{18}$$

$$T_{d,sag} = \int_0^T \begin{cases} 1, \mathit{for}\ 0.1 \leq \mathrm{V}_{rms}(t) \leq 0.9 \\ 0, \quad \mathit{elsewhere} \end{cases} dt \tag{19}$$

$$T_{d,\mathrm{int}} = \int_0^T \begin{cases} 1, \mathit{for}\ \mathrm{V}_{rms}(t) < 0.1 \\ 0, \quad \mathit{elsewhere} \end{cases} dt \tag{20}$$

$$V_{rms,ave} = \frac{1}{T}\int_0^T V_{rms}(t)dt \tag{21}$$

Meanwhile, the signal characteristics of transient signal can be identified from the instantaneous total waveform distortion. The duration of transient can be expressed as:

$$t_{trans} = \int_0^T \begin{cases} 1, \mathit{for}\ \mathrm{TWD(t)} \geq \mathrm{TWD}_{trans,thres} \\ 0, \quad \mathit{elsewhere} \end{cases} \tag{22}$$

where, $\mathrm{TWD}_{trans,thres}$ is the total waveform distortion threshold for transient. The threshold is set at 0.05.

For analyzing the signal characteristic of waveform distortion the instantaneous total harmonic distortion and instantaneous total interharmonic distortion are used in gaining the average of total harmonic and interharmonic distortion as in equation below:

$$THD_{ave} = \frac{1}{T}\int_0^T THD(t)dt \tag{23}$$

$$TnHD_{ave} = \frac{1}{T}\int_0^T TnHD(t)dt \tag{24}$$

Signal Classifications: The rule-based classifier is a deterministic classification method that has been widely used in real world application. The performance of the classification is much dependent on the expert rules and threshold settings. The system is simple and easy to implement. In this analysis, since the signal characteristics provide good prior knowledge of the power quality signals, the rule-based classifier is suitable to be used for signal classification [4, 14].

The signal characteristics are consists of duration of swell, sag, interruption and transient and average of RMS voltage, total harmonic distortion and total interharmonic distortion. Based on the signal characteristics, the flow chart in Fig. 2 are described a rule based classifier of the power quality disturbances. The threshold settings of the signal characteristics to classify the disturbances are set based on IEEE std. 1159-2009.

System Developments: The power quality disturbances classifiction system consists of three major parts which are input, interfacing and computer as shown in Fig. 3. In this system, voltage and current transducers that are used as input can measure power line voltage and current up to 500 V and 100 A, respectively. The transducers are connected to data acquisition card (DAQ) for interfacing with computer.

DAQ involves the conversion of analog waveforms into digital values and transfers the data to computer. In this system, NI USB 6009 is used to give better accuracy, flexible, maximized performance and cost-effective measurement solution. It provides connection to eight single-ended analog input (AI) channels, two analog output (AO) channels, 12 digital input/output (DIO) channels and a 32-bit counter with a full-speed USB interface. The input that have been used in this system is AI 0 (AI 0+) and AI 4 (AI 0-) for voltage transducer and AI 1 (AI 1+) and AI 5 (AI 1-) for current transducer.

On computer, a user-friendly graphical user interface (GUI) is developed using Visual Basic to analyze the captured signals from DAQ and then displays and record the signal parameters. Visual Basic is a programming system that offers new integrated development environment. It is a tool used to design and create graphical user interface (GUI) applications for the Microsoft Windows of operating systems. The interface of Visual Basic is well organized, optimized for fast functionality and its simplicity is an advantage for programmers.

System Validation: The experiment setup for system validation is shown in Fig. 4. Input voltage is supplied to RLC load and the measurements are collected using the system and fluke power quality analyzer (PQA). In order to present the accuracy, the performance of the system measurement is verified based on mean absolute percentage error (MAPE) [13]. Smaller value of MAPE shows high accuracy of the measurement. The MAPE is adopted to evaluate the accuracy of measurement and can be expressed as follows:

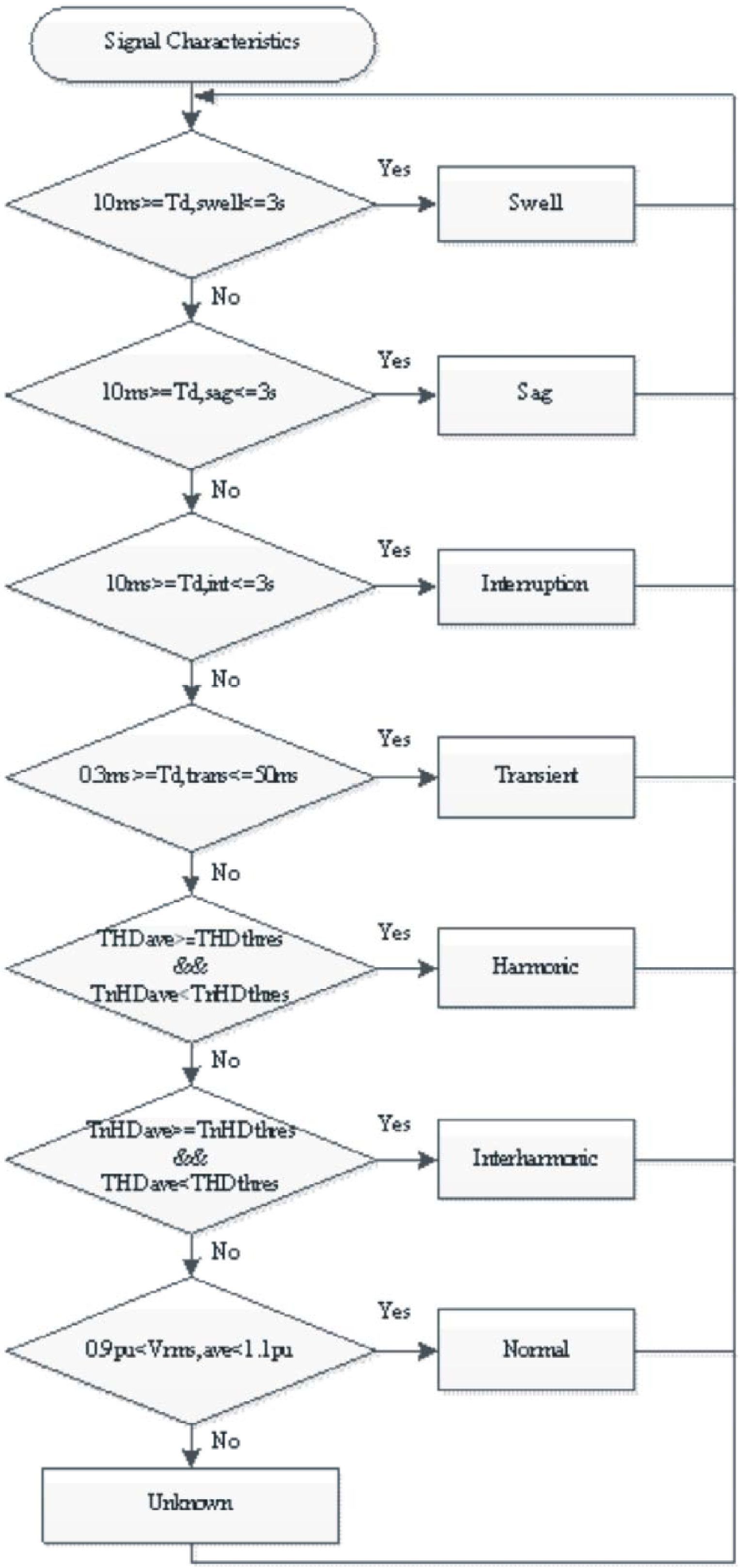


Fig. 2: Flow chart of the rule based classifier

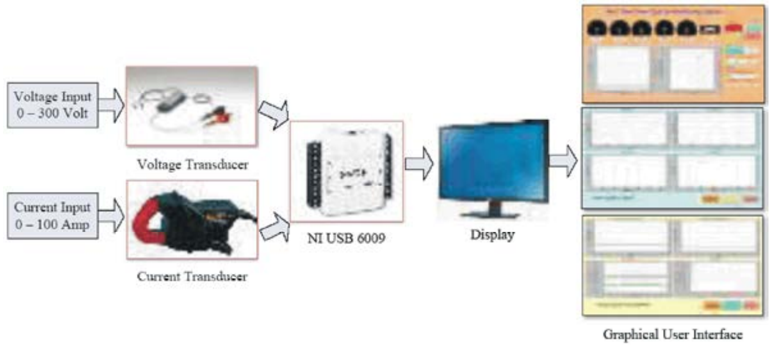


Fig. 3: System development

Fig. 4: Experiment setup

$$MAPE = \frac{1}{N}\sum_{n=1}^{N}\left|\frac{x_i(n) - x_m(n)}{x_i(n)}\right| \times 100\% \quad (25)$$

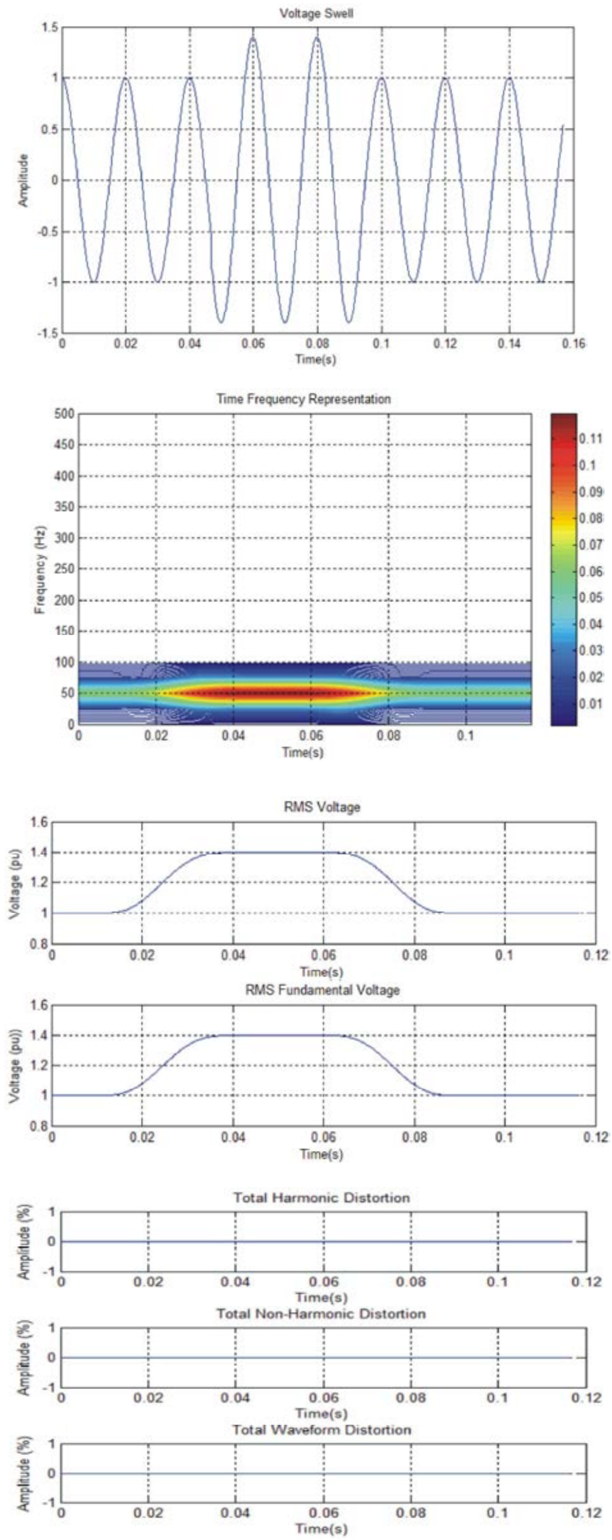
where, $x_i(n)$ is actual value, $x_m(n)$ is measured value, N is number of data

RESULTS

Simulation Results: Power quality disturbances are simulated using MATLAB and analyzed using spectrogram technique to identify their characteristics. The example of swell signal with increasing the magnitude is shown in Fig. 5(a). The TFR are obtained using Hanning window with size 256 is presented in Fig. 5(b). The red color represents the highest power of the signal while blue color indicates the lowest power. The TFR shows that the magnitude of the signal increases from 20 to 80ms and its frequency is 50 Hz. Based on the TFR, Fig. 5(c) and 5(d) show the parameters of the swell signals. Fig. 5(c) presents that a momentary voltage increase from 1.0 to 1.4pu starting at 20ms for duration of 60ms for RMS fundamental voltage and RMS voltage. For THD, TnHD and TWD, there is no value because the signals only occur at fundamental frequency which is 50Hz.

The example of signal parameters for harmonic is illustrated in Fig.6. Fig. 6(a) shows the harmonic signal in time domain while its TFR is presented in Fig. 6(b). The signal consists of two frequency components which are fundamental frequency, 50 Hz and multiple frequency components, 200Hz as indicated in contour plot. The RMS fundamental voltage and RMS voltage of the harmonic signal are shown in Fig. 6(c) respectively, constant at 1.0 pu and 1.12 pu. In Fig. 6(d), the values of THD and TWD are steady at 50% while for TnHD is zero along the axis. Therefore the figures clearly show that the signals only consist of harmonic component and the classification can be determined based on these signal parameters obtained.

By using rule-based classifier, the power quality disturbances with various characteristics are analyzed and classified. The system has classified with 100 signals of power quality disturbances at SNR from 0dB to 40dB and the percentage graph of power quality classification against SNR is plotted as shown in Fig. 7. From the graph plotted, the system achieves precise power quality classification starting point at 34 db of SNR. Interruption signal presents the high performance accuracy where it gives 100% correct at 10 db while the low performance is normal signal which indicated 100% correct at 34 db of SNR. Thus, it is proved that spectrogram is suitable to be implemented in a classification system.



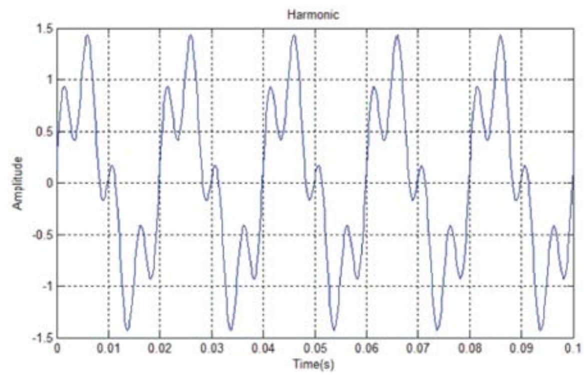
(a)

(b)

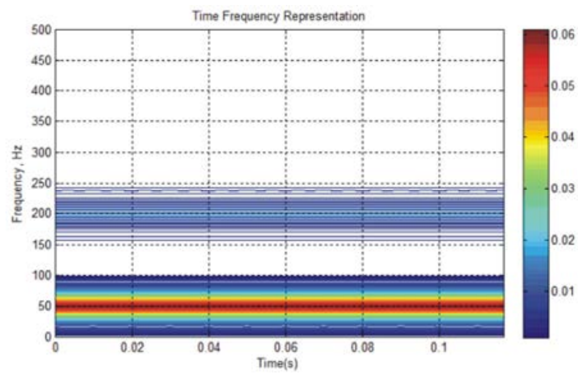
(c)

(d)

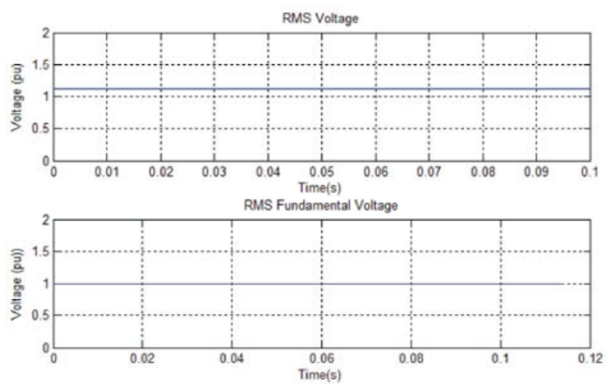
Fig. 5: (a) Voltage Swell Signal, (b) Time Frequency, Representation (TFR), (c) RMS Voltage and RMS, Fundamental Voltage, (d) Total Harmonic, Distortion (THD), Total Non-Harmonic Distortion, (TnHD) and Total Waveform Distortion (TWD)



(a)



(b)



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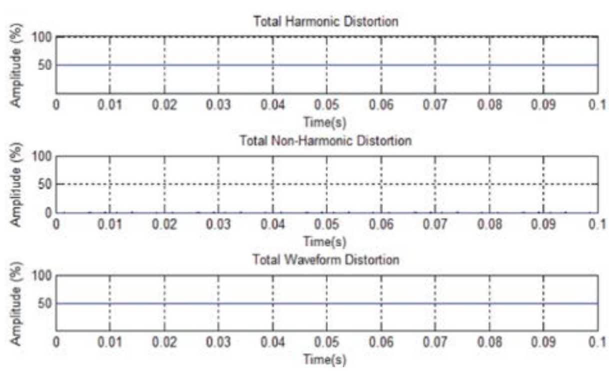


(d)

Fig. 6: (a) Harmonic Signal, (b) Time Frequency, Representation (TFR), (c) RMS Voltage and RMS, Fundamental Voltage, (d) Total Harmonic Distortion, (THD), Total Non-Harmonic Distortion (TnHD) and Total Waveform Distortion (TWD)

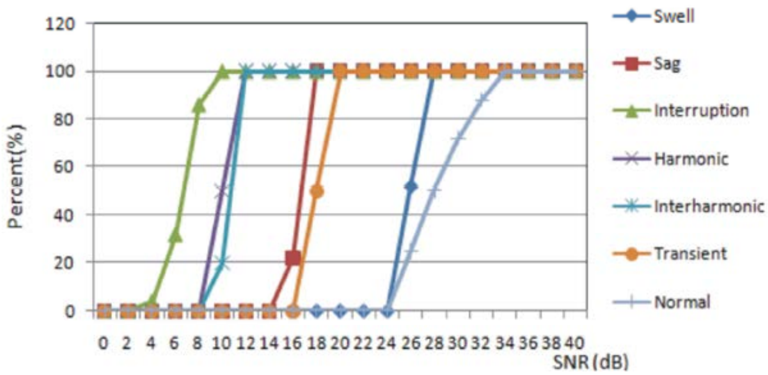
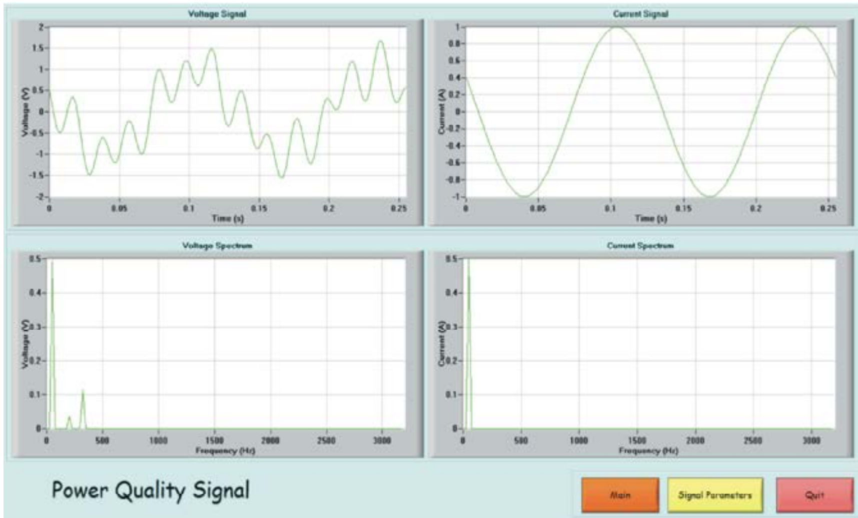


Fig. 7: The percentage of power quality classification versus SNR

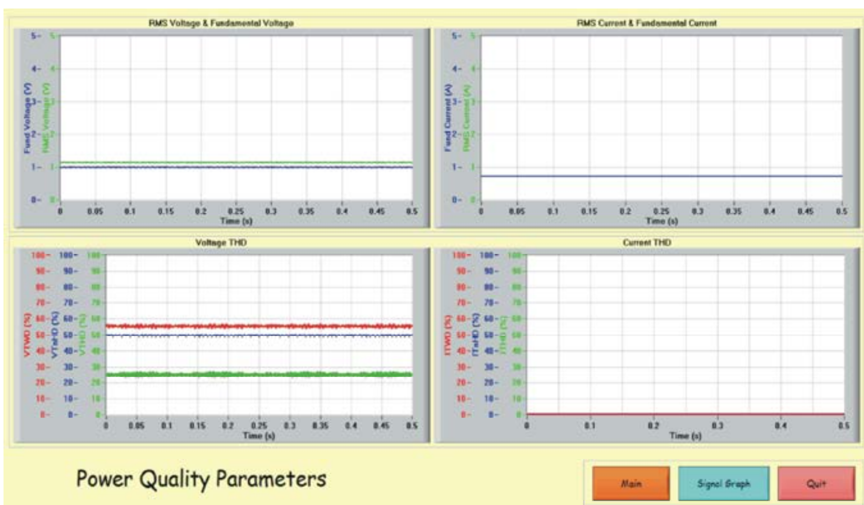
(a)

(b)

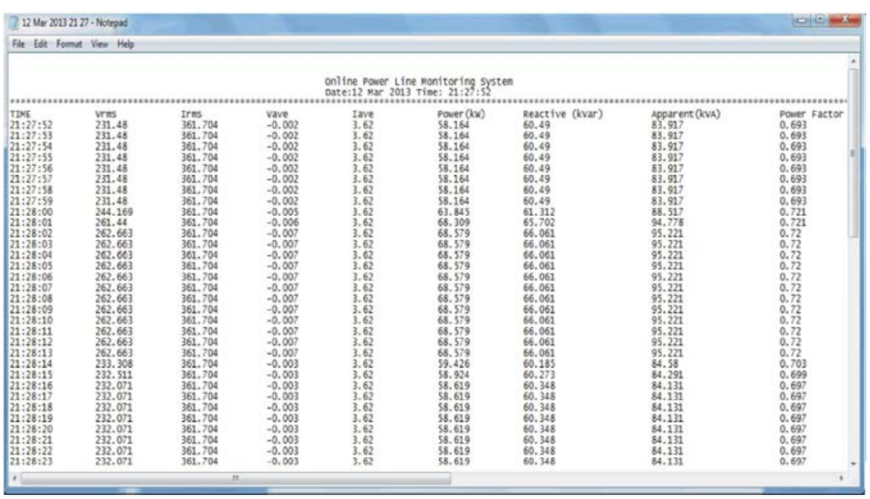
Continued Fig. 8:



(c)



(d)



12 Mar 2013 21 27 - Notepad

Online Power Line Monitoring System
Date:12 Mar 2013 Time: 21:27:52

TIME	Vrms	Irms	Vave	Iave	Power(kW)	Reactive (kVar)	Apparent(kVA)	Power Factor
21:27:52	231.48	361.704	-0.002	3.62	58.164	60.49	83.917	0.693
21:27:53	231.48	361.704	-0.002	3.62	58.164	60.49	83.917	0.693
21:27:54	231.48	361.704	-0.002	3.62	58.164	60.49	83.917	0.693
21:27:55	231.48	361.704	-0.002	3.62	58.164	60.49	83.917	0.693
21:27:56	231.48	361.704	-0.002	3.62	58.164	60.49	83.917	0.693
21:27:57	231.48	361.704	-0.002	3.62	58.164	60.49	83.917	0.693
21:27:58	231.48	361.704	-0.002	3.62	58.164	60.49	83.917	0.693
21:27:59	231.48	361.704	-0.002	3.62	58.164	60.49	83.917	0.693
21:28:00	244.169	361.704	-0.005	3.62	63.845	61.312	88.517	0.721
21:28:01	261.44	361.704	-0.006	3.62	68.309	65.702	94.778	0.721
21:28:02	262.663	361.704	-0.007	3.62	68.579	66.061	95.221	0.72
21:28:03	262.663	361.704	-0.007	3.62	68.579	66.061	95.221	0.72
21:28:04	262.663	361.704	-0.007	3.62	68.579	66.061	95.221	0.72
21:28:05	262.663	361.704	-0.007	3.62	68.579	66.061	95.221	0.72
21:28:06	262.663	361.704	-0.007	3.62	68.579	66.061	95.221	0.72
21:28:07	262.663	361.704	-0.007	3.62	68.579	66.061	95.221	0.72
21:28:08	262.663	361.704	-0.007	3.62	68.579	66.061	95.221	0.72
21:28:09	262.663	361.704	-0.007	3.62	68.579	66.061	95.221	0.72
21:28:10	262.663	361.704	-0.007	3.62	68.579	66.061	95.221	0.72
21:28:11	262.663	361.704	-0.007	3.62	68.579	66.061	95.221	0.72
21:28:12	262.663	361.704	-0.007	3.62	68.579	66.061	95.221	0.72
21:28:13	262.663	361.704	-0.007	3.62	68.579	66.061	95.221	0.72
21:28:14	233.308	361.704	-0.003	3.62	59.426	60.185	84.58	0.703
21:28:15	232.511	361.704	-0.003	3.62	58.924	60.273	84.291	0.699
21:28:16	232.071	361.704	-0.003	3.62	58.619	60.348	84.131	0.697
21:28:17	232.071	361.704	-0.003	3.62	58.619	60.348	84.131	0.697
21:28:18	232.071	361.704	-0.003	3.62	58.619	60.348	84.131	0.697
21:28:19	232.071	361.704	-0.003	3.62	58.619	60.348	84.131	0.697
21:28:20	232.071	361.704	-0.003	3.62	58.619	60.348	84.131	0.697
21:28:21	232.071	361.704	-0.003	3.62	58.619	60.348	84.131	0.697
21:28:22	232.071	361.704	-0.003	3.62	58.619	60.348	84.131	0.697
21:28:23	232.071	361.704	-0.003	3.62	58.619	60.348	84.131	0.697

(e)

Fig. 8: (a) Power quality measurement and classification, (b) Power quality measurement and classification, (c) Voltage and current signal, (d) Signal parameters, (e) Recorded data

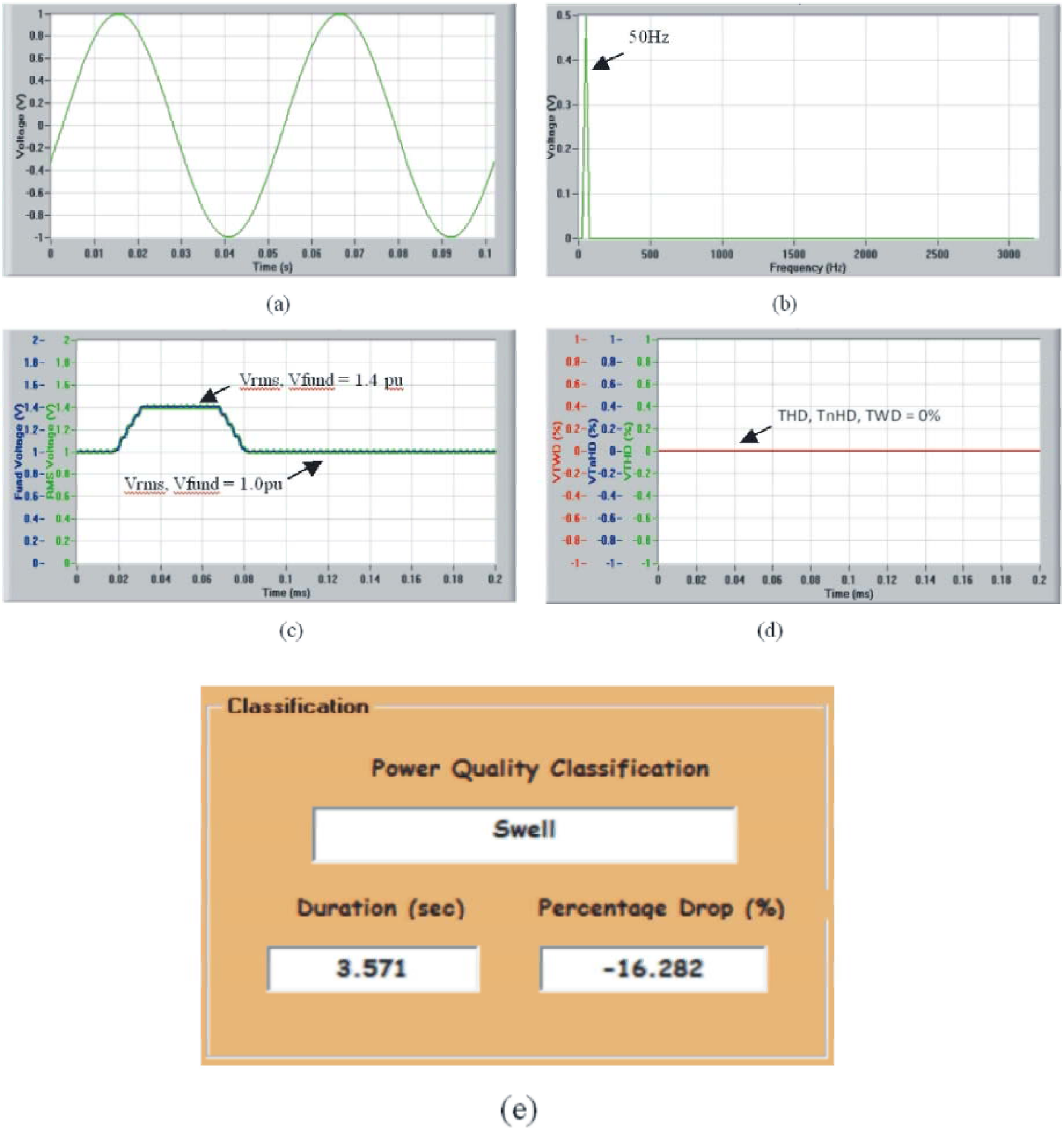


Fig. 9: (a) Swell Signal in time domain, (b) Frequency component, (c) RMS voltage and RMS fundamental voltage, (d) THD, TnHD and TWD, (e) System classification

System Results: The development GUI of the power quality disturbances detection and classification system is shown in Fig. 8(a). The system is able to measure standard power line measurements such as RMS value for voltage and current, frequency, active power, reactive power, apparent power and power factor which are illustrated in graph as shown in Fig. 8(b). The system can detect and classify the power quality disturbances as well as provides the characteristics information of the signals computes of the duration and percentage drop. In Fig. 8(c), the voltage and current signals are represented in time and frequency domain.

Besides the standard power line measurements, signal parameters such as voltage and current in RMS and fundamental, THD, TnHD and TWD can also be displayed and monitored by using the system as shown in Fig. 8(d).

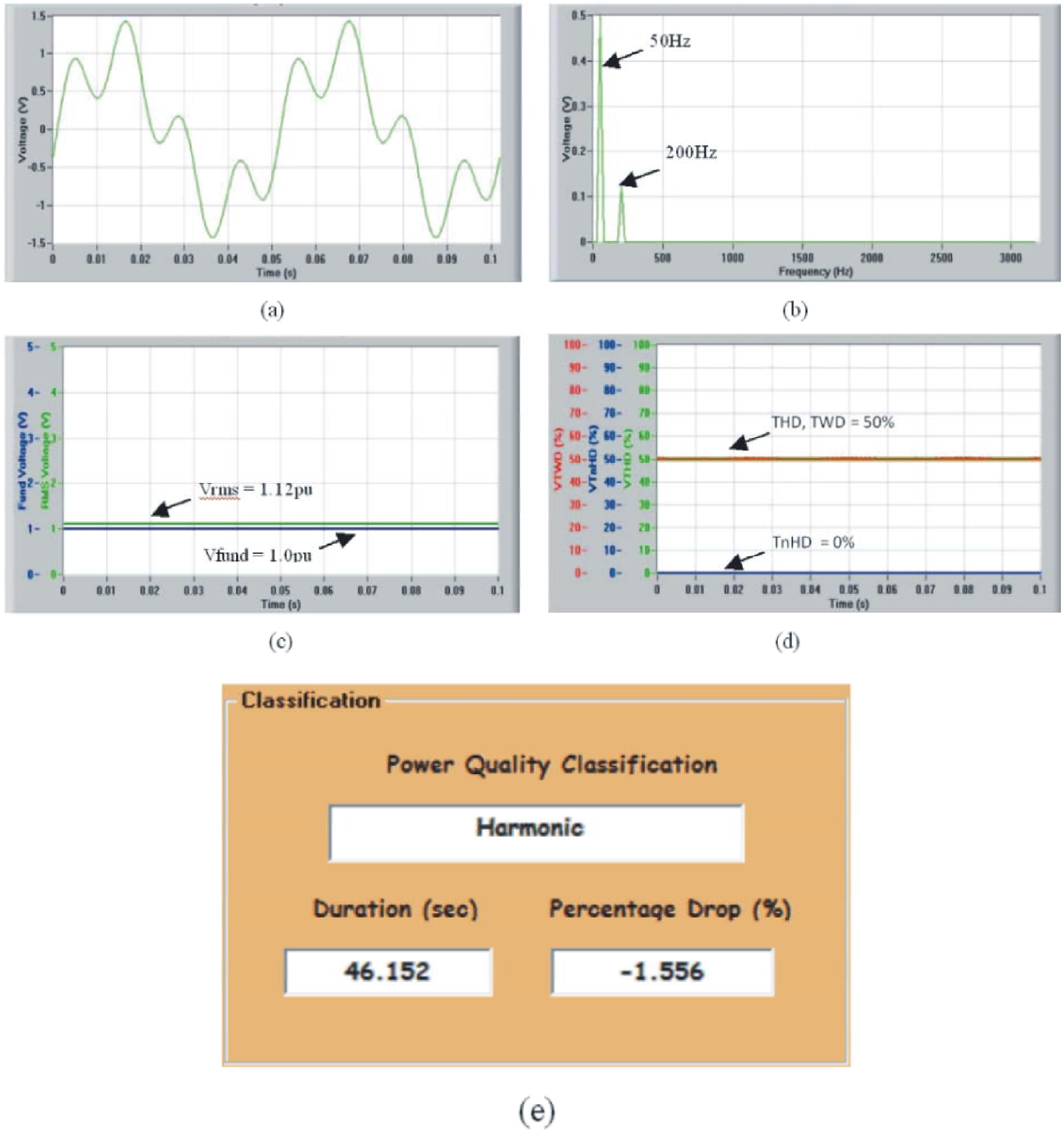


Fig. 10: (a) Harmonic Signal in time domain, (b) Frequency component, (c) RMS voltage and RMS fundamental voltage, (d) THD, TnHD and TWD, (e) System classification

The system can also be utilized to capture continuous sampling as well as collecting and recording the real time signal. The data captured is then analyzed to be stored in database as well as setting specific duration to store data into computer automatically. The example of data executed by the system had been stored in notepad and displayed in Fig. 8(e).

The system result based on the spectrogram, were carried out by GUI using Visual Basic. Based on time frequency analysis technique which is spectrogram, the parameters obtained from the power quality disturbances are showed in Fig. 9. The system provides the characteristics information of the signals. The characteristics information is then used as input for signal classification of power quality disturbances. In Fig. 9(a) shows a swell signal in time domain while its power spectrum is represented in Fig. 9(b). As presented in the power spectrum, the fundamental frequency is 50 Hz and the magnitude of the signal increases from 1.0 to 1.4 pu for both RMS and fundamental voltage from 20 to 80ms as displayed in Fig. 9(c). The value of THD, TnHD and TWD generated '0' percentage since the signal only occurs at fundamental frequency as illustrated in Fig. 9(d). The type, duration and percentage drop of the signal are also provided in the system as represented in Fig. 9(e) to give better information of the signal. The region which voltage swell happened is indicated as 3.571sec and 16.282% of percentage drop.

Other than that, the example of waveform distortion which is harmonic signal in time domain is shown in Fig. 10(a) meanwhile the signal that consists of two frequency components which are fundamental frequency, 50Hz and multiple frequency, 200Hz represented as 4th harmonic as illustrated in Fig. 10(b). In Fig.10(c), the RMS voltage and RMS fundamental voltage of the harmonic signal are, respectively, constant at 1.12 pu and 1.0 pu. There is 50% of display percentage for THD and TWD as shown in Fig. 10 (d) whereas the example of harmonic signal only consists of harmonic component, so there is no value for the TnHD. In addition, the system offered more information such as type, duration and percentage drop of the signal for classification system as displayed in GUI of the system as shown in Fig. 10(e). The region which harmonic happened is indicated as 46.152sec and 1.556% of percentage drop.

Based on the measured values for voltage and current using the system, the results obtained are comparable to the measured values using PQA. Referring to Fig. 11, 12 and 13, the measured value versus actual value for voltage, current and power measurement are illustrated in the graph. According to the graph plotted in Fig. 11 and Fig. 12, it represents voltage and current using PQA and proposed system. The voltage verification generated by PQA and proposed systems are gradually increased and value of MAPE is 0.025%. Then, for current verification produced by PQA and proposed system are steadily increased but the value of MAPE is 0.048%. The MAPE for both figure are obviously produced less than 0.05%, showing the accuracy of the system.

By analyzing the power measurement verification as shown in Fig. 13, the system is efficiently proven, whereby the calculated MAPE for active power and apparent power are 0.049% and 0.038% for reactive power.

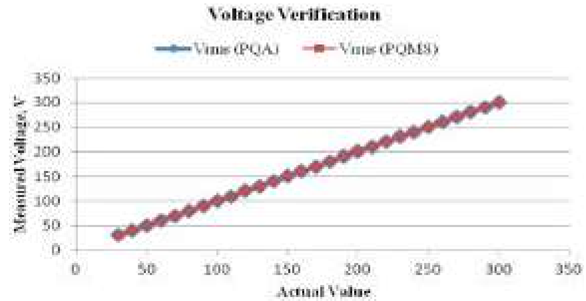


Fig. 11: Voltage and current verification

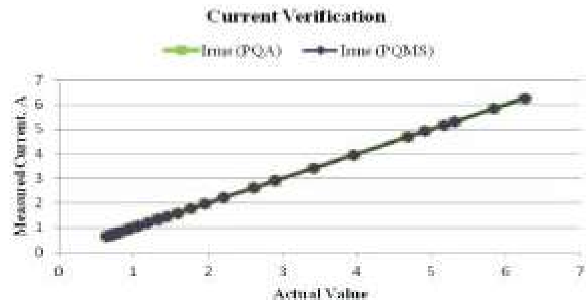


Fig. 12: Current verification

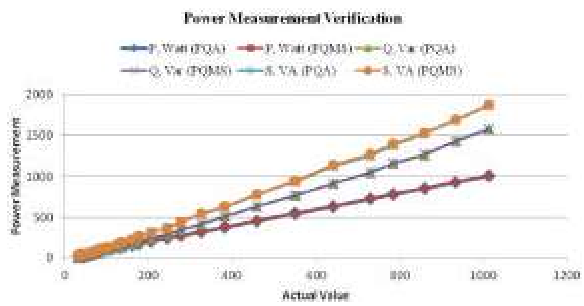


Fig. 13: Power measurement verification

The low percentage of MAPE proved the close resemblance of the value measured by proposed system with that of PQA, thus indicating the system proposed is indeed efficient.

CONCLUSION

This paper presents the simulation analysis as well as detection and classification system of power quality disturbances by using spectrogram. The signal parameters estimated from TFR are used to calculate signal characteristics and then used as an input for classification of power quality disturbances. The system can classify major types of power quality disturbances including voltage sag, swell, interruption, transient, harmonic and interharmonic. The performance of the rule-based classifier for classification process is demonstrated and verified and the result obtained give

100 percent accuracy at 34dB of SNR. Therefore, it clearly shows that time-frequency distribution (TFD) which is spectrogram is suitable to be used for classification system. An automated signal classification system using spectrogram is developed successfully to identify, classify as well as provide the information of the signal. Besides that, the system is able to show the signal including the standard power line measurements, its power spectrum and signal parameters that also can be stored in computer, automatically.

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