UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Faculty of Electrical Engineering

REAL-TIME POWER QUALITY SIGNALS DETECTION AND CLASSIFICATION SYSTEM

Noor Athira binti Abidullah

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REAL-TIME POWER QUALITY SIGNALS DETECTION AND CLASSIFICATION SYSTEM

NOOR ATHIRA BINTI ABIDULLAH

A thesis submitted
in fulfilment of the requirements for the degree of Master of Science
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DECLARATION

I declare that this thesis entitled “Real-time Power Quality Signals Detection and Classification System” is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature	:	……………………………..
Name	:	Noor Athira Binti Abidullah
Date	:	……………………………..

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APPROVAL

I hereby declare that I have read this thesis and in my opinion, this thesis is sufficient in terms of scope and quality for the award of the Master of Science in Electrical Engineering.

Signature : ……………………………………….

Supervisor Name : Dr. Abdul Rahim Bin Abdullah

Date : ………………………………………..

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DEDICATION

A million praise towards my family, my respectful supervisor, examiner and lecturers and to all my friends for their support and cooperation in helping me to complete this thesis.

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ABSTRACT

The increasing number of power electronics equipment contributes to the poor quality of electrical power supply and has become a vital concern to electricity users at all levels of usage. The power quality signals can affect manufacturing process, malfunction of equipment and economic losses. Thus, it is necessary to detect and classify different kind of power quality signals for rectify failures and ensure quality of power line signal. This research presents the analysis power quality signals using time-frequency distributions (TFDs) which are spectrogram, Gabor transform and S-transform for signals detection and classification. Since the signals consist of multi-frequency components and magnitude variation, the TFDs are very appropriate to be used that represent the signals, jointly, in time-frequency representation (TFR). From the TFR, parameters of the signals are estimated and then are used to identify the characteristics of the signals. Referring to IEEE Std. 1159-2009, the signal characteristics are obtained and then served as the input for signal classifier to classify power quality signals. Based on the analysis, the best TFD is identified in terms of accuracy of the signal characteristics, memory size and computation complexity of data processing and chosen for power quality signals detection and classification system. By simulating in MATLAB, the performance of the classification system is verified by generating and classifying 100 signals with various characteristics for each type of power quality signals. In addition, the system is also tested using 100 real signals which were recorded from a power line. The results show that, S-transform is the best TFD and the classification system gives 100 percent correct classification for all power quality signals. For the real signals, the system also presents 100 percent correct classification. Thus, the outcome of this research shows that the system is very appropriate to be implemented for power quality monitoring system.

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ABSTRAK

Peningkatan jumlah peralatan elektronik kuasa menyumbang kepada kualiti rendah bekalan kuasa elektrik dan telah menjadi perhatian penting kepada pengguna elektrik di semua peringkat penggunaan. Isyarat kualiti kuasa boleh mempengaruhi proses pembuatan, kepincangan tugas peralatan dan kerugian ekonomi. Oleh itu, adalah perlu untuk mengesan dan mengklasifikasikan pelbagai jenis isyarat kualiti kuasa untuk membetulkan kegagalan dan memastikan kualiti isyarat talian kuasa. Penyelidikan ini membentangkan isyarat analisis kualiti kuasa menggunakan taburan kekerapan masa-linear (TFDs) seperti spectrogram, transformasi Gabor dan transformasi-S untuk mengesan isyarat dan klasifikasi. Disebabkan isyarat terdiri daripada pelbagai frekuensi komponen dan magnitud, TFDs adalah sangat sesuai untuk digunakan yang mewakili isyarat bersama dalam perwakilan masa-frekuensi (TFR). Dari TFR, parameter isyarat dianggarkan dan kemudian digunakan untuk mengenal pasti ciri-ciri isyarat. Merujuk kepada IEEE Std. 1159-2009, ciri-ciri isyarat diperolehi dan kemudian berkhidmat sebagai input bagi isyarat pengelas untuk mengklasifikasikan isyarat kualiti kuasa. Berdasarkan analisis, TFD terbaik dikenal pasti dari segi ketepatan ciri-ciri isyarat, saiz memori dan kerumitan pengiraan pemprosesan data dan dipilih untuk mengesan isyarat kualiti kuasa dan sistem klasifikasi. Dengan simulasi menggunakan MATLAB, pelaksanaan sistem klasifikasi yang disahkan dengan menjana dan mengklasifikasikan 100 isyarat dengan pelbagai ciri-ciri bagi setiap jenis isyarat kualiti kuasa. Di samping itu, sistem ini juga diuji menggunakan 100 isyarat sebenar yang dicatatkan dari talian kuasa. Hasil kajian menunjukkan bahawa, transformasi-S adalah TFD yang terbaik dan sistem klasifikasi memberikan 100 peratus pengelasan yang betul untuk semua isyarat kualiti kuasa. Bagi isyarat sebenar, sistem itu juga membentangkan 100 peratus klasifikasi betul. Oleh itu, hasil kajian ini menunjukkan bahawa sistem ini adalah sangat sesuai untuk dilaksanakan untuk sistem pemantauan kualiti kuasa.

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LIST OF SYMBOLS

t	-	Time
f	-	Frequency
f_0	-	Fundamental frequency
f_s	-	Sampling frequency
Δf	-	Frequency resolution
A_k	-	Signal component amplitude
x_i	-	Actual value
x_m	-	Measured value
x_{vv}	-	Voltage variation signal
x_{wd}	-	Waveform distortion signal
x_{trans}	-	Transient signal
pu	-	Per-unit
V_{rms}	-	Root mean square voltage
V_{1rms}	-	Fundamental root mean square voltage
$T_{d,swell}$	-	Duration of swell
$T_{d,sag}$	-	Duration of sag
$T_{d,int}$	-	Duration of interruption
$T_{d,trans}$	-	Duration of transient
THD_{ave}	-	Average of total harmonic distortion
$TnHD_{ave}$	-	Average of total nonharmonic distortion
TWD_{ave}	-	Average of total waveform distortion
$x(t)$	-	Continuous time signal
$X(f)$	-	Continuous frequency response
$w(t)$	-	Window function
$\Pi(t)$	-	Box function

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LIST OF PUBLICATIONS

A. Journal

1) A. R. Abdullah, N. A. Abidullah, N. H. Shamsudin, N. H. T. H. Ahmad and M. H. Jopri, "Performance Verification of Power Quality Signals Classification System," Applied Mechanics and Materials, vol. 753, pp. 1158-1163, 2015.

2) N. A. Abidullah, A. R. Abdullah, A. Z. Sha'ameri, N. H. Shamsudin, N. H. T. H. Ahmad and M. H. Jopri, " Real-Time Power Quality Disturbances Detection and Classification System", World Applied Sciences Journal, vol. 32, no. 8,pp. 1637-1651, 2014.

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5) N. H. T. Ahamd, A. R. Abdullah, N. A. Abidullah, M. H. Jopri, "Analysis of Power Quality Disturbances using Spectrogram and S-Transform" International Review of Electrical Engineering (IREE 2014), Vol. 9, N.3, 611-619.

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B. Conference

1) N. A. Abidullah, A. R. Abdullah, N. H. Shamsudin, N. H. T. H. Ahmad, and M. H. Jopri, " Real-Time Power Quality Signals Monitoring System", 2013 IEEE Student Conference on Research and Development (SCOReD), 16-17 December 2013, Putrajaya Malaysia, pp. 16-17, 2013.

C. Exhibition

1) Awarded i-ENVEX 2015 bronze medal for the invention "Harmonic Source Identification System" at International Engineering Invention & Innovation Exhibition 2015 (i-ENVEX).

2) Awarded SIIF silver medal for the invention "Power Quality Detection and Classification System" at the Seoul International Invention Fair 2014.

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3) Awarded ITEX silver medal for the invention “Power Quality Monitoring System” at the 24th International Invention, Innovation & Technology Exhibition ITEX 2013 Kuala Lumpur, Malaysia from 9-11th May 2013

4) Awarded PECIPTA 2013 gold medal for the invention “Real-Time Power Quality Monitoring System” at International Conference and Exposition on Invention of Institutions of Higher Learning 7-9th Nov 2013

5) Awarded ENVEX 2013 gold medal for the invention “Real Time Power Quality Monitoring System (PQMS)” at International Engineering Invention & Innovation Exhibition 2013 (ENVEX).

6) Awarded ENVEX 2013 Asia Invention Association Grand Award for the invention “Real Time Power Quality Monitoring System (PQMS)” at International Engineering Invention & Innovation Exhibition 2013 (ENVEX)

7) Awarded ENVEX 2013 gold medal for the invention “Smart Traffic Light System for Emergency Vehicle” at International Engineering Invention & Innovation Exhibition 2013 (ENVEX).

8) Awarded ENVEX 2013 bronze medal for the invention “Green Energy Monitoring System” at International Engineering Invention & Innovation Exhibition 2013 (ENVEX).

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D. Others

1) M. Manap, A. R. Abdullah, N. Z. Saharuddin, N. A. Abidullah, N. S. Ahmad, and M. H. Jopri, "Performance Comparison of VSI Switches Faults Analysis Using STFT and S-transform", Applied Mechanics and Materials Journal, 2015.
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5) N. S. Ahmad, M. Manap, A. R. Abdullah, N. A. Abidullah and N. Bahari, "Voltage Source Inverter Fault Detection System using Time-Frequency Distribution", Applied Mechanics and Materials Journal, 2014.

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CHAPTER 1

INTRODUCTION

1.1 Introduction

The term power quality is, generally, applied to a wide variety of electromagnetic phenomena occurring within a power system network and has become a vital concern to electricity users at all levels of usage (Bhim Singh, Ambrish Chandra 2015). The electric power quality is also defined as a term that refers to maintaining the near sinusoidal waveform of power system at rated magnitude and frequency (Mahela et al. 2015). According to the survey, power quality signals which were, mainly, due to sensitivity of equipment to the voltage and frequency variations had caused million-dollar losses in commercial and industrial (Mittal et al. 2012). In addition to that, this has resulted in loss of time, loss of productions, loss of sales, delivery delays and damaged of production equipment. These include system equipment malfunction, computer data loss, memory malfunction, erratic operation of electronic controls, diminishing lifetime of the load, erroneous of protection devices, instabilities and interruptions in production (Saini and Kapoor 2012).

A prompt and accurate diagnosis of disturbances is needed to ensure the quality of electrical power and reduce the risk of failure. The difficulty to diagnose of power quality signals requires an engineering expertise and proficient knowledge in many areas of electrical power. Since this is, relatively, a complicated subject, it is important to

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understand the underlying of power quality signals (Srividya & Sankar 2013). There are different classifications for power quality issue, each using a specific property to categorize the disturbance (Zhang et al. 2011).

According to ANSI C84.1 standard, the most important factor is the duration of the disturbances. This is supported by IEEE-519-2014 standard which stated that the wave shape (duration and magnitude) of each disturbance is vital to classify the power quality signals (Ali Moukadem 2014). Other standard such as International Electrotechnical Commission (IEC) rely on frequency range of the disturbances for the classification

Power quality signals analysis is carried out using transformation technique. Many transformation techniques have been developed to detect and classify different kind of power quality signals. Recently, researches use digital signal processing (DSP) as techniques to assess power quality issues for its accuracy and ability to provide analysis in terms of time or frequency as well as joint time-frequency domains. These techniques have been successfully employed in other signal processing applications such as speech recognition, audio processing, communications, radars, biomedical engineering, automotive emission, sonar applications and others (Poyil 2012).

The most widely adopted approach in signal processing is spectral analysis using Fourier analysis or in other words Fourier transform. It is a tremendous technique for analyzing stationary signal as the characteristics of the signal was not affected by the change of time. However, it is unfavourable for non-stationary signal because of its inadequacy in tracking the changes in the magnitude, frequency or phase (Granados-Lieberman et al. 2011). Thus, the time-frequency representation is introduced to eliminate the limitation of this technique. There are numerous time frequency distributions techniques namely short time Fourier transform (STFT), spectrogram, Gabor transform, wavelet transform and S-transform (Mahela et al. 2015).

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