UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Faculty of Electrical Engineering

HARMONIC DISTORTION ANALYSIS IN POWER QUALITY SIGNAL USING TIME-FREQUENCY DISTRIBUTION

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A thesis submitted
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DECLARATION

I declare that this thesis entitled "Harmonic Distortion Analysis in Power Quality Signal Using Time-Frequency Distribution" 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 : ………………………………...

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Date : 30th June 2021.................................

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 Doctor of Philosophy.

Signature : ....

Supervisor Name : Associate Professor Ir. Ts. Dr. Abdul Rahim Bin Abdullah

Date : 1st July 2021

DEDICATION

Especially for my parents,

Jopri Bin Md Rawi & Aminah Binti Rahmat

My beloved wife, children & family and best friends

"*There are solutions for every problem*"

ABSTRACT

Harmonic distortion in the electrical power supply is caused by an increase in the number of power electronics devices. Harmonic distortion may have an effect on the production process, as well as economic losses and equipment failure. As a result, it is important to detect harmonic signals, identify, and to diagnose type of harmonic source in order to take precautionary measures to avoid the negative effects of harmonic distortion. Mostly, the power quality (PQ) analysis only focuses on the harmonic signal measurement, whereas it is also necessary to identify the location and type of harmonic sources with low complexity and high accuracy capability. Therefore, this research presents PQ signal analysis, detection, harmonic source identification and diagnosis method. The power quality signals consist of multi-frequency components and magnitude differences, thus, the time-frequency distribution (TFD) is very suited to present the signals within time-frequency representation (TFR) and to detect power quality signals accurately. The TFDs namely spectrogram, Gabor transform and S-transform are used in this study. The signal parameters are estimated and then are used to identify the signal characteristics based on the IEEE Standard 1159-2019. The best TFD in harmonic signal detection is identified in regards to the accuracy, calculation complexity, and memory size of signal analysis. Next, using the best TFD, the harmonic source is identified either from downstream and/or upstream of the point of common coupling (PCC) based on impedance spectral. Afterwards, five machine learning methods include k-nearest neighbour (KNN), support vector machine with linear function (SVM-L), support vector machine with radial basis function (SVM-RBF), linear discriminate analysis (LDA) and naïve Bayes (NB) are used to diagnose the harmonic sources. Three harmonic signal parameter groups which are harmonic voltage parameters, harmonic current parameters, and harmonic voltage and current parameters are examined. The performance of the detection method is verified by generating and detecting 100 multiple characteristics signals for each type of power quality signal. Meanwhile, 100 signals of harmonic sources, which are from rectifier and inverter loads with various characteristics in terms of firing angle, amplitude and frequency modulation indexes are evaluated in identification and diagnosis of the harmonic source method. The diagnosis results indicate that the LDA with harmonic voltage parameters offer the highest accuracy and fastest computation speed. To validate the proposed method, the real signals of field testing were recorded and analysed for detection, identification, and diagnosis methods. The results show that the proposed method provides high accuracy and fast computational analysis, making it ideal for use with an embedded device in detecting power quality signals, identifying, and diagnosing harmonic sources. The proposed method gives high-impact to the industry especially in reducing maintenance cost, and trouble-shoot duration of power system failure.

ANALISA HEROTAN HARMONIK DI DALAM SIGNAL KUALITI KUASA MENGGUNAKAN PENGAGIHAN MASA-FREKUENSI

ABSTRAK

Herotan harmonik dalam bekalan kuasa elektrik disebabkan oleh peningkatan jumlah peranti elektronik kuasa. Herotan harmonik boleh memberi kesan pada proses pengeluaran, serta kerugian ekonomi dan kegagalan peralatan. Akibatnya, penting untuk mengesan isyarat harmonik, mengenal pasti, dan mendiagnosis jenis sumber harmonik untuk mengambil langkah berjaga-jaga bagi mengelakkan kesan negatif dari herotan harmonik. Sebilangan besarnya, analisa isyarat kualiti kuasa (PQ) hanya tertumpu pada pengukuran isyarat harmonik, sedangkan perlu juga untuk mengenal pasti lokasi dan jenis sumber harmonik dengan kemampuan kerumitan rendah dan ketepatan tinggi. Oleh itu, penyelidikan ini berkenaan kaedah analisa, pengesanan, isyarat kualiti kuasa, pengenalpastian dan diagnosis sumber harmonik. Isyarat kualiti kuasa terdiri daripada komponen berbilang frekuensi dan perbezaan magnitud, oleh itu, pengagihan masa-frekuensi (TFD) sangat sesuai untuk menunjukkan isyarat dalam perwakilan masa-frekuensi (TFR) dan untuk mengesan isyarat kualiti kuasa dengan tepat. TFD iaitu spectrogram, Gabor transform dan S-transform digunakan di dalam kajian ini. Parameter isyarat dianggarkan dan kemudian digunakan untuk mengenal pasti ciri-ciri isyarat berdasarkan IEEE Standard 1159-2019. TFD terbaik dalam pengesanan isyarat harmonik dikenal pasti berdasarkan ketepatan, kerumitan pengiraan, dan saiz memori analisis isyarat. Seterusnya, dengan menggunakan TFD terbaik, sumber harmonik dikenal pasti sama ada dari hilir dan / atau hulu di titik gandingan sama (PCC) berdasarkan galangan spektrum. Selepas itu, lima kaedah pembelajaran mesin (ML) merangkumi k-nearest neighbour (KNN), mesin vektor sokongan linear (SVM-L), mesin vektor sokongan dengan fungsi asas jejari (SVM-RBF), analisa diskriminasi linear (LDA) dan naïve Bayes (NB) digunakan untuk mendiagnosis sumber harmonik. Tiga kumpulan parameter isyarat harmonik iaitu parameter voltan harmonik, parameter arus harmonik, dan parameter voltan dan arus harmonik diperiksa. Prestasi kaedah pengesanan disahkan dengan menghasilkan dan mengesan 100 isyarat pelbagai ciri bagi setiap isyarat kualiti kuasa. Sementara itu, 100 isyarat sumber harmonic, dari beban penerus dan penyongsang dengan pelbagai ciri dari segi sudut penembakan, indeks modulasi amplitud dan frekuensi dinilai dalam kaedah pengenalpastian dan diagnosis sumber harmonik. Hasil diagnosis menunjukkan bahawa LDA dengan parameter voltan harmonik menawarkan ketepatan tertinggi dan kelajuan pengiraan terpantas. Untuk mengesahkan kaedah yang dicadangkan, isyarat sebenar ujian lapangan direkodkan dan dianalisis untuk kaedah pengesanan, pengenalan, dan diagnosis. Hasilnya menunjukkan bahawa kaedah yang dicadangkan memberikan ketepatan tinggi dan analisa pengiraan yang pantas, menjadikannya ideal untuk digunakan bersama sistem terbenam dalam mengesan isyarat kualiti kuasa, mengenal pasti, dan mendiagnosis sumber harmonik. Kaedah yang dicadangkan memberikan impak tinggi kepada industri terutama di dalam mengurangkan kos penyelenggaraan, dan jangka masa penyelesaian masalah kegagalan sistem kuasa.

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LIST OF ABBREVIATIONS

A	-	Ampere
AC	-	Alternating current
ADSP	-	Advance digital signal processing
AI	-	Analog input
ANN	-	Artificial Neural Network
ANSI	-	American National Standards Institute
DC	-	Direct Current
DFT	-	Discrete Fourier transform
DSP	-	Digital signal processing
ELM	-	Extreme learning machine
FFT	-	Fast Fourier transform
FL	-	Fuzzy logic
FT	-	Fourier transform
GT	-	Gabor transform
Hz	-	Frequency unit, Hertz
IEC	-	International Electro-technical Commission
IEEE	-	Institute of Electrical and Electronics Engineers
KNN	-	k-nearest neighbour
LDA	-	Linear discriminate analysis

MAPE	-	Mean absolute percentage error
MATLAB	-	MATLAB software
ML	-	Machine learning
MS	-	Malaysia Standard
NB	-	Naïve Bayes
p.u	-	Per-unit system
RMS	-	Root mean square
ST	-	S-transform
STFT	-	Short time Fourier transform
SVM	-	Support vector machine
SVM-L	-	Support vector machine with linear function
SVM-RBF	-	Support vector machine with radial basis function
TFD	-	Time frequency distribution
TFR	-	Time frequency representation
THD	-	Total harmonic distortion
TnHD	-	Total nonharmonic distortion
TWD	-	Total waveform distortion
UTeM	-	Universiti Teknikal Malaysia Melaka
WT	-	Wavelet transform

LIST OF SYMBOLS

A_k	-	Signal component amplitude
$x(t)$	-	Observation window in continuous
ms	-	milliseconds
t	-	Time
f	-	Frequency
f_0	-	Fundamental frequency
fhi	-	High frequency
flo	-	Low frequency
fr	-	Frequency resolution
fs	-	Sampling frequency
$g(t)$	-	Scalable Gaussian window
$H(t)$	-	Time-smooth function
H_I	-	Inverter harmonic source
H_R	-	Rectifier harmonic source
K	-	Number of the signal components
N	-	Number of signal length
N_w	-	Number of window length
t	-	Time
$T_{d,int}$	-	Duration of interruption