



Faculty of Electrical Engineering

**VOLTAGE VARIATION SIGNALS SOURCE
IDENTIFICATION SYSTEM BY TIME-FREQUENCY
ANALYSIS TECHNIQUE**

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Master of Science in Electrical Engineering

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**VOLTAGE VARIATION SIGNALS SOURCE IDENTIFICATION SYSTEM BY
TIME-FREQUENCY ANALYSIS TECHNIQUE**

TEE WEI HOWN

**A thesis submitted
in fulfillment of the requirements for the degree of Master of Science
in Electrical Engineering**

Faculty of Electrical Engineering

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2019

DECLARATION

I declare that this thesis entitled “Voltage Variation Signals Source Identification System by Time-Frequency Analysis Technique” 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 :

Date :

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 Master of Science in Electrical Engineering.

Signature :

Supervisor Name : Assoc. Prof. Ts. Mohd. Rahimi Bin Yusoff

Date :

DEDICATION

Specially dedicated to

My beloved family,

To my respectful supervisor, co-supervisor and friends

Thank you for all the encouragement and support

ABSTRACT

The quality of power supplies has become one of the issues concern of power supply utilities and users these days. Power quality (PQ) can bring severe problems such as processing interruption within the industries, malfunction and downtime of the equipment and impact in economic losses. Voltage variation signals are the common events in power systems that will affect the equipment or load within the premise. Thus, the source identification of the voltage variation is needed to reduce the impacts caused by the variation. This research presented the analysis and detection of voltage variation signals with time-frequency distributions (TFDs) which included spectrogram, Gabor transform and S-Transform. The voltage variation signals were generated in MATLAB/Simulink according to IEEE Standard 1159-2009. Parameters of the signals were calculated from the time-frequency representations (TFRs) and used for detection of the signals. The detection of the voltage variation signals were performed by k-Nearest Neighbors (kNN), Support Vector Machine (SVM) and rule-based classifiers in which both kNN and SVM gave 100% successful signals detection while rule-based gave successful detection above 97%. Based on the analysis, the best TFD was distinguished by comparing the performance analysis of the TFDs in terms of accuracy, memory size used and computational complexity of the signal analysis. Result showed that S-Transform was the best TFD to be used to analyze voltage variation signals among the three TFDs. In the source identification analysis, voltage variation signals from upstream, downstream and both upstream and downstream were simulated and analyzed by phase TFR. The phase angle of voltage and current variation signals calculated were similar to the input angle with precision above 0.95. The average impedance TFR phase power of the signals were calculated from the phase TFR of each variation signal at each problem source. The classification accuracy of source identification was performed by kNN, SVM and rule-based classifiers. SVM showed the best performance of 94.22% overall classification accuracy followed by kNN of 93.56% while rule-based showed the worst performance among the three classifiers with overall classification accuracy of 83.44%.

ABSTRAK

Kualiti bekalan kuasa telah menjadi salah satu isu kebimbangan bekalan utiliti dan pengguna bekalan pada masa kini. Kualiti Kuasa (KK) boleh membawa masalah yang teruk seperti gangguan pemprosesan dalam industri, kerosakan dan tidak fungsi peralatan dan kesan dalam kerugian ekonomi. Isyarat variasi voltan adalah kejadian biasa dalam sistem kuasa yang akan menjejaskan peralatan atau beban di dalam premis. Oleh itu, pencarian sumber variasi voltan diperlukan untuk mengurangkan kesan yang disebabkan oleh variasi. Kajian ini membentangkan analisis isyarat variasi voltan dengan taburan kekerapan masa (TKM) yang merangkumi spectrogram, Gabor transform dan S-Transform. Isyarat variasi voltan dihasilkan dalam MATLAB / Simulink mengikut IEEE Standard 1159-2009. Parameter isyarat dikira dari perwakilan frekuensi masa (PFM) dan digunakan untuk pengesanan isyarat. Pengesanan isyarat variasi voltan dilakukan oleh K-Nearest Neighbors (kNN), Mesin Vektor Sokongan (SVM) dan pengelasan berasaskan peraturan di mana kedua-dua kNN dan SVM memberikan pengesanan isyarat sebanyak 100% manakala kaedah berasaskan peraturan memberikan pengesanan sebanyak 97 %. Berdasarkan analisis, TKM terbaik dibezakan dengan membandingkan analisis prestasi TKM dari segi ketepatan, saiz memori yang digunakan dan kerumitan komputasi analisis isyarat. Keputusan menunjukkan bahawa S-Transform adalah TKM terbaik yang digunakan untuk menganalisis isyarat variasi voltan antara ketiga-tiga TKM. Untuk analisis pengenalan sumber, isyarat variasi voltan dari hulu, hiliran dan kedua-dua hulu dan hiliran telah disimulasi dan dianalisis oleh fasa PFM. Sudut fasa voltan dan arus elektrik variasi dikira adalah sama dengan sudut input dengan ketepatan lebih daripada 0.95. Kuasa fasa impedans PFM purata isyarat dikira dari fasa PFM setiap isyarat variasi pada setiap sumber masalah. Ketepatan pengelasan pengenalan sumber dilakukan oleh kNN, SVM dan pengelasan berasaskan peraturan. SVM menunjukkan prestasi terbaik dengan 94.22% ketepatan klasifikasi keseluruhan diikuti oleh kNN dengan 93.56% manakala berasaskan peraturan menunjukkan prestasi terburuk di kalangan tiga pengelasan dengan ketepatan kelas keseluruhan sebanyak 83.44%.

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LIST OF ABBREVIATIONS

| | |
|-----------|---|
| AC | - Alternating Current |
| ANN | - Artificial Neural Network |
| Atan | - Arc Tangent |
| CR | - Computation Ratio |
| DC | - Direct Current |
| DCI | - Downstream Current Interruption |
| DCSG | - Downstream Current Sag |
| DCSL | - Downstream Current Swell |
| DFT | - Discrete Fourier Transform |
| DVSG | - Downstream Voltage Sag |
| DVSL | - Downstream Voltage Swell |
| DVI | - Downstream Voltage Interruption |
| FT | - Fourier Transform |
| FFT | - Fast Fourier Transform |
| <i>FF</i> | - Fundamental Frequency |
| <i>FN</i> | - False Negative |
| Hz | - Frequency unit, Hertz |
| I | - Current |
| IEC | - International Electrotechnical Commission |

| | |
|-----------|---|
| IEEE | - Institute of Electrical and Electronics Engineers |
| Imag | - Imaginary |
| KNN | - <i>K</i> -Nearest Neighbor |
| MAPE | - Mean Absolute Percentage Error |
| MRA | - Multi Resolution Analysis |
| MS | - Malaysian Standard |
| OSWS | - One Sample Window Shift |
| PQ | - Power Quality |
| p.u | - Per-unit System |
| R | - Resistant |
| RMS | - Root Mean Square |
| ST | - Stockwell Transform |
| STD | - Standard |
| STFT | - Short Time Fourier Transform |
| SVM | - Support Vector Machine |
| TFD | - Time-Frequency Distribution |
| TFDs | - Time-Frequency Distributions |
| TFR | - Time-Frequency Representation |
| TFRs | - Time-Frequency Representations |
| THD | - Total Harmonic Distortion |
| <i>TP</i> | - True Positive |
| TWD | - Total Waveform Distortion |
| UCI | - Upstream Current Interruption |
| UCSG | - Upstream Current Sag |

| | |
|-------|--|
| UCSL | - Upstream Current Swell |
| UDCI | - Upstream and Downstream Current Interruption |
| UDCSG | - Upstream and Downstream Current Sag |
| UDCSL | - Upstream and Downstream Current Swell |
| UDVI | - Upstream and Downstream Voltage Interruption |
| UDVSG | - Upstream and Downstream Voltage Sag |
| UDVSL | - Upstream and Downstream Voltage Swell |
| UVI | - Upstream Voltage Interruption |
| UVSG | - Upstream Voltage Sag |
| UVSL | - Upstream Voltage Swell |
| UTeM | - Universiti Teknikal Malaysia Melaka |
| V | - Voltage |
| WT | - Wavelet Transform |
| Z | - Impedance |

LIST OF SYMBOLS

| | |
|---------------|--------------------------------|
| $a(n)$ | - Actual value |
| A_m | - Signal magnitude |
| d_{st} | - Euclidean distance |
| f | - Frequency |
| f_o | - Fundamental frequency |
| f_{hi} | - High frequency |
| f_{lo} | - Low frequency |
| f_s | - Sampling frequency |
| $i(t)$ | - Input current |
| m | - Signal sequence component |
| $m(n)$ | - Measured value |
| N | - Length of the input signal |
| N_s | - Number of sample shift |
| N_w | - Number of window length |
| $STFT_x(t,f)$ | - Short time fourier transform |
| $S_x(t,f)$ | - TFR of signal |
| t | - Time |
| $T_{d,int}$ | - Duration of interruption |
| $T_{d,sag}$ | - Duration of sag |

| | |
|-----------------------|---|
| $T_{d, \text{swell}}$ | - Duration of swell |
| $THD(t)$ | - Instantaneous total harmonic distortion |
| $TWD(t)$ | - Instantaneous total waveform distortion |
| $v(t)$ | - Input voltage |
| $V_{h, rms}(t)$ | - Instantaneous RMS harmonic voltage |
| $V_{rms}(t)$ | - Instantaneous RMS voltage |
| $V_{I rms}(t)$ | - Instantaneous RMS fundamental voltage |
| $w(t)$ | - Window function |
| $x(t)$ | - Input signal interested |
| $\pi(t)$ | - Function of the signal |
| % | - Percentage |
| σ | - Gaussian window sigma parameter |
| γ | - Kernel parameter |

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