Faculty of Electrical Engineering

VOLTAGE INSTABILITY ANALYSIS OF ELECTRIC POWER SYSTEMS USING ARTIFICIAL NEURAL NETWORK BASED APPROACH

Ahmad Fateh bin Mohamad Nor

Doctor of Philosophy

2017

VOLTAGE INSTABILITY ANALYSIS OF ELECTRIC POWER SYSTEMS USING ARTIFICIAL NEURAL NETWORK BASED APPROACH

AHMAD FATEH BIN MOHAMAD NOR

A thesis submitted
in fulfillment of the requirements for the degree of Doctor of Philosophy

Faculty of Electrical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2017

DECLARATION

I declare that this thesis entitled "Voltage Instability Analysis of Electric Power Systems Using Artificial Neural Network Based Approach" 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 : Ahmad Fateh bin Mohamad Nor

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 Doctor of Philosophy.

Signature	:	.....
Supervisor Name	:	Professor Dr. Marizan bin Sulaiman
Date	:	.....

DEDICATION

To my beloved mother, father, brother and sisters.

ABSTRACT

Voltage instability analysis in electric power system is one of the most important factors in order to maintain the equilibrium of the electric power system. A power system is said to be experiencing voltage instability whenever the system is not able to maintain the voltage at all buses in the system remain the same after the system is being subjected to a disturbance. Voltage instability can lead to total system blackout. Therefore, it is important to implement voltage instability analysis in order to make sure that the voltage level at all buses is at stable state. Even though the research regarding voltage instability analysis has been carried out for decades, there is still room for improvement especially in terms of accuracy and time execution. The research work presented in this thesis is about the analysis of voltage instability of electric power system by using reactive power-voltage (QV) and real power-voltage (PV) curves. PV and QV curves are very important for calculating voltage instability indices. These voltage instability indices are voltage stability margin (VSM) and load power margin (LPM). VSM can be divided into two indices which are VSM for real and reactive power of load, VSM (P) and VSM (Q). Similarly, there are two categories of LPM which are LPM of real power and reactive power of load, LPM (P) and LPM (Q). Besides that, modal analysis technique is used in this research for determining the weakest load buses in the electrical power system. This research will explore the implementation of real power (P) modal analysis technique in addition to the reactive power (Q) modal analysis technique. It was found that reactive power (Q) of load gives more effects towards the stability of the system voltages than real power (P) of load. Subsequently, Artificial Neural Network (ANN) and Adaptive Neuro-Fuzzy Inference System (ANFIS) are used for providing the target values of VSM (P), VSM (Q), LPM (P) and LPM (Q). The accuracy and computing time of both ANN and ANFIS are being recorded and compared. The research showed that the accuracy and computing time of ANFIS are better than ANN's. Finally, Probabilistic Neural Network is applied for classifying the voltage instability indices. IEEE 14, 30 and 39-Bus Test Power System were selected as the reference power systems in this research. The load flow analyses were simulated by using Power World Simulator software version 16. Both Q and P modal analysis were done by using MATLAB application software.

ABSTRAK

Analisa ketidakstabilan voltan dalam sistem kuasa elektrik adalah salah satu faktor yang paling penting untuk mengekalkan keseimbangan dalam sistem kuasa elektrik. Sesebuah sistem kuasa dikatakan mengalami ketidakstabilan voltan apabila sistem tersebut tidak mampu untuk memastikan nilai voltan pada semua bas dalam sistem tidak berubah selepas sistem tersebut mengalami gangguan. Ketidakstabilan voltan boleh menyebabkan terputusnya bekalan elektrik secara besar-besaran. Oleh itu, keperluan untuk menganalisis ketidakstabilan voltan adalah sangat pentimg bagi memastikan tahap voltan di semua bas berada pada keadaan stabil. Walaupun penyelidikan mengenai analisa ketidakstabilan voltan telah dijalankan sejak beberapa dekad yang lalu, masih terdapat ruang untuk penambahbaikan terutama dari segi ketepatan dan masa pelaksanaan. Kerja-kerja penyelidikan yang dibentangkan di dalam tesis ini adalah mengenai analisa ketidakstabilan voltan sistem kuasa elektrik dengan menggunakan lengkungan kuasa aktif-voltan (PV) dan kuasa reaktif-voltan (QV). Lengkungan PV dan QV adalah sangat penting untuk mengira indeks ketidakstabilan voltan. Indeks-indeks ketidakstabilan voltan tersebut adalah margin kestabilan voltan (VSM) dan margin kuasa beban (LPM). VSM ini boleh dibahagikan kepada dua indeks iaitu VSM untuk kuasa sebenar, VSM (P) dan VSM untuk kuasa reaktif, VSM (Q). Begitu juga untuk LPM di mana terdapat dua kategori LPM iaitu LPM untuk kuasa sebenar, LPM (P) dan LPM untuk kuasa reaktif, LPM (Q). Selain itu, teknik analisis modal digunakan dalam kajian ini untuk menentukan bas beban yang paling lemah di dalam sistem kuasa elektrik. Kajian ini akan meneroka pelaksanaan teknik analisis modal kuasa sebenar (P) sebagai tambahan kepada teknik analisis modal kuasa reaktif (Q). Adalah didapati daripada kajian ini bahawa beban kuasa reaktif (Q) memberi lebih kesan ke arah kestabilan voltan di dalam system dibandingkan dengan beban kuasa sebenar (P). Berikutnya, Artificial Neural Network (ANN) dan Inference Adaptive Neuro-Fuzzy System (ANFIS) digunakan untuk meramalkan nilai sasaran VSM (P), VSM (Q), LPM (P) dan LPM (Q). Ketepatan dan masa pelaksanaan oleh ANN dan ANFIS direkodkan dan dianalisa. Kajian menunjukkan bahawa ketepatan dan masa pengiraan ANFIS adalah lebih baik daripada ANN. Akhir sekali, Probabilistic Neural Network (PNN) digunakan untuk mengklasifikasikan indeks ketidakstabilan voltan. IEEE 14, 30 dan 39 sistem kuasa telah dipilih sebagai sistem kuasa rujukan dalam kajian ini. Analisis aliran beban telah disimulasikan dengan menggunakan perisian Power World Simulator versi 16. Kedua-dua Q dan analisis modal P telah dilakukan dengan menggunakan perisian aplikasi MATLAB.

ACKNOWLEDGEMENTS

Alhamdulillah, all the praises and thanks be to Allah for all of His infinite blessings.

First and foremost, I would like to express my sincere acknowledgement to my supervisor, Prof. Dr. Marizan bin Sulaiman for his excellent supervision and never-ending support. His guidance and advices are very helpful and useful in completing this research. I could not have imagined having a better supervisor for my study. Furthermore, special thanks are in order to my co-supervisor, Dr. Aida Fazliana binti Abdul Kadir for her kind guidance and great cooperation.

I would also like to express my gratitude to the Universiti Teknikal Malaysia Melaka (UTeM) especially to the Faculty of Electrical Engineering and to the Centre of Graduate Studies for giving me the opportunity to pursue the degree of Doctor of Philosophy (PhD.) in this beautiful university. Nevertheless, all of the UTeM staffs also deserve my appreciation, as they work hard to help the students to reach their goals.

Besides that, I would like to thank the Ministry of Higher Education Malaysia for providing the financial support under the MyBrain15 program. Sincere thanks to all of my friends especially my lab mates in the Energy and Power System (EPS) Research Laboratory, Center of Excellent for Robotics and Industrial Automation (CeRIA) for all the help, friendships and sweet memories.

Last but most importantly, my deepest gratitude goes to the closest people to my heart, my beloved parents, Associate Prof. Dr. Mohamad Nor bin Mohamad Than and Mrs. Norlida binti Shaharuddin, my brother Ahmad Fadhli, my sister in law Dr. Akmal Hanisah, my sister Nabila, my niece Faiha Adreena and all of my family members for their endless love, prayers, supports, motivation, patience, care and encouragement. Thank you very much once again to every single person who directly or indirectly contributed to this research.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES