ABSTRACT

Voltage instability has become a major concern in many power systems around the world, and it has been recognized that many of the blackouts that have been reported are caused by voltage instability due to gradual voltage collapse. The problem has been aggravated recently because electric power utilities are forced to transmit maximum power through existing networks due to tighter budgets and that additionally, excessive restrictions have been put in place by regulators for environmental reasons, which make extension of current transmission systems more expensive.

In this thesis, several techniques for voltage stability analysis are described and applied to the IEEE 14-bus, IEEE 30-bus systems (as a benchmark) and the National Grid of Sudan. The most common methods used in static voltage stability analysis have been considered; these are the L-index, modal analysis, V-Q sensitivity analysis, voltage change index and continuation power flow method in order to detect weak buses and/or areas in the power systems which are likely to cause a voltage collapse or a blackout. The weak buses or areas which are prone to voltage collapses in the IEEE 14-bus, IEEE 30-bus systems and the Sudan National Grid have been identified using computer simulation. The validity of the results has been confirmed through detailed comparison of the results for the five different methods mentioned above. The simulation results obtained from these five different methods lead to similar conclusions in most of the cases with some degree of discrepancy. Comparison of the five methods was discussed and it has been found that the L-index offered the simplest method with minimum computational effort and with good agreement with most of the other methods. It was also found that the Q-V sensitivity method was not able to differentiate

between different stability modes, and it could be misleading when applied to a large system having more than one area.

مستخلص

أصبح عدم استقرار الجهد مصدر قلق كبير في كثير من أنظمة القدرة في مختلف أنحاء العالم ، وكان من المسلم به أن كثيرا من انقطاع التيار الكهربائي التام ناتج عن عدم استقرار الجهد بسبب الانهيار التدريجي للجهد. المشكلة تفاقمت في الآونة الأخيرة ، وذلك لأن مستخدمى القدرة يضطرون لنقل القدرة القصوى من خلال الشبكات القائمة بسبب تشديد الميزانيات والقيود المفرطة التي وضعت من قبل المنظمين لأسباب بيئية ، الأمر الذي يجعل من تمديد شبكات النقل الحالية أكثر تكلفة تحتوى هذة البحث على العديد من التقنيات والادوات المستخدمة لتحليل استقرار الجهد الساكن فى نظم القدرة الكهربائية ، ووصف تطبيقها على IEEE 14-bus, IEEE 30-bus (كاساس للمقارنة) والشبكة القومية (سودان). ينظر البحث لمعظم الاساليب المستخدمة فى تحليل جهد الاستقرار مثل الرقم القياسى ل ، تحليل النمط (مودل) ، تحليل الحساسية V-Q، موشر تغير الجهد ،وطريقة إستمرارية تدفق الجهد وذلك لكشف نقاط و/أو المناطق فى منظومة القدرة التى من المرجح أن تؤدى الى الانهيار أو انقطاع الجهد الكهربى التام.وفضلاً عن ذلك ،فأن ضعف النقاط او المناطق التى هى عرضة لانهيار الجهد الكهربائى فى IEEE 14-bus, IEEE 30-bus والشبكة القومية بالسودان والتى قد تم تحديدها باستخدام المحاكاة بالحاسوب. نم نأكيد صحة النتائج من خلال المقارنة التفصيلية لهذة النتائج بالنسبة للطرق الخمس المختلفة المذكورة أعلاه. نتائج المحاكاة التى تم التحقيق عنها فى الخمس طرق المختلفة تعطى نتائج متماثلة فى معظم الحالات مع درجة من الاختلاف. تم مقارنة الخمس طرق أعلاه لاختيار أفضل الطرق حيث وجد الرقم القياسى ل أعطى طريقة مبسطة مع تقليل المجهود الحسابى ومع اتفاق تام مع بقية الطرق الاخرى. وجد ان تحليل الحساسية غير قادر على التميز بين اساليب الاستقرار المختلفة؛ كما انهامضللة عنداستخدمهافى انظمة كبيرة تتكون عدة مناطق.

ACKNOWLEDGEMENTS

This work has been carried out at Sudan University of Science and Technology department of Electrical Engineering. I would like to thank my supervisor Professor Alamin Hamoda for his guidance and support during all these years.

First and foremost, I would like to express my sincere appreciation and deep gratitude to Co-supervisor Dr. A/Rahman Ali Karrar for his continuous, patient and excellent associate supervision through out my Ph.D. research. The successful completion of all research tasks would not have been possible if not for the consistent guidance of my mentor Dr. Karrar. I am especially thankful to Dr. Grain Phillip Adam for providing insights to solve my problems in research and giving comments on my thesis. Special thanks are extended to Dr. Kamal Ramdan, Dr. Tahani A/Alla Amro Kambal and Mohammed Bashir Bello for their encouragement and help. I am very grateful to all the people who have supported me during the pursuit of my Ph.D. degree. This work would not have been possible without their encouragement and help.

Acknowledgement is extended to University of Khartoum, College of Engineering, Department of Electrical & Electronic Engineering, for providing an internship opportunity in protection laboratory during my research. I wish to extend my acknowledgement to Computer Man College (CMC) for a good working environment and Sudan National Grid (SNG), for providing me the data.

I would like to mention the encouragement from all my colleagues PH.D. Studends, in particular, Mohamed Osman, A/aziz Yousif, Nagam Mustafa Abdo and Hag Ahmed Yousif for providing me a lot of papers and references. I also would like to thank the staff of Sudan University of Science and Technology department of Electrical Engineering, for providing the stimulating atmosphere.

Finally, I would like to thank my family for their unfailing love and constant support in all my endeavors. Most of all, I am grateful to my dearest wife, Rabab Mahdi, for without her support and understanding this work would not have been complete.

TABLE OF CONTENTS

LIST OF FIGURES

FIGURE **Page**

LIST OF TABLES

TABLE **Page**

LIST OF ABBREVIATIONS

CPF	Continuation Power Flow
CPF-VS	Continuation Power Flow and/or Voltage Stability Analysis
CPU	Central Process Unit
DFC	Data Format Conversion
DVR	Dynamic Voltage Restorer
EMT	Electromagnetic Transient Analysis
EPRI	Electric Power Research Institute
EST	Educational Simulation Tool
FACTS	Flexible AC Transmission Systems
HVDC	High Voltage Direct Current
GNE	Graphical Network Editor
GUI	Graphical User Interface
MatEMTP	Electromagnetic Transient Program in Matlab
IEEE	Institute of Electrical and Electronics Engineers
IEE	Institution of Electrical Engineers
OPF	Optimal Power Flow
PAT	Power Analysis Toolbox
PF	Power Flow
PSAT	Power System Analysis Toolbox
PST	Power System Toolbox
SNG	Sudan National Grid
SPS	Sim Power Systems
SSA	Small-Signal Stability Analysis
STATCOM	Static Synchronous Compensator
SVC	Static VAR Compensator
TD	Time-Domain Simulation
UDMs	User Defined Models
ULTC	Under-load Tap Changing
WSCC	Western System Coordinating Council
VST	Voltage Stability Toolbox

LIST OF SYMBOLS

λ	Eigenvalue
J	Jacobian matrix
J_R	Reduce Jacobian matrix