

# 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 مستخدمي 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 تحتوي هذه البحث على العديد من التقنيات والادوات المستخدمة لتحليل استقرار الجهد الساكن في نظم القدرة الكهربائية ، ووصف تطبيقها على IEEE 14-bus, IEEE 30-bus (كاساس للمقارنة) والشبكة القومية (سودان). ينظر البحث لمعظم الاساليب المستخدمة في تحليل جهد الاستقرار مثل الرقم القياسي ل ، تحليل النمط (مودل) ، تحليل الحساسية V-Q ، مؤشر تغير الجهد ، وطريقة إستمرارية تدفق الجهد وذلك لكشف نقاط و/أو المناطق في منظومة القدرة التي من المرجح أن تؤدي الى الانهيار أو انقطاع الجهد الكهربى التام. وفضلاً عن ذلك ،فأن ضعف النقاط او المناطق التي هي عرضة لانهيار الجهد الكهربائى فى IEEE 14-bus, IEEE 30-bus والشبكة القومية بالسودان والتي قد تم تحديدها باستخدام المحاكاة بالحاسوب. نم نأكيد صحة النتائج من خلال المقارنة التفصيلية لهذه النتائج بالنسبة للطرق الخمس المختلفة المذكورة أعلاه. نتائج المحاكاة التي 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 القياسي ل أعطى طريقة مبسطة مع تقليل المجهود الحسابى ومع اتفاق تام مع بقية الطرق الاخرى. وجد ان تحليل الحساسية غير قادر على التمييز بين اساليب الاستقرار المختلفة؛ كما انها مضللة عند استخدامها فى أنظمة كبيرة تتكون عدة مناطق.

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## 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

|           |                        |
|-----------|------------------------|
| $\lambda$ | Eigenvalue             |
| $J$       | Jacobian matrix        |
| $J_R$     | Reduce Jacobian matrix |