International Journal of Electrical and Computer Engineering (IJECE)
Vol. 5, No. 2, April 2015, pp. 189~197
ISSN: 2088-8708

Voltage Stability Analysis and Stability Improvement of Power System

Pavithren Thannimalai, Raman Raghu Raman, Pratap Nair, K. Nithiyananthan
Faculty of Engineering and Computer Technology, AIMST University
Bedong, Kedah, Malaysia
Email: pratapsamrat@gmail.com, raman_raguraman@aimst.edu.my, nithiieee@yahoo.co.in

Article Info

Article history:

Received Nov 22, 2014
Revised Jan 26, 2015
Accepted Feb 10, 2015

Keyword:

Continuation
Power flow analysis
Power system
Reactive power
Voltage collapse
Voltage stability

ABSTRACT

The main objective of this research work is to analysis the voltage stability of the power system network and its improvement in the network voltage stability of a power system. A system enters a state of voltage instability when a disturbance, increase in load demand, or change in system condition causes a progressive and an uncontrollable drop in voltage or voltage collapse. The continuing increase in demand for electric power has resulted in an increasingly complex, interconnected system, forced to operate closer to the limits of the stability. This has necessitated the implementation of techniques for analyzing and detecting voltage collapse in bus bar or lines prior to its occurrence. Simple Newton Raphson algorithm based voltage stability analysis has been carried out. Matlab based simulations for all the factors that causes voltage instability has been implemented and analyzed for an IEEE 30 bus system. The proposed model is able to identify the behavior of the power systems, network under various voltage stability conditions and its possibility of recovery/stability improvement of the power system network has been discussed.

Corresponding Author:

Dr K. Nithiyananthan
Faculty of Electrical and Computer Engineering,
AIMST University
Bedong, Kedah
email: nithiieee@yahoo.co.in, nithi@aimst.edu.my

1. INTRODUCTION

The voltage stability problem is now a serious concern to the electric utility industry. Electric power utilities today are facing many challenges due to ever-increasing complexity in their operation and structure. In the recent years, one of the problems that receive wide attention is the voltage instability. With an open-access market, poorly scheduled generation for the competitive bidding is one of many reasons for voltage instability problem in the deregulated electricity environment. Thus, in order to relieve or at least minimize the system from the voltage instability problem many electric utilities and researchers have devoted a great deal of efforts in system studies related to static voltage stability. In the static voltage stability study, Continuation Power Flow (CPF) and optimization methods are the main analysis techniques and they are used to find voltage stability margin or loading margin (LM) of the system. Utilities and researchers are developing software based on these techniques, for the study. The CPF technique involves in solving a series of load flow calculation with predictor and corrector steps. The optimization technique involves in solving equations of necessary conditions based on an objective function and constraints. Many large interconnected power systems are experiencing abnormally high or low voltages and voltage collapse. These voltage problems are associated with the increased load of transmission lines, insufficient local reactive supply, and the shipping of power across long distances. The heart of the voltage stability problem is the voltage drop that occurs when the power system experiences a heavy load, and one serious type of voltage instability is voltage collapse. Voltage collapse is characterized by an initial slow progressive decline in the voltage magnitude of the power system buses and a final rapid decline in the voltage magnitude. The tripping of fairly small generators could, if they are placed in positions that need voltage support (voltage weak positions), cause a large increase of reactive power losses in the transmission network. This causes large voltage drops which can generate stability problems. Two examples are the 1970 New York disturbance and the disturbance at Zealand in Denmark 1979. In the New York disturbance, an increased loading on the transmission system and a tripping of a 35 MW generator resulted in a post-contingency voltage decline. At Zealand, a tripping of the only unit in the southern part of the island producing 270 MW caused a slow voltage decline in that part. After 15 minutes the voltages had declined to 0.75 pu, making the synchronization of a 70 MW gas turbine impossible. Both systems were saved by manual load shedding. The collapse in Canada, in B. C Hydros north coast region in July 1979 is also interesting in this respect [1, 2, 3].

A loss of 100 MW load along a tie-line connection resulted in an increased active power transfer between the two systems. The generators close to the initial load loss area were on manual excitation control (constant field current), which aggravated the situation. When voltages started to fall along the tie-line due to the increased power transfer, the connected load decreased proportionally to the voltage squared. This increased the tie-line transmission even more since there was no reduction in the active power production. About one minute after the initial contingency, the voltage in the middle of the tie-line fell to approximately 0.5 Pu and the tie-line was tripped due to over current at one end and due to a distance relay at the other. The heart of the voltage stability problem is the voltage drop that occurs when the power system experiences a heavy load, and one serious type of voltage instability is voltage collapse. Voltage collapse is characterized by an initial slow progressive decline in the voltage magnitude of the power system buses and a final rapid decline in the voltage magnitude. named after Isaac Newton and Joseph Raphson, is a method for finding successively better approximations to the roots (or zeroes) of a real-valued function. In the proposed voltage stability analysis the Newton–Raphson method has been implemented because of its accuracy in approximation. In voltage stability, accuracy in predicting the voltage margin is critical because low accuracy may lead to fatality of the whole system.

2. RESEARCH METHOD

The heart of the voltage stability problem is the voltage drop that occurs when the power system experiences a heavy load, there are few tools can be used to simulate the power system load flow. In the static voltage stability study, Continuation Power Flow (CPF) and optimization methods are the main analysis techniques and they are used to find voltage stability margin or loading margin (LM) of the system. The CPF technique involves in solving a series of load flow calculation with predictor and corrector steps. The optimization technique involves in solving equations of necessary conditions based on an objective function and constraints. Voltage instability occurs when the reactive power available to a portion of the grid falls below that required by customers, transmission lines, and transformers in that portion of the grid. The period of "instability" is not so much an instable as it is the behavior and interaction of various elements following the instant when the reactive shortage first develops and until intervention occurs, voltage collapse occurs, or, hopefully, a stable voltage is reached. This period of "slow dynamics" involves generator excitation limiting controls, on-load tap changers, operator actions, and the response of customer loads to decaying voltage (e.g., thermostats and manual activities that respond to the decaying voltage and attempt to restore the load to its original demand in spite of decaying voltage). As voltage decays, the resulting drop in customer load allows continued operation. However, the action of distribution transformer on-load-tap changers and self-restoring load elements pull voltage ever lower. While voltage may stabilize in systems with relatively strong ties to healthy neighbors, others will require heroic action by operators or under voltage load shedding to prevent voltage collapse. To overcome or predict this voltage collapse, the voltage stability analysis technique will be used to predict or analyze the system. The result of analysis will be used to give remedial to prevent it from further damage to the system. The analysis can be done based on the power flow equation in power system. Based on the power flow equation, the simulation will be done using Matlab. In the simulation all the factors that cause voltage instability can be implemented when analyzing the simulation of voltage stability. The analysis will be done based on IEEE 30 bus system (Figure 1) [4, 5, 6, 7].

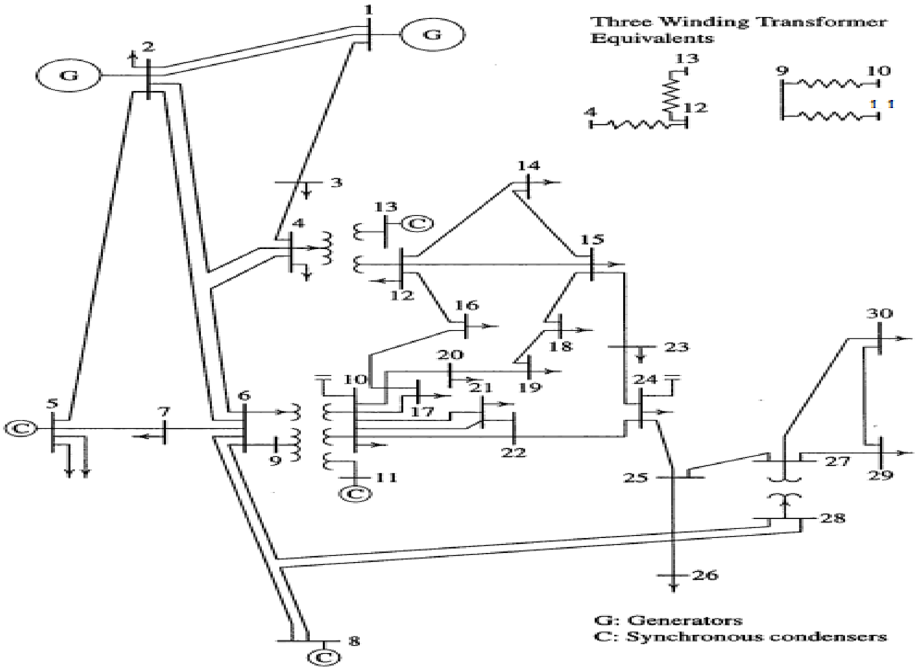


Figure 1. IEEE 30 bus system

As shown in figure the bus 10 and bus 24 has capacitor banks injecting reactive power to support the system. The analysis has been carried out in four sections in which are section 1 and section 3 with the capacitor banks of bus 10 and bus 24 supporting the system and in the section 2 and section 4 without the capacitor banks. This analysis will help to know the sensitivity of the voltage stability influenced by the capacitor banks in the system. The reactive power (Q) of each bus will be increased by 20% until it reaches the 400%. Then the reading of the voltage magnitude (V) of the bus and the nearest bus connected to it has been tabulated and graph plotted. Similarly selected bus reactive power (Q) was increased simultaneously, then the changes to the voltage magnitude (V) of the buses.

3. VOLTAGE STABILITY CASES AND SIMULATION RESULTS

Voltage stability analysis has been carried out in the selected the buses are selected based on active power greater than15 MW. In the proposed power system network, 5 buses to be analyzed are Bus 2, 5, 7, 8 and 21. The analysis will be done by increasing the Q on bus 5. The data going to analysis are, the increase in Q, the changes on the voltage magnitude of bus 5 and the changes on the voltage magnitude of bus connected to bus 5 which are bus 2 and bus 7.

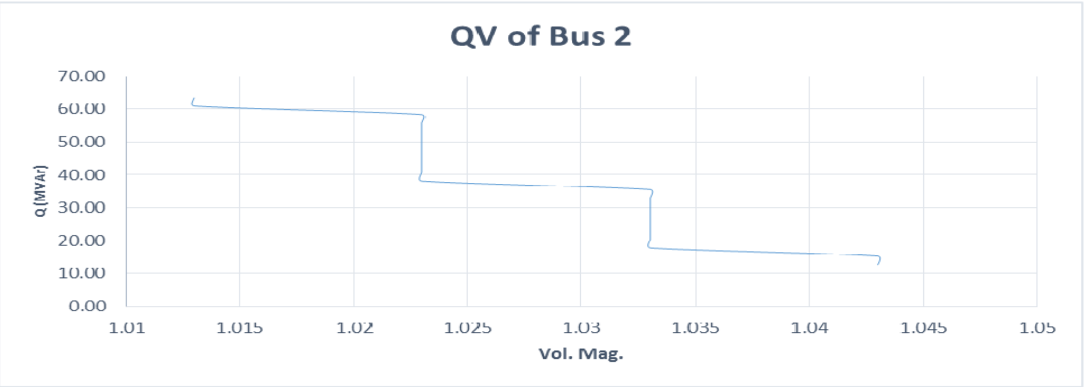


Figure 2. QV of Bus 2 with reactive power injection

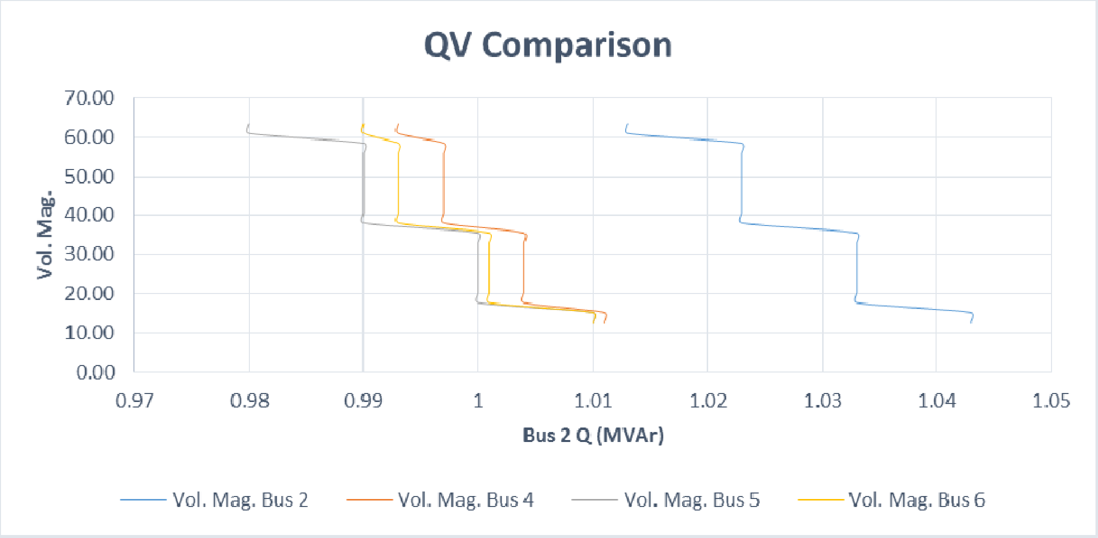


Figure 3. QV Comparison of Bus 2 with reactive power injection

Bus 2 is a generating bus on the 30 bus systems. These generating buses are usually very stable and do not prone to any voltage instability. The initial reactive power load at bus 2 was 12.7 MVAr and it was increased by 400% till it reaches 63.5 MVAr. The voltage magnitude is not affected much as its drops 1.043 V to 1.013 V. It doesn't go close to voltage instability. The buses connected to bus 2 are bus 4, 5 and 6. Due to stable voltage at bus 2 these buses are also not being affected much.

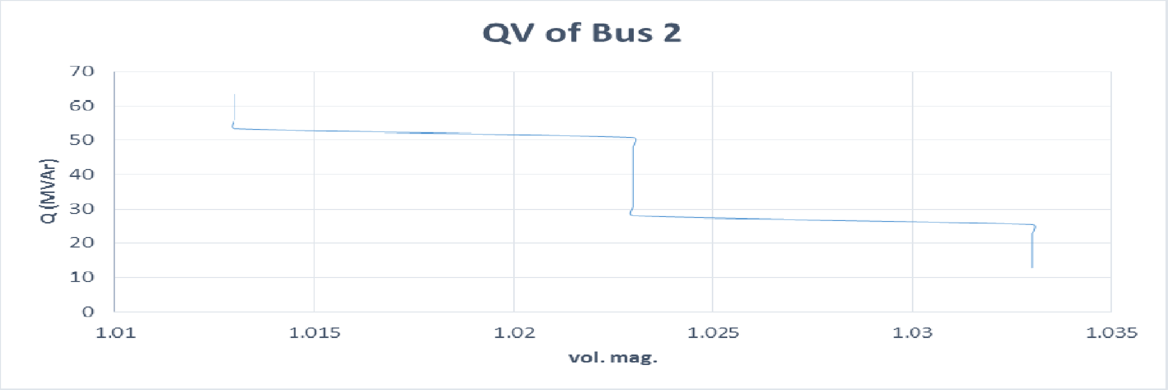


Figure 4. QV of Bus 2 without reactive power injection

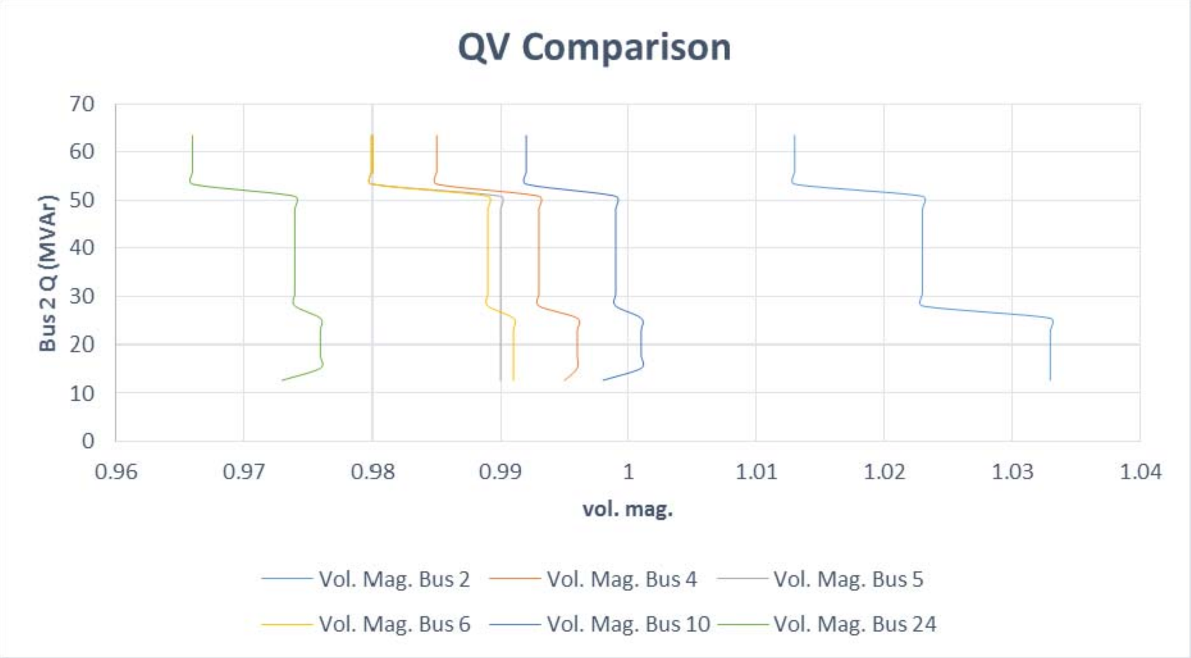


Figure 5. QV Comparison of Bus 2 without reactive power injection

It has been identified that there is a significant drop in the voltage magnitude of all the analyzed buses without the reactive power injection. But bus 2 still able to operate in a stable condition. If this condition continuously for long hours there might be some damage to the generator of bus 2 as it's operates at higher load and produces more heat.

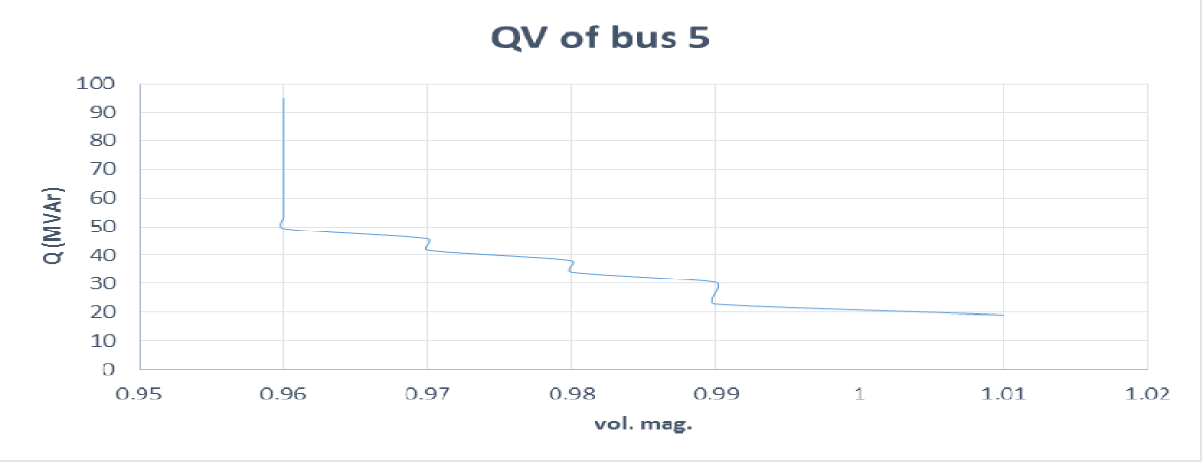


Figure 6. QV of Bus 5 with reactive power injection

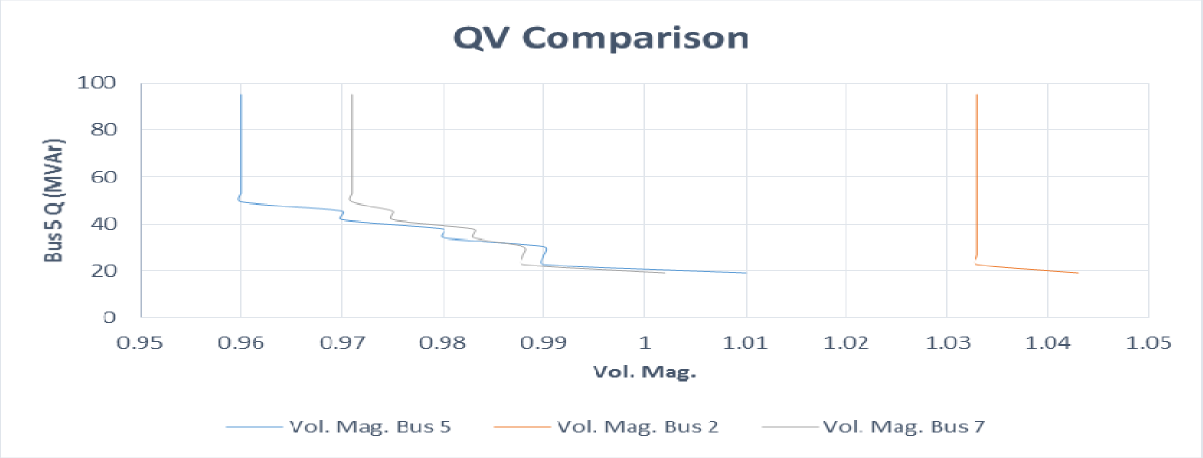


Figure 7. QV Comparison of Bus 5 with reactive power injection

Bus 5 reactive power load was increased from 19 MVAr to 95 MVAr. The voltage magnitude drop is 1.01 to 0.96 V. After the increase of 160% of reactive power which is 49.4 MVAr the voltage magnitude of bus 5 does not drop. This is due to the synchronous condenser connected to bus 5. Synchronous condenser is a device that can inject and absorb reactive power based on the situation of the system. The bus connected to bus 5 is bus 2 and 7. There is no significant drop in the voltage of bus 2 whereby in the bus 7 there was a drop but it become constant after the bus 5 voltage magnitude become constant.

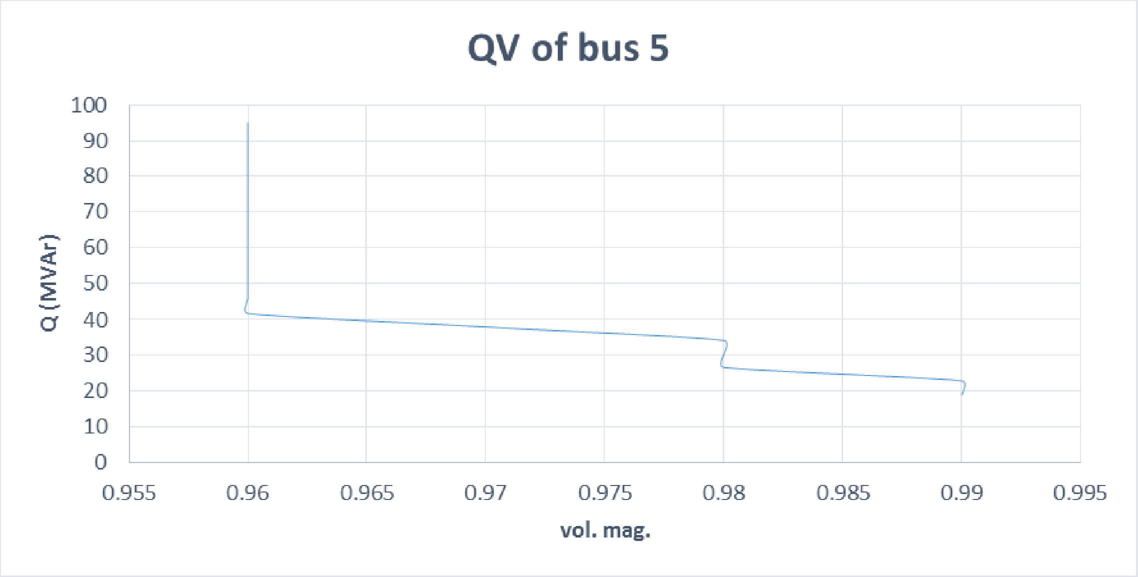


Figure 8. QV of Bus 5 without reactive power injection

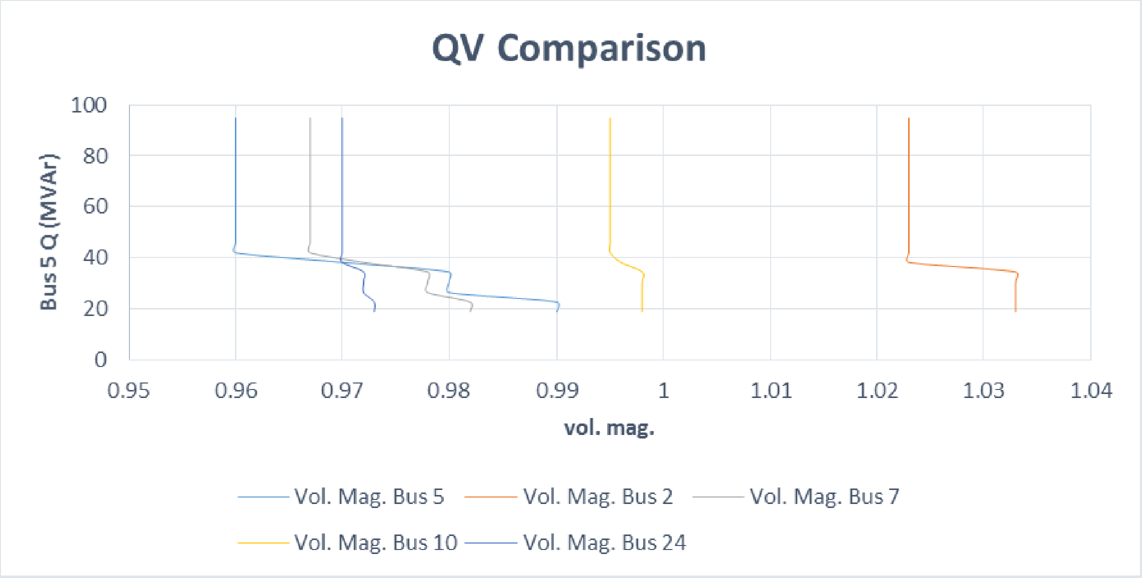
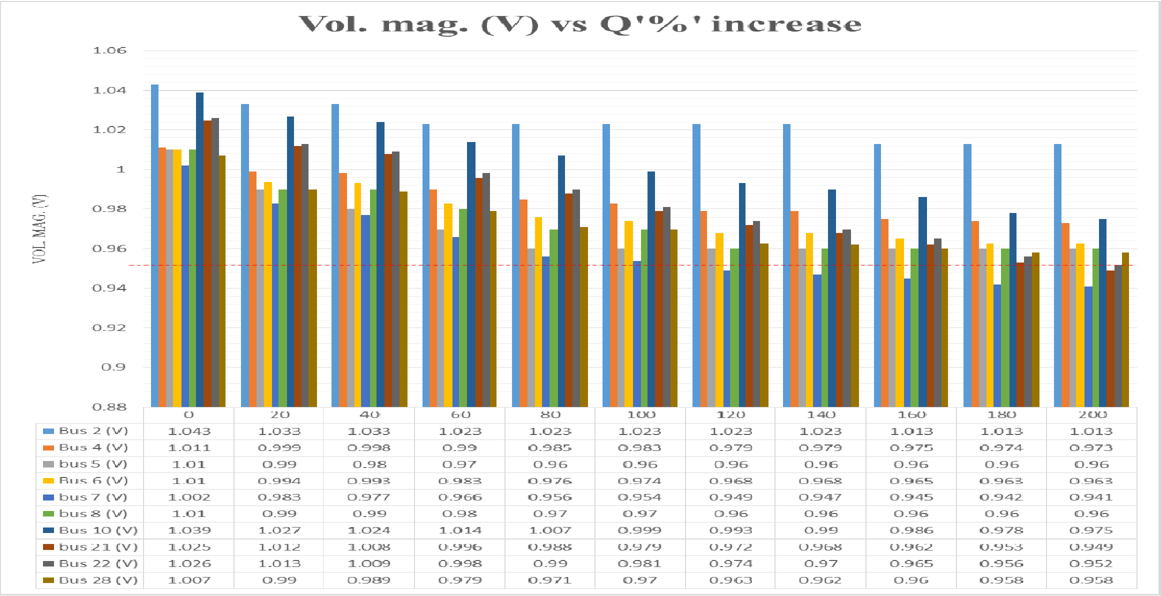


Figure 9. QV Comparison of Bus 5 without reactive power injection

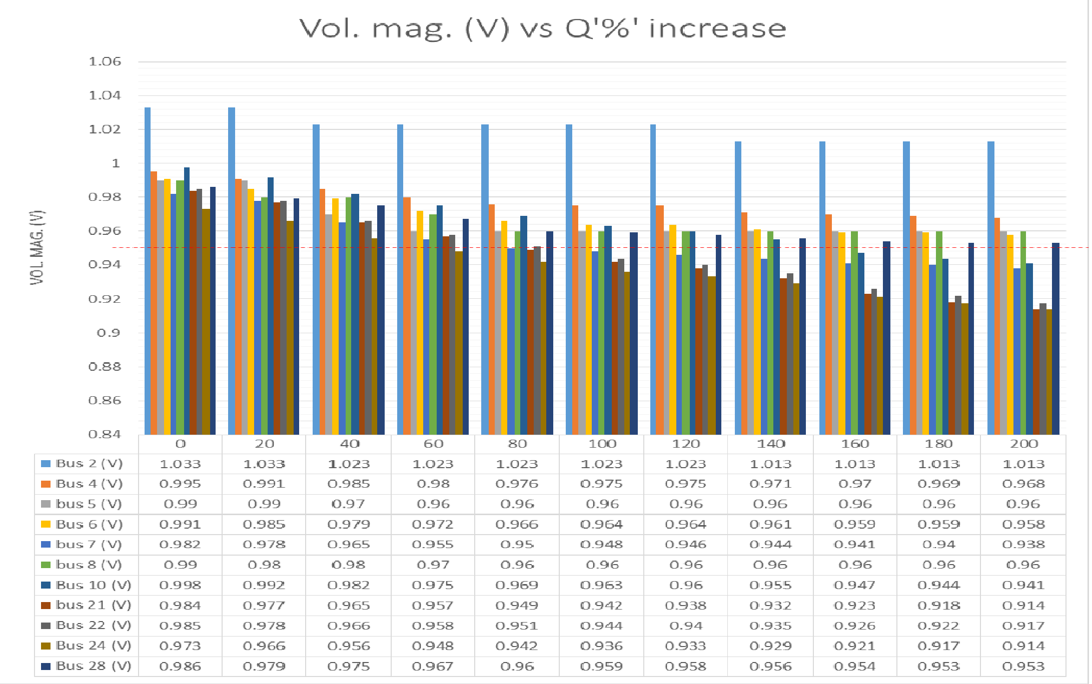
Due to bus 10 and bus 24 does not have any direct connection and it's from the bus 5, it does not give any noticeable changes on the reading as they are almost the same. Similar analysis has been carried out on remaining selected buses to analyize the system's resistance to voltage instability, its capacity limit, the changes in the voltage magnitude of the bus and the effect on other nearest buses connected to it.



	0	20	40	60	80	100	120	140	160	180	200
Bus 2 (V)	1.043	1.033	1.033	1.023	1.023	1.023	1.023	1.023	1.013	1.013	1.013
Bus 4 (V)	1.011	0.999	0.998	0.99	0.985	0.983	0.979	0.979	0.975	0.974	0.973
bus 5 (V)	1.01	0.99	0.98	0.97	0.96	0.96	0.96	0.96	0.96	0.96	0.96
Bus 6 (V)	1.01	0.994	0.993	0.983	0.976	0.974	0.968	0.968	0.965	0.963	0.963
bus 7 (V)	1.002	0.983	0.977	0.966	0.956	0.954	0.949	0.947	0.945	0.942	0.941
bus 8 (V)	1.01	0.99	0.99	0.98	0.97	0.97	0.96	0.96	0.96	0.96	0.96
Bus 10 (V)	1.039	1.027	1.024	1.014	1.007	0.999	0.993	0.99	0.986	0.978	0.975
bus 21 (V)	1.025	1.012	1.008	0.996	0.988	0.979	0.972	0.968	0.962	0.953	0.949
Bus 22 (V)	1.026	1.013	1.009	0.998	0.99	0.981	0.974	0.97	0.965	0.956	0.952
Bus 28 (V)	1.007	0.99	0.989	0.979	0.971	0.97	0.963	0.962	0.96	0.958	0.958

Figure 10. QV Comparison of all the analyzed bus with reactive power injection

Above graph shows the comparison of all the buses analyzed. Here the reactive power increased until 200% only compare to the 400% increase in part 1 and part 2. Since all the 5 buses reactive power (Q) were increased simultaneously it will give more impact on the system, thus the increase of reactive power were lowered to 200%. In this case, as you can see bus 6 and bus 21 were the only buses collapsed were bus 6 collapses at reactive were increased more than 100% and bus 21 at 180%. Overall, the increase in reactive power of a bus not only affects its own bus, but affects all the buses connected nearby to it.



	0	20	40	60	80	100	120	140	160	180	200
Bus 2 (V)	1.033	1.033	1.023	1.023	1.023	1.023	1.023	1.013	1.013	1.013	1.013
Bus 4 (V)	0.995	0.991	0.985	0.98	0.976	0.975	0.975	0.971	0.97	0.969	0.968
bus 5 (V)	0.99	0.99	0.97	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96
Bus 6 (V)	0.991	0.985	0.979	0.972	0.966	0.964	0.964	0.961	0.959	0.959	0.958
bus 7 (V)	0.982	0.978	0.965	0.955	0.95	0.948	0.946	0.944	0.941	0.94	0.938
bus 8 (V)	0.99	0.98	0.98	0.97	0.96	0.96	0.96	0.96	0.96	0.96	0.96
Bus 10 (V)	0.998	0.992	0.982	0.975	0.969	0.963	0.96	0.955	0.947	0.944	0.941
bus 21 (V)	0.984	0.977	0.965	0.957	0.949	0.942	0.938	0.932	0.923	0.918	0.914
Bus 22 (V)	0.985	0.978	0.966	0.958	0.951	0.944	0.94	0.935	0.926	0.922	0.917
Bus 24 (V)	0.973	0.966	0.956	0.948	0.942	0.936	0.933	0.929	0.921	0.917	0.914
Bus 28 (V)	0.986	0.979	0.975	0.967	0.96	0.959	0.958	0.956	0.954	0.953	0.953

Figure 11. QV Comparison of all the analyzed buses with reactive power injection

In this case the capacitor banks were removed, thus the system is more vulnerable to instability. Here more buses were collapsed. The impact being served to the bus connected nearby to the capacitor banks. As you can see bus 10 and bus 24 collapsed with low percentage of increase in the reactive of all the buses.

The prevention of voltage collapse has been divided into two sections which are the system design measures. In the system design measures, the things will be looking into are the changes that can be implemented in the design of an existing power system or a new power system to prevent voltage collapse. In the system operating measures, the things that will be looked into being the measures can be taken on an operating power system and prevent it from collapsing [8. 9. 10, 11].

3.1 The System Design Measures

(i) Application of reactive power-compensating devices

- The size, ratings, locations of the compensating devices should be based on a detailed study of the system during all different system conditions
- The design of compensating devices criteria should be based on maximum allowable voltage drop
- Recognize the voltage control areas and the weak transmission boundaries of the system
- There are different types of reactive power compensating devices:
  Shunt capacitor, regulated shunt compensation, series capacitor

(ii) Coordination of protection/controls

- Lack of coordination between equipment protections/controls and power system requirements. Adequate coordination should be ensured based on dynamic simulation studies.
- Tripping of equipment to prevent an overloaded condition should be the last resort. Wherever possible, adequate control measures (automatic or manual) should be provided for relieving the overload condition before isolating the equipment from the system.

(iii) Control of transformer tap changer

- Tap changers can be controlled, either locally or centrally, so as to reduce the risk of voltage collapse. Where tap changing is damaging, a simple method is to block tap changing when the source side voltage drops, and unblock when the voltage recovers.
- Microprocessor-based ULTC controls offer virtually unlimited flexibility for implementing ULTC control strategies so as to take advantage of the load characteristics.

3.2 The System Operating Measures

(i) Stability margin

- The system should be operated with an acceptable voltage stability
- There are at present no widely accepted guidelines for selection of the degree of margin before the system goes unstable
- For example, in my research I have made assumption that "if a voltage magnitude of a bus decreased below than 0.95 voltage magnitude, the bus is considered collapsed and fail to meet the demand of the power system".
- If the required margin cannot be met by using available reactive power resources and voltage control facilities, additional generating units have to be started up to provide voltage support at critical areas.

(ii) Spinning reserve

- The spinning reactive power reserve of each generator must be known
- It can help the operators to predict on how much power each generator can supply
- The spinning reserve must be maintained for emergency used "in the event of sudden demand of reactive power"

(iii) Operator's action

- Operators must be able to recognize and identify any voltage stability symptoms and take appropriate remedial which should solve the problem or limit the damage.
- The operators must be constantly monitored and analysis the system to identify potential voltage stability problems and possible counteractive measures to overcome the problems.

In this section, it is explained the results of research and at the same time is given the comprehensive discussion. Results can be presented in figures, graphs, tables and others that make the reader understand easily [2], [5]. The discussion can be made in several sub-chapters.

4. CONCLUSION

Reactive power is inversely proportional to the voltage magnitude of a bus. Increase on reactive power load on a bus stresses the particular bus and causes the voltage to drop, if this condition continues the particular bus will collapse. This can be overcome by connecting synchronous condenser to the bus as you can see on the bus 5 and bus 8. Capacitor banks on a system have a major impact on the systems stability. As we removed the capacitor banks for the part 2 analyses the system had two major failures. The constant injection of reactive power gives the system a stable flow of power. In part 3, we can conclude that increase in reactive power of more than one bus can have major impact on the whole power system. The increase in the reactive power on a particular bus affects all the nearest bus connected to the particular affected bus. As for the part 4, removing of the capacitor banks made the system weaker. The system becomes unstable for small increase of reactive power of all the buses. In this analysis, we can conclude that major increase in reactive power will have severe impact the bus connected to the load and may stress the whole system.

REFERENCES

[1] Byung Ha Lee and Kwang Y. Lee. Senior Member Department of Electrical and Computer Engineering The Pennsylvania State University. *A study on voltage collapse mechanism in electric power systems.*

[2] "IEEE at a Glance > IEEE Quick Facts". *IEEE*. December 31, 2010. Retrieved August 14, 2013.

[3] "IEEE 2012 Annual Report". *IEEE*. October 2011. Retrieved May 5, 2013.

[4] Jan Veleba University of West Bohemia in Pilsen, Regional Innovation Centre of Electrical Engineering, Pilsen, Czech Republic, e-mail: jveleba@rice.zcu.cz

[5] Jose O. Pessanha, 7th july 2005, Testing a differential algebric equation solver in long term voltage stability simulation.

[6] K.S. Sastry Musti, University of West Indies, musti.sastry@sta.uwi.edu, Ricardo B. Ramkhelawan, University of West Indies, ricardo.ramkhelawan@gmail.com - *Power System Load Flow Analysis using Microsoft Excel.*

[7] Mohd Shahimi Bin Mohamad Isa, University Malaysia Pahang, *Power Flow Analysis Software Using Matlab.*

[8] N Biglari, Iran, *Static and dynamic assessment of voltage stability.*

[9] Scott greene, Ian Doboson. USA, IEEE,vol12,feb-1997, *Sensitivity of loading margin to voltage collapse with respect to arbitrary parameters.*

[10] Stefan johanson & Fredrik siogren, SWEDEN, *Voltage collapse in power system_theinfluence of generator current limiter, on load tap changers and load dynamics.*

[11] The History of CIGRE – *A key player in the development of electric power system since 1921.*