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POWER SYSTEM VOLTAGE STABILITY ANALYSIS

Abdul Samad Khan[1], Ms Alka Thakur[2]
[1]M.Tech Student of SSSUTMS , [2] Assistant Professor,
[1]Department of Electrical Engineering,
[2]Head of Department of Electrical Engineering,
[1,2] Satya Sai University of Technology and Medical Sciences, Sehore, INDIA

Abstract— Power system is facing new challenges as the present system is subjected to severely stressed conditions. Voltage instability is a quite frequent phenomenon under such a situation rendering degradation of power system performance. In order to avoid system blackouts, power system is to be analysed in view of voltage stability for a wide range of system conditions. In voltage stability analysis, the main objective is to identify the system maximum loadability limit and causes of voltage instability. Static voltage stability analysis with some approximations gives this information. Voltage stability problem is related to load dynamics and therefore different load characteristics are to be considered in the voltage stability analysis In this work, the first objective is to find out the maximum load ability limit by using various methods. Initially, the maximum load ability limit is calculated by using P-V and Q-V curve methods. However these two methods are quite time consuming because of successive power flow studies. To reduce computational time, continuation power flow method is used and it also provides information about voltage sensitive buses. From these methods, buses with least stability margin are identified as critical buses. The second objective of this work is to find out the causes of voltage instability. Modal analysis is performed and critical buses, critical lines are identified using participation factors. For critical buses, Q-V curves are generated and their reactive power margins are calculated to crosscheck the modal analysis result. Voltage stability indices which provides an accurate information about line and bus stability conditions are studied for various loading scenarios. The different voltage stability indices are calculated and compared for IEEE standard 14 bus system.

***Keywords — P-V and Q-V curve ,* Load Tap Changers**

I. INTRODUCTION

The Modern power systems are operating under very stressed conditions and this is making the system to operate closer to their operating limits. Operation of power system is becoming difficult owing to the following reasons:

- Increased competition in power sector.
- Social and environmental burdens; resulting to limited expansion of transmission network.
- Lack of initiatives to replace the old voltage and power flow control mechanisms.
- Imbalance in load-generation growth.

All these factors are causing power system stability problems. A power system operating under stressed conditions shows a different behavior from that of a non-stressed system. As the system is operating close to the stability limit, a relatively small disturbance may causes the system to become unstable. As the power system is normally a interconnected system, it's operation and stability will be severely affected [15].

II. VOLTAGE STABILITY PROBLEM

Voltage stability problem is significant since it affects the power system security and reliability. Voltage stability [1] is related to the "ability of a power system to maintain acceptable voltages at all buses under normal conditions and after being subjected to a disturbance". Definitions proposed by various authors related to voltage stability are mentioned in Chapter 2. Voltage instability is a periodic, dynamic phenomenon. As most of the loads are voltage dependent and during disturbances, voltages decrease at a load bus will cause a decrease in the power consumption. However loads tend to restore their initial power consumption with the help of Distribution Voltage Regulators, Load Tap Changers (LTC) and thermostats. These control devices try to adjust the load side voltage to their reference voltage. The increase in voltage will be accompanied by an increase in the power demand which will further weaken the power system stability. Under these conditions voltages undergo a continuous decrease, which is small at starting and leads to voltage collapse.

When a single machine is connected to a load bus then there will be pure voltage instability. When a single machine is connected to infinite bus then there will be pure angle instability. When synchronous machines, infinite bus and loads are connected then there will be both angle and voltage instability but their influence on one another can be separated [2]. The dynamics involved in voltage instability are restricted to load buses with LTC, restorative loads etc.,. These load voltage control devices are operated for few minutes to several minutes. So, generator dynamics can be substituted by appropriate equilibrium conditions. Under stressed conditions, coupling between voltage and active power is not weak [3]. So, insufficient active power in the system also leads to voltage instability problems [11].

III. LITERATURE REVIEW

The fundamental concepts of power system modeling and operation are discussed in [6]. The stability problems involved in power system operation are well presented in [1]. Types of voltage stability and factors affecting it are well explained in [3] [7].

Voltage stability and Rotor angle stability problems occurs in same time-frame and thus both are interlinked. Although both are interlinked, in many cases, one form of instability predominates. The relation between rotor angle stability and voltage stability is explained in [2] [7].

There are various methods [8] used for static voltage stability analysis. The most applied method for indicating voltage stability limit is by calculating system load margin.

The two most widely used indicators are real power (P) margin, and the reactive power (Q) margin.

In P-V curve [3], real power at a bus or area is gradually increased by keeping power factor constant. Successive power flow studies are done until the bifurcation point or nose point is reached. The points above the nose point corresponds to stable operating condition. We can use continuation power flow method to find the solutions below the operating point, which is not necessary. In this curve the nose point represents the maximum real power loading point. Real power margin is the distance between present operating point to critical operating point. Since power flow calculations are involved in generating P-V curves, it takes lot of time for large networks. P-V curves gives only proximity to critical point but no information about causes of voltage stability problem.

Reactive power margin is computed by using Q-V curve [6]. For scheduled bus voltages, the reactive power to be injected or drawn is calculated from successive power flow. The reactive power margin is the difference of reactive power at present operating point and minimum reactive power. The calculated reactive power margin is helpful to find the size of shunt compensator. Similarly to the P-V curve, Q-V curve also provides no information about key contributing factors to voltage stability problem and computational time is also high.

Minimum singular value method proposed by Thomas and Lof [9]is used to calculate the voltage stability margin by observing how close is the Jacobian matrix to become singular. In the analysis, load value is increased in steps and power flow Jacobian matrix J is calculated. Whenever the smallest singular value of J reaches zero, it is inferred that loadability limit is reached. This method however , cannot find the specific causes for voltage instability. Although it gives relative proximity to voltage stability limit but isnot a absolute or linear measurement. This is due to the non-linear behavior shown by the system after stable operating point up to the bifurcation point.

IV. CLASSIFICATION OF POWER SYSTEM STABILITY

A definition of power system stability as given in [1] is: Power system stability is the ability of an electric power system, for a given initial operating condition, to regain a state of operating equilibrium after being subjected to a physical disturbance, with most system variables bounded so that practically the entire system remains intact. Classification of power system stability [1] is shown in Figure 1.

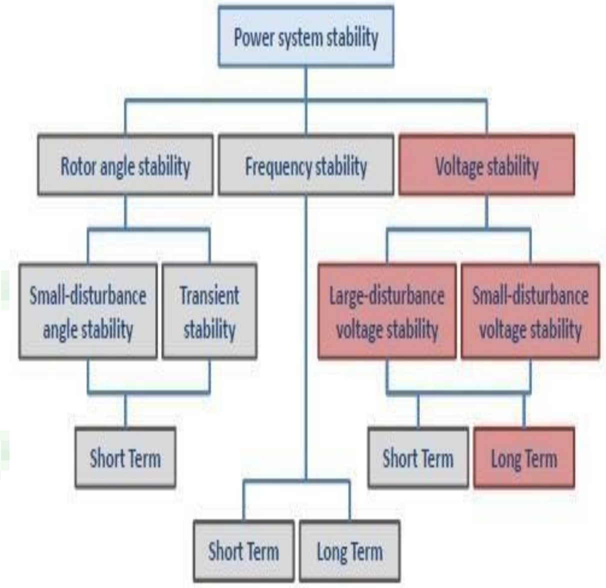

Fig. 1 Classification of power system stability [1]

A. Definitions of Voltage Stability

In literature several definitions of voltage stability are found which are based on time frames, system states, size of disturbance etc. During voltage instability, a broad spectrum of phenomena will occur.

B. Definitions according to CIGRE

CIGRE [1] defines voltage stability in a general way similar to other dynamic stability problems. According to CIGRE,

- A power system at a given operating state is small-disturbance voltage stable if, following any small disturbance, voltages near loads are identical or close to there-disturbance values.
- A power system at a given operating state and subject to a given disturbance is voltage stable if voltages near loads approach post-disturbance equilibrium values. The disturbed state is within the region of attraction of the stable post- disturbance equilibrium.
- A power system undergoes voltage collapse if the post-disturbance equilibrium volt- ages are below acceptable limit.

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V. CAUSES OF VOLTAGE INSTABILITY

There are three main causes of voltage instability:

A. Load dynamics: Loads are the driving force of voltage instability. Load dynamics are due to the following devices

B. Load tap changing (LTC) transformer role [16] is to keep the load side voltage in a defined band near the rated voltage by changing the ratio of transformer. As most of the loads are voltage dependent, a disturbance causing a voltage decrease at a load bus will cause a decrease in the power consumption. This tends to favor stability. However, the LTC will then begin to restore the voltage by changing the ratio step by step with a predefined timing. The increase in voltage will be accompanied by an increase in the power demand which will further weaken the power system stability.

- Thermostat will control the electrical heating. The thermostat acts by regularly switching the heating resistance on and off. In the case of a voltage decrease, the power consumption, hence the heating power, will be reduced. Therefore, the thermostat will tend to supply the load during a longer time interval. The aggregated response of a huge group of this kind of loads is seen as a restoration of the power, comparable to the one of the LTC.
- Induction motors have dynamic characteristics with short time constants. Restora-tion process occurs following voltage reduction because the motor must con- tinue to supply a mechanical load with a torque more or less constant.

C. Transmission system: Each transmission element, line or transformer, has a limited transfer capability. It is dependent on several factors:

- The impedance of the transmission element.
- The power factor of the load.
- The presence of voltage controlled sources (generators or Static Var Compensator- SVC) at one or both extremities of the element and the voltage set point of these sources.
- The presence of reactive compensation devices (mechanically switched capaci- tors or reactors).

C. Generation system: When the power system flows increase, the transmission system consumes more reactive power. The generators must increase their reactive power output. Operating point of generator can be found from it's capability curve. But due to over- excitation limiter (OEL) and stator current limiter (SCL), voltage can't be controlled after this limiters are activated As described above, the three sources are strongly linked one to another. In a real voltage collapse case, the complete instability mechanism generally involves all three aspects, and often other instability phenomena too. The following Figure 2.2 shows the act of power system devices in voltage collapse in different time- frames.

VI. CONCLUSION

In this work, voltage stability problem is analyzed in view of maximum loadability limit. Simulations are carried out on IEEE standard 6 bus and 14 bus systems. Load modeling is an loadability limit is computed.

The maximum loadability limit is calculated using continuation power flow method in which the power-flow solutions are traced. Critical loading factor is calculated and it is nearly equal to that of from P-V curves. Modal analysis is used and the maximum load ability is identified at the P-V curves and Q-V curves are drawn for various load buses with different load models. From these curves, maximum important aspect in voltage stability analysis and various load models are therefore considered.

Voltage stability indices are calculated and voltage instability is observed for various loading scenarios. When the system is voltage stable, these indices are close to zero and move towards to 1 as system is gradually moving towards critical point. Different voltage stability indices are calculated and compared for single and multiple load change scenarios. Using these indices, Critical buses and branches are identified and these results are matching with that of Modal analysis..

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