CHAPTER 1

INTRODUCTION

1.1 Introduction

With the increased loading of existing power systems, the problem of voltage stability and voltage collapse, has become a major concern in power system planning and operation. The trend of the de-regulated power system operation is also causing over loading of some of the transmission corridors. The application of FACTS devices to enhance the power transmission capabilities also involves reactive power control and voltage stability problems. The voltage collapse phenomenon can be related to the action of OLTC transformers, current limiters of generators, inadequate reactive power supply (at least locally) and load characteristic in load voltage magnitude. Voltage collapse is characterized by a slow variation in the system operating point, due to increase in the loads; in such a way that the voltage magnitude gradually decreases until a sharp accelerated change occurs. It has been observed that voltage magnitudes do not give a good indicator of proximity to a voltage stability limit [1]. In a day-to-day operation of power system, preventing 'loss of voltage control', instability requires sitting additional capacitors or SVCs to maintain reactive power reserves on generators, SVCs or synchronous condensers that otherwise exhaust reactive reserves and lose voltage control [2]. Since 'loss of voltage control' instability and 'clogging voltage instability' are both due to a shortage of reactive power supply to a bus or coherent bus group the structural stress test used must assess when and why a shortage of reactive power supply exists. Thus Q–V curves are used in this voltage stability security assessment methodology since it directly assesses shortage of reactive supply [9].

In the literatures many voltage stability and voltage collapse prediction methods have been presented. Some of these methods [3] are:

. Voltage collapse index based on closely located power flow solution pairs;

. Voltage collapse index based on P-V curves, Q-V curves;

. Voltage collapse index based on normal load flow solution (L-index) [1];

. Minimum singular value (MSV) of the power flow related Jacobian matrices [4];

. Voltage collapse index is based on the optimal impedance solution at maximum power transfer. While the different methods indicated above give a general picture of the proximity of the system to voltage collapse, the index proposed in [5] gives a scalar number to each load bus, called L-index. This index values ranges from 0 (no load system) to 1 (voltage collapse). The bus with the highest L-index value will be the most vulnerable bus in the system and hence this method helps in identifying the weak areas in the system which critical reactive power needs support. Among the different indices for voltage stability and voltage collapse prediction the L-index gives fairly consistent results [6,7]. The advantage of this method lies in the simplicity of the numerical calculations and expressiveness of the results. Different methods have been proposed in the literatures to improve the voltage stability margin. Bansilal et al. [6] and D. Thukaram et al. [7] have shown the suitability of L-index as objective function for improvement of voltage stability and also they compared the results with other well-known voltage stability indices.

Static VAR compensators are used by utilities in both transmission and distribution systems. The primary purpose is usually rapid control of voltage at weak points in a network. There are two major applications of installation of static VAR compensators in a power system. One is for load compensation.

The locations such as steel plants arc furnace fluctuating loads which cause voltage fluctuations. There are two main reasons for compensating fluctuating Loads [8].

The AC supply system is too weak to maintain the terminal voltage within the acceptable variations and it is neither economical nor practical to supply the reactive power demand from the AC system. Installation of SVC at these load busses helps in reducing the voltage fluctuations; improve load power factor and also voltage profile. The size of these SVCs generally decided by the local load.

The other application of SVC is in the EHV network. The purpose of installation of static VAR compensator in EHV network is to provide dynamic reactive power (VAR injection) support to maintain the bus voltage close to the nominal (acceptable) value under varying load conditions and also improve voltage stability. It also provides fast response to control the bus voltages under disturbed conditions. The size and location of SVC is obtained based on detailed both steady state and dynamic analysis of the system.[8]

Recently lEEE/CIGRE task force [9] proposed various definitions related to power system stability including voltage stability. Fig. 1.1 summarizes these definitions. In general terms, voltage stability is defined as the ability of a power system to maintain steady voltages at all the buses in the system after being subjected to a disturbance from a given initial operating condition. It depends on the ability to maintain/restore equilibrium between load demand and load supply from the power system. Instability that may result appears in the form of a progressive fall or rise of voltages of some buses. A possible outcome of voltage instability is loss of load in an area, or tripping of transmission lines and the other elements by their protection leading to cascading outages that in turn may lead to loss of synchronism of some generators. This task force further classified the large disturbance voltage stability, small disturbance voltage stability, short-term voltage stability and long-term voltage stability. A short summary of these classifications is given below [9].

Large-disturbance voltage stability refers to the system's ability to maintain steady voltages following large disturbances such as system faults, loss of generation, or circuit contingencies. This ability is determined by the system and load characteristics, and the interactions of both continuous and discrete controls and protections. The study period of interest may extend from a few seconds to tens of minutes.

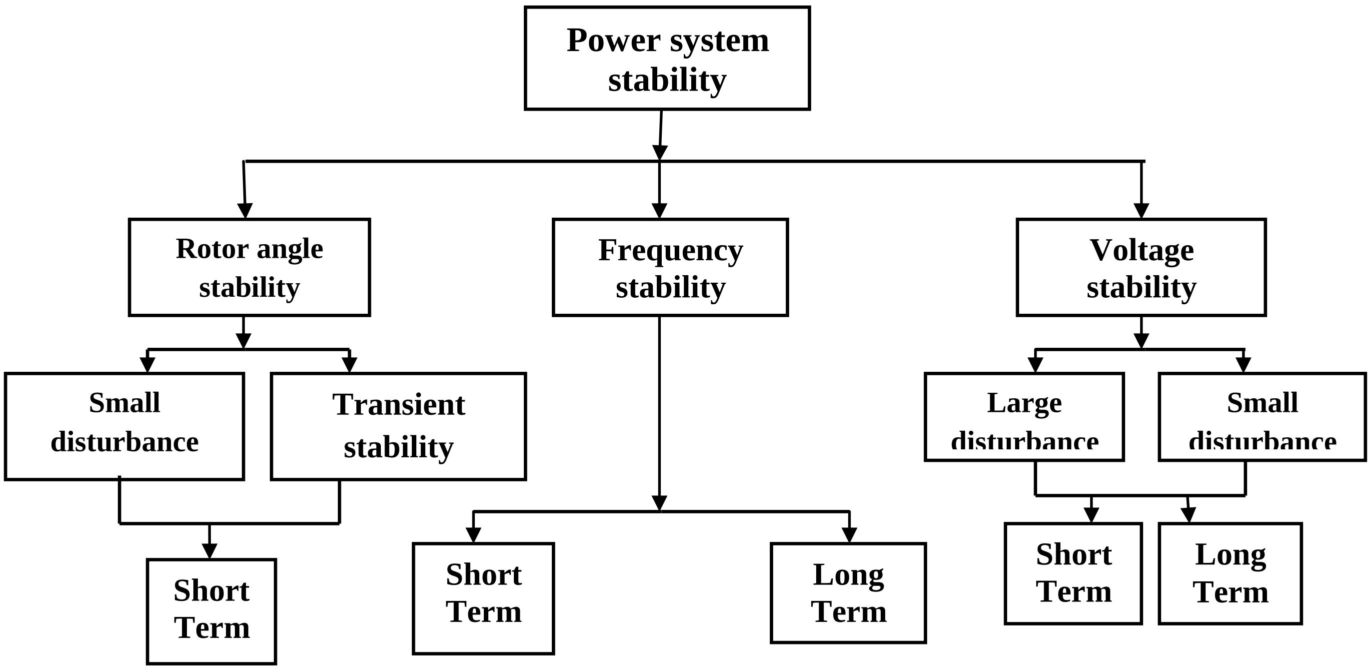

Fig. (1.1) Classification of power System stability [9]

Small-disturbance voltage stability refers to the system's ability to maintain steady voltages when subjected to small perturbations such as incremental changes in system load. This form of stability is influenced by the characteristics of loads, continuous controls, and discrete controls at a given instant of time.

Short-term voltage stability involves dynamics of fast acting load components such as induction motors, electronically controlled loads and HVDC converters. The study period of interest is in the order of several seconds, and analysis requires solution of appropriate system differential equations.

Long-term voltage stability involves slower acting equipment such as tap-changing transformers, thermostatically controlled loads and generator current limiters. The study period of interest may extend to several or many minutes, and long-term simulations are required for analysis of system dynamic performance. Instability is due to the loss of long-term equilibrium, post-disturbance steady-state operating point being small disturbance unstable, or a lack of attraction towards the stable post disturbance equilibrium. The disturbance could also be a sustained load buildup [10].

1.2 Voltage stability [11]

The voltage stability can be defined with several definitions according to the points of views. It's the system ability to maintain its voltage within certain specified limits at all loading conditions all over the hour. From the load point of view it can be defined as the load ability to give more power as the loading is increased without voltage dips beyond the limits (The system possibility to provide the required reactive power to support its load voltage as load increases). Voltage stability is also called the load stability, it is a characteristic of a power system that is required to transmit sufficient power to meet load demand.

Voltage stability includes mainly three issues:

1- The voltage levels must be acceptable.

2- The system must be controllable in the operating point.

3- It must survive a contingency or change in the system.

1.2.1 Stationary analysis

The simplest form of voltage stability assessment involves the determination of network's power transfer capability. This capability must be greater than the anticipated load. The capability assessment therefore needs to be conducted for a number of contingency scenarios. P-V and Q-V curves are two most commonly used techniques to assess the capability of a network. These curves show the voltages of selected buses as functions of increased system load. The "nose points" of these curves are the system limit.

1.2.2Investigation of behavior between active power and voltage

One very common way of analyzing the transfer capacity of a system regarding voltage stability is to make a so called P-V plot of the bus bars with load or production. P-V curves are often referred to as "nose curves" due to their shape. They are obtained by plotting the total system load (P) versus the voltage of the critical bus (V). These curves are plotted from the results obtained from the load flow solutions by slowly increasing the loads in discrete steps. They are parabolic in shape .in the top half of the curve the voltage decreases as the system load increases. Here the slope of the curve is negative. The nose point (normally referred to as the critical point) of the curve gives the maximum power which can be delivered to the load. The bus voltage corresponding to the critical point is referred to as the critical voltage. A disadvantage in this P-V curve is that near the critical point the power flow jacobian matrix tends to be singular and the power flow solution starts to diverge near this point. Hence special tools such as the continuation power flow should be used to obtain the load flow solution near the critical point. These curves are also used to determine the voltage stability margin of the system. Voltage stability margin can be considered as the amount of additional load in a specific pattern of load increase that would cause a voltage collapse in the system. This can be estimated from the P-V curves as the difference (in MW) between the critical point and the base case loading .As the power factor changes the critical point varies The critical point is higher for a leading power factor compared to a lagging power factor .also the critical voltage is higher for a leading power factor .This is an important aspect in voltage stability [12].

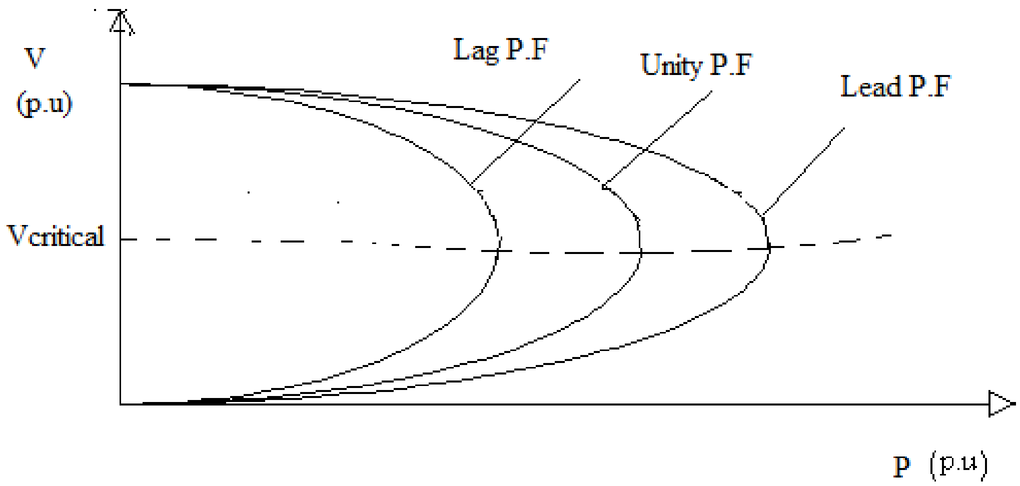

Fig. (1.2) Relation between active power and voltage (P-V curve).

1.2.3 Investigation of behavior between reactive power and voltage

The Q-V curve for a bus bar shows the reactive power which must be injected into a bus bar to maintain a certain voltage .the steeper the curve is the more reactive power is required to raise the voltage of the bus bar .These curves are plots of the critical bus voltage versus reactive power of the same bus. To obtain the Q-V curve of a bus a fictitious synchronous condenser is represented at that particular bus and the bus is assumed to be a voltage controlled bus without reactive power limits. Some of the main advantages of the Q-V curves are:

1- As the voltage stability problem is closely related to the reactive power, reactive power margin can be directly obtained from these curves. This is the margin between the operating point and the bottom point of the curve.
2- The characteristics of the shunt compensating devices can be directly plotted on the same plots. In this case the reactive power margin is calculated as the distance between the operating point and the point at which the compensating device characteristics is tangent to the Q-V curve. These curves are widely used in utilities to analyze the voltage stability problem.

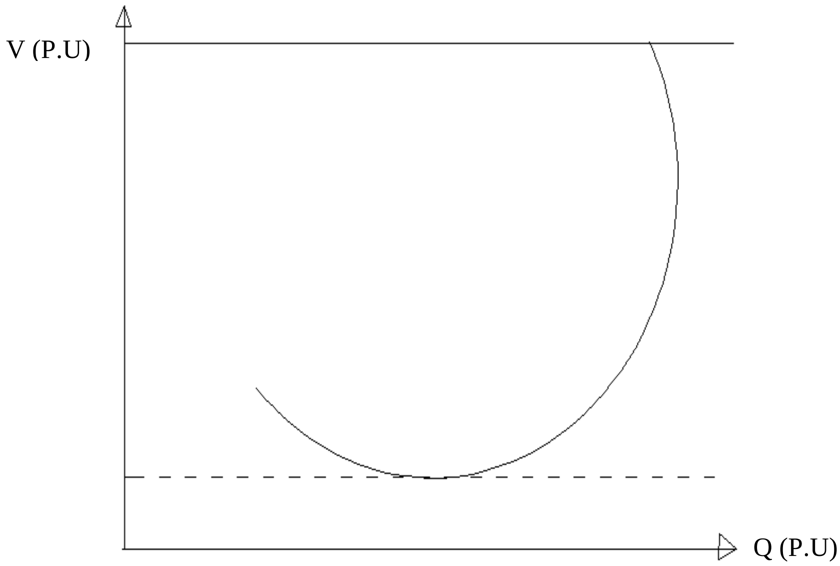

Fig (1.3) Relation between reactive power and voltage (Q-V Curve)

1.2.4 Load ability limit

Is defined as the tangent between the load and the network voltage power characteristic. If the load is increased above the load ability limit there is no solution of the load flow equations. That is the system has a singular solution where the determinant of the network Jacobian is zero which also defines the system load ability [12].

1.2.5 The Saddle Node Bifurcation Point

Is defined as the point where two branches of equilibrium point merge into a single solution. For constant power load this point is defined as the tip of the nose curve, but will change for at different load characteristics. The relationship between the active power transmitted and the receiving end voltages are important when studying the characteristics of transmission systems.

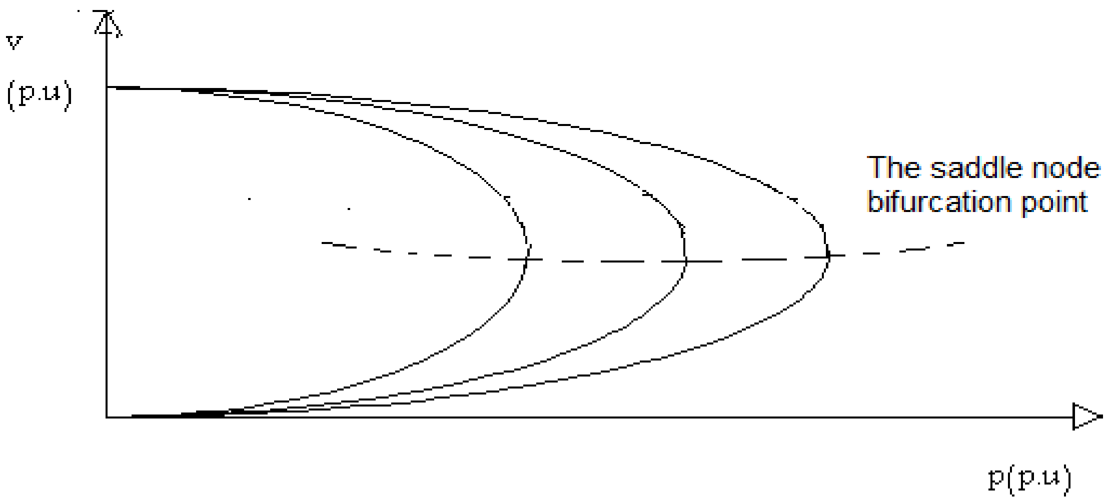

Fig. (1.4) The Saddle Node Bifurcation Point at (P-V) curve.

The dashed line shows the locus of points of voltage collapse, referred to as the critical points or saddle node bifurcation point. These points determine the steady state load ability limits of the system for voltage stability of the network .only the equilibrium points above the critical points represent stable operating conditions. The loci below the dashed line are that of unstable equilibrium points [12].