PV curve –Approach for Voltage Stability Analysis

NEHA PARSAI   ALKA THAKUR

Department of electrical engineering , sssist shore, M.P. INDIA

Department of electrical engineering, sssist shore, M.P.INDIA

*Email-*neha.parsai11@gmail.com *,*   electricalhod06@gmail.com

ABSTRACT

Voltage stability is the ability of a power system to maintain acceptable voltage at all buses under normal operating conditions and after being subjected to a emergency .Voltage stability is a local phenomenon, but its cost may have a extensive impact .Voltage stability has become a very important issue of power systems analysis. Voltage Stability Analysis has become more important as a result of inadequate reactive resources in bulk transmission systems. Usually the objective of Voltage Stability Analysis is to identify the weak regions in terms of reactive power deficiency and determine the critical emergencies and voltage stability margins for various power transfers within regions. Voltage stability is an significant factor, which needs to be taken into consideration during the planning and operation of electrical power systems in order to avoid voltage collapse and later partial or full system collapse. From the voltage stability analysis peak of vision, system operators need to know not only the unkindness of their system, but also the system that cause voltage instability.

This paper presents study of different methods and techniques used to improve the voltage stability of electrical power systems. Conventional P-V curve methods are taken as a basic analysis tool. The effectiveness of the analyze methods re verified through numerical studies in IEEE 6 bus bar test system, using several different scenario of load increase.

Keywords: *Voltage stability, PV curve, QV curve*

I. INTRODUCTION

Voltage instability has been given much attention by power system researchers and planners in recent years, and is being regarded as one of the major sources of power system uncertainty. Voltage instability phenomena are the ones in which the receiving end voltage decreases well below its normal value and does not come back even after setting restoring mechanisms such as VAR compensators, or continues to fluctuate for lack of damping against the instability. Voltage collapse is the procedure by which the voltage falls to a low unacceptable value as a result of an avalanche of events accompanying voltage instability [1]. Once associated with weak systems and long lines, voltage troubles are now also a source of concern in highly developed networks as a result of heavier loading. Voltage stability concerned with the ability of a power system to maintain acceptable voltages at all buses in the system under normal conditions and after being subjected to a disturbance. A power system at a given operating state is voltage stable if, following the disturbances; voltages near loads are identical or close to the predisturbance values. A power system is said to have entered a state of voltage instability

when a disturbance results in a progressive and uncontrollable decline in voltage. Following voltage instability, a power system may undergo voltage collapse, if the post disturbance equilibrium voltages near loads are below acceptable limits. Voltage collapse is also defined as a process by which voltage instability leads to very low voltage profile in a significant part of the system. Voltage collapse may be total blackout or limited. The main cause of voltage collapse may be due to the inability of the power system to supply the reactive power or an excessive absorption of the reactive power by the system itself. The voltage stability can be studied either on static (slow time frame) or dynamic (long time frame) considerations [6,8]. The static voltage stability methods are mainly depends on steady state model in the analysis, such as power flow model or a liberalized dynamic model. Dynamic stability analysis describes the use of a model characterized by nonlinear differential and algebraic equations which include generators dynamics, tap changing transformers etc. Since the steady state analysis only involve the explanation of algebraic equations it is computationally less extensive than dynamic analysis. Thus, lot of work is carried out to determine voltage stability on static analysis method. Several methods have been used in static voltage stability analysis such as the PV and QV curves , model analysis ,optimization method , continuation load flow method etc.

In this paper, a variety of methods for improving voltage stability have been studied and a two bus system has been investigated for the purpose of voltage stability of power system using one of the basic static analysis method- conventional P-V curve methods.

II. POWER SYSTEM STABILITY-

At any point of time, a power system operating condition should be stable, meeting various operational criteria, and it should also be protected in the event of any realistic emergency. Power system

stability may be defined as that property of a power system that enable it to remain in a state of operating equilibrium under normal operating conditions and to regain an acceptable state of equilibrium after being subjected to disturbances. Present day power systems are being operated closer to their stability limits due to economic and environmental constraints. Maintaining a stable and secure operation of a power system is therefore a very important and challenging issue. Power system stability is broadly classified as rotor angle stability-steady state stability and transient state stability, frequency stability and voltage stability-short term and long term voltage stability and it is load driven. The tree chart of power system stability are shown below:-
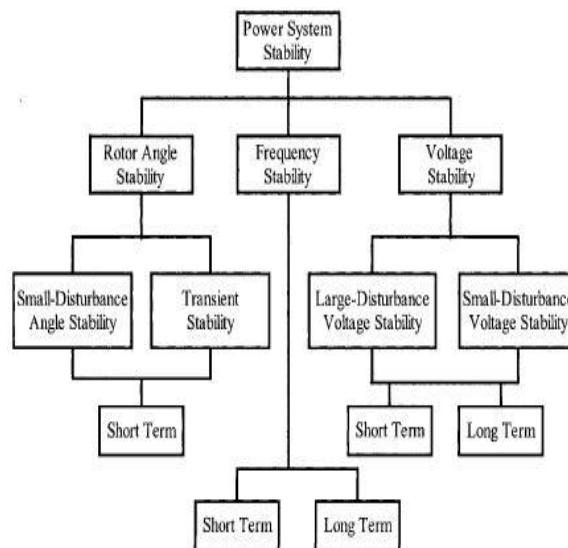

Figure.1 tree chart of power system stability

III. POWER SYSTEM VOLTAGE STABILITY

The main factors cause voltage instability in a power system are now well explore and understand A brief introduction to the basic concepts of voltage stability and some of the conventional methods of voltage

stability analysis are presented in this chapter. Simulation results on test power systems are presented to illustrate the problem of voltage stability and the conventional methods to analyze the problem.

The voltage stability problem is now a serious concern to the electric utility industry. Many large interconnected power systems are increasingly experiencing abnormally high or low voltages and voltage collapse. These voltage problems are associated with the increased loading of transmission lines, insufficient local reactive supply, and the shipping of power across long distances. The spirit of the voltage stability problem is the voltage drop that occurs when the power system experience a heavy load, and one solemn type of voltage instability is voltage collapse.

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. Voltage collapse typically occurs in power system which are usually heavily loaded, faulted and/or have reactive power shortages. Voltage collapse is system instability and it involves large disturbances (including rapid increase in load or power transfer) and mostly associated with reactive power deficits

Voltage collapse is the process by which the sequence of events associated voltage instability Leads to a low undesirable voltage profile in a significant part of system. The main factors causing voltage instability are –
1) The inability of the power system to meet demands for reactive power in the heavily stressed system to keep voltage in the desired range
2) Characteristics of the reactive power compensation devices
3) Action and Coordination of the voltage control devices
4) Generator reactive power limits
5) Load characteristics
6) Parameters of transmission lines and transformer

IV. VOLTAGE STABILITY ANALYSIS

There are Different methods be present in the system for moving out a steady state voltage stability analysis. But the conventional methods can be broadly classified into the following types.
A. P-V curve method.
B. V-Q curve method and reactive power reserve.
C. Methods based on singularity of power flow Jacobian matrix at the point of voltage collapse.
D. Continuation power flow method. We discuss the main two main method PV curve and QV curve.

A. PV curve analysis -The voltage stability are interest are the relationships between transmitted power (P), receiving end voltage (V), and reactive power injection (Q) Traditional forms of displaying these relationships are PV and QV curves obtained through steady state analysis. P-V curve analysis is use to determine voltage stability of a radial system and also a large meshed network. For this analysis P i.e. power at a particular area is increased in steps and voltage (V) is observed at some critical load buses and then curves for those particular buses will be plotted to determine the voltage stability of a system by static analysis approach. The "PV" (Power Voltage) analysis process involves using a series of power flow solutions for increasing transfers of MW and monitoring what happens to system voltages as a result. Relationship of voltage to MW transfer is nonlinear, which requires the full power flow solutions. To explain P-V curve analysis let us assume two-bus system with a single generator, single transmission line and a load, as shown in Figure2.
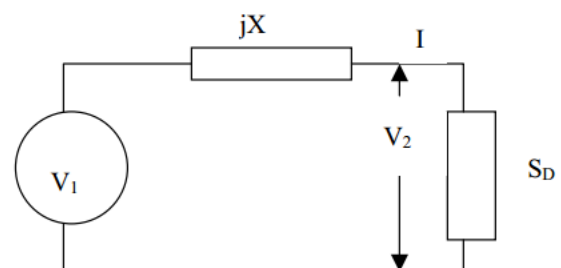

Figure2: Two bus representation model

P-V curves are useful in deriving how much load shedding should be done to establish prefault network conditions even with the maximum increase of reactive power supply from various automatic switching of capacitors or condensers.

Here, the complex load assume is $S_{12}=P_{12}+jQ_{12}$ with V1 is the sending end voltage and V2 is receiving end voltage $COS\emptyset$ and is load power factor From the figure

$S_{12}=P_{12}+jQ_{12}$

$P_{12}=V_1^2 G - V_1 V_2 \cos(\emptyset 1 - \emptyset 2)G + V_1 V_2 B\sin(\emptyset 1 - \emptyset 2)$

$Q_{12}=V_1^2 B - V_1 V_2 B\cos(\emptyset 1 - \emptyset 2) - V_1 V_2 G\sin(\emptyset 1 - \emptyset 2)$

Let G=0 Then

$P_{12}=V_1 V_2 B\sin(\emptyset 1 - \emptyset 2)$

$Q_{12}=V_1^2 B - V_1 V_2 B\cos(\emptyset 1 - \emptyset 2)$

Now we get

$S_D = P_D + JQ_D = -(P_{21} + JQ_{21})$

$P_D = -P_{21} = -(V_1 V_2 B\sin(\emptyset 2 - \emptyset 1))$
$= V_1 V_2 B\sin(\emptyset 1 - \emptyset 2)$

$Q_D = -Q_{21} = -V_1^2 B - V_1 V_2 B\cos(\emptyset 2 - \emptyset 1)$
$= -V_2^2 B + V_1 V_2 B\cos(\emptyset 1 - \emptyset 2)$

Define $\emptyset 12 = (\emptyset 1 - \emptyset 2)$

$P_D = V_1 V_2 B\sin\emptyset 12$

$Q_D = -V_2^2 B + V1 V2 B\cos\emptyset 12$

From figure.2 we can also express

$S_D = P_D(1+j\beta)$

$Q_D = P_D \beta$

The resulting voltage equation will be

$V_2^2 = (1-\beta P_D \pm \sqrt{1 - PD(PD + 2\beta)})/2$

As seen from equation, the voltage at the load point is influenced by the power delivered to the load, the reactance of the line, an\d the power factor of the load. The voltage has two solutions; the higher one is the stable solution. The load at which the two solutions have one value indicates the steady state voltage collapse point. Using this equation we have plotted P-V curve using MATLAB program [7] for various power factors, lagging as well as leading as shown in fig.3.
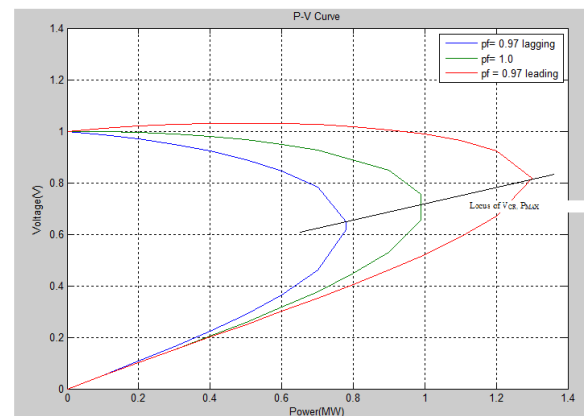

Fig 3: P-V Curve for various load power factors

The dotted line can be shown by connecting nose points of the P-V curve. Only the operating points above the critical points represent satisfactory operating condition. At the knee of the P-V curve, the voltage drops rapidly with the increase in loads. P-V curves are useful for conceptual analysis of voltage stability especially for radial systems Result of PVCurve are-

1) At the "knee" of the PV curve, voltage drops rapidly with an increase in MW transfer.
2) The power flow solution fails to converge beyond this limit, which is indicative of instability You may remember the term

"Maximum Power Transfer" from electrical engineering courses. This is the same topic

3) Operation at or near the stability limit risks a large scale blackout   A satisfactory operating condition is ensured by allowing sufficient "power margin

B. QV curve analysis- Q-V curve is the relationship between the reactive power support (Q) and receiving end voltage (V2) for different values of active power P[3] . The V-Q curve method is one of the most popular ways to investigate voltage instability problems in power systems during the post transient period . Unlike the P-V curve method, it doesn't require the system to be represented as two-bus equivalent. Voltage at a test bus or critical bus is plotted against reactive power at that bus.

We consider our simple (lossless) system again, with equations

$P_D=V_1V_2BSin\emptyset12$

$Q_D=-V_2{}^2B+V1V2BCos\emptyset12$

For the simple two-bus system shown in Figure 1., equations of V-Q curves for constant power loads can be derived as follows. For a range of values of voltage and different active power levels, normalized V-Q curves are shown in Figure 4. The critical point or nose point of the characteristics corresponds to the voltage where dQ/dV becomes zero. If the minimum point of the V-Q curve is above the horizontal axis, then the system is reactive power deficient. Additional reactive power sources are needed to prevent voltage collapse. Busses having V-Q curves below the horizontal axis have a positive reactive power margin. The system may still be called reactive power deficient, depending on the desired margin.
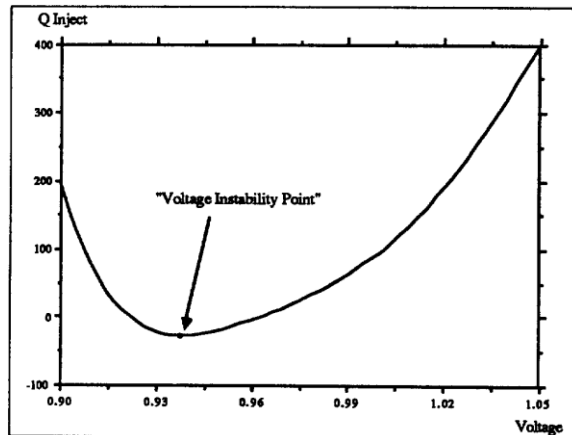

Fig.4:- QV Curve for various load factor

One of the information that can be accessed from the curves is the sensitivity of the loads to the reactive power sources. Thus P-V curve play a measure role in understanding and explaining voltage stability. However, it is not necessarily the most efficient way of studying voltage stability since it requires a lot of computations for large complex networks.

V. METHODS OF IMPROVING VOLTAGE STABILITY

The power system voltage instability can be improved using the following methods

1. Generator AVRs
2. Under-Load Tap Changers
3. Load shedding during contingencies
5.Reactive Power Compensation

A. Generator AVRs-
Generator AVRs are the most important means of voltage control in a power system. Under normal conditions the terminal voltages of generators are maintained constant. When there exist voltage stability problem due to reactive power demand, generators can supply more power to system in the range of field current limits. AVRs act on the exciter

side of synchronous generators. The exciter supplies the field voltage in the field winding. Within the capability limits of the generator, it can regulate the bus voltage.

B. Under-Load Tap Changers-
Transformers enable utilization of different voltage levels across the system. In addition to voltage transformation, transformers are often used for control of voltage and reactive power flow. From the power system aspect, changing the ratio of transformer is required to compensate for variations in system voltages. The ULTC is used when the ratio has to be changed frequently due to simultaneous changes in load such as- daily variations. Therefore, in order to maintain voltage stability ULTCs are often used. Generally, taps allow the ratio to vary in the range of $\pm10\%$ to $\pm15\%$.

C. Load Shedding During Contingencies -
The risk of collapse due to voltage instability can be reduced by load shedding. Under voltage load shedding during contingencies is the cheapest way to prevent voltage instability. Load shedding may be manual or automatic. System planners conduct numerous studies using V-Q curve and other analytical method to determine the amount of load that needs to be sheds to retain voltage stability during contingencies. Voltage collapse is most probable under heavy load conditions. Therefore, amount of load to be shed depends on system load peak and generation sources.

D. Reactive Power Compensation –
Voltage instability is basically the effect of reactive power imbalance between generation and demand. Load bus is most susceptible to voltage instability .Therefore localized reactive support may be use to improve voltage stability. The following methods are use to give the reactive power support

- Shunt Capacitors
- Series Capacitor
- shunt reactors
- synchronous condensers
- Static Var Systems

Shunt capacitors are used to compensate for the reactive power requirement in transmission and to ensure acceptable voltage levels during heavy loading conditions. Capacitor banks of appropriate sizes are connected either directly to bus or tertiary winding of the main transformer. Switching of capacitor banks provides a convenient means of controlling transmission bus voltages. They are normally distributed throughout the system in order to minimize losses and voltage drops. Series capacitors are connected in series with the transmission line to compensate for the inductive reactance of the line. This reduces the reactance of the transmission line between the generation and load bus. Therefore, the maximum power that can be transferred increases and it reduces the reactive power requirement of the line. Since series capacitors permit economical loading of long transmission lines they are used frequently in power systems. Shunt reactors are used to compensate for the effects of line capacitance. They absorb reactive power from system. In case of unacceptable voltage rises they are activated so as to limit voltage rise. A synchronous condenser is a synchronous machine running without a prime mover or a mechanical load. By controlling the field excitation, it can be made to either generate or absorb reactive power. They can automatically adjust the reactive power output to maintain constant terminal voltage with a voltage regulator. Static var compensators are shunt-connected static generators or absorbers whose outputs are varied so as to control specific parameters of the electric power system. Static var systems are capable of controlling individual phase voltages of the buses to which they are connected. Generally, thyristor controlled circuits are used in these systems. A static var system is ideally suited for applications requiring direct and rapid control of voltage.
Reactive power compensation is often the most effective way to improve both power transfer capability and voltage stability

VI. CONCLUSION

This paper shows the simple analytical expression for real power and reactive power at receiving end and sending end of simple two bus system has been formulated and had been used to obtain voltage V2 at

load point. The same voltage expression is used to draw P-V curve of a radial transmission line system. In this paper it is observed that real power transfer increases from lagging to leading power factor. It means the real power depend upon the power factor of the system. Using the Q-V curves the sensitivity of the load to the reactive power sources can be obtained Thus basic voltage stability analysis tools i.e. P-V curve and Q-V curve are found to be effective tools to understand static voltage stability analysis.

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AUTHOR PROFILES

NEHA PARSAI *M.tech student Department of electrical engineering sssist shore, M.P. INDIA*
ALKA THAKUR *Assist. Prof*essor *Department of electrical engineering sssist shore, M.P.INDIA*