Voltage Stability Assessment in Radial Distribution Power System

Shivley Sageer[*1], Om Sharma[2], Ratul Rana Patel[3] and Ruchika Khare[4]

ABSTRACT

The voltage stability problem of distribution networks is associated with a rapid voltage drop because of heavy system load. To operate the distribution system under such critical conditions the integration of distributed resource improves the reliability of supplying power by improving voltage stability and reducing the power losses. This paper presents voltage stability analysis of radial distribution networks in the presence of distributed generation. The analysis is accomplished using different methods which can be evaluated at each node of the distribution system. In this paper study the all types of methods which is used to improve the Voltage Stability Assessment in radial distribution power system.

Keywords: *distributed generation, radial distribution network, Different methods of improving voltage stability.*

1. INTRODUCTION

In a distribution system Voltage stability is one of the keen interests of industry and research sectors around the world. It concerns stable load operation, and acceptable voltage levels all over the distribution system buses. The distribution system in a power system is loaded more heavily than ever before and operates closer to the limit to avoid the capital cost of building new lines. Distributed resources are the power sources (active or reactive) that can be connected to a distribution system by a distribution company or by the customer at the customer side of the meter. The distributed resources, if strategically located and operated, defer or eliminate system upgrades by improving various energy efficiency defining parameters like voltage profile, power losses and load ability limit. However, for better energy performance the simultaneous improvement in these parameters is required. Radial distribution systems having a high resistance to reactance ratio causes a high power loss so that the radial distribution system is one of the power systems, which may suffer from voltage instability. Different methods used to improve the voltage stability such as bifurcation analysis, p-v curve ,q-v curve and other types of load scheduling methods which is related to different software and different types of numerical problems related to various load condition.

2. ELECTRICAL POWER SYSTEM

Electric power supply system in a country comprises of generating units that produce electricity; high voltage transmission lines that transport electricity over long distances; distribution lines that deliver the electricity to consumers; substations that connect the pieces to each other; and energy control centers to coordinate the operation of the components.

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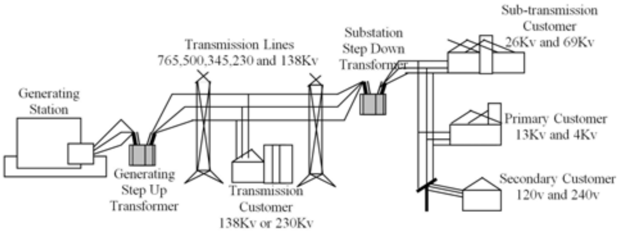

Fig.1. Schematic Power Supply System

2.1Generation System

Electric power is generated in the range of 11 kV to 25 kV, which is increased by stepped up transformers to the main transmission voltage. At sub-stations, the connections between various components are made, for example, lines and transformers and switching of these components is carried out. Transmission level voltages are in the range of 66 kV to 400 kV (or higher). Large amounts of power are transmitted from the generating stations to the load centers at 220 kV or higher. In USA it is at 345 kV, 500 kV and 765 kV and Britain, it is at 275 kV and 400 kV. The network formed by these very high voltage lines is sometimes called as the Super Grid. This grid, in turn, feeds a sub-transmission network operating at 132 kV or less. In our country, networks operate at 132 kV, 66 kV, 33 kV, 11 kV or 6.6 kV and supply the final consumer feeders at 400 volt three phase, giving 230 volt per phase.

2.2 Transmission System

AC system is used in the transmission of bulk power, instead of DC (Direct Current), because of its ability to transform voltage to various levels using a transformer. The voltage transformation follows the Faraday's Law which states; the emf induced in a circuit is directly proportional to the time rate of change of magnetic flux through the circuit. Ability to transform voltage and to flow power in two opposite directions (bidirectional) are the only major advantages of AC system over DC system. DC transmission system on the other hand has more advantages over AC transmission system. The industrial growth of a nation requires increased consumption energy, particularly electrical energy. This has lead to increase in the generation and transmission facilities to meet the increasing demand. The generation can be increased to the required level but the problem is in transmission due to the thermal limit, because the transmission line load ability is fixed up to 60% of the power to be transmitted.

2.3 Distribution System

The part of the power system which distributes electric power for local use is known as distribution system. The effectiveness, with which it achieves its objectives of distributing electric energy to various consumers, is measured in terms of voltage regulation, flexibility, security of supply efficiency and cost. Distribution networks are different than transmission networks in many ways, quite apart from voltage magnitude. The general structure or topology of the distribution system is different and the number of branches and sources is much higher. A typical distribution system consists of a step-down transformer (e.g., 132/11 kV or 66/11 kV or 33/11 kV) at a bulk supply point feeding a number of lines with varying length from a few hundred meters to several kilometers. Several three-phase step-down transformers, e.g., 11 kV/400 V are spaced along the feeders and from these, three-phase four-wire networks of consumers are supplied which give 230 volt single-phase supply to houses and similar loads. In general, the distribution system consists of feeders, distributors and service mains. A feeder is a conductor which connects the sub-station (or localized generating station)to the areas to be fed by those stations. Generally, no tapping are taken by from feeders to the consumers. Therefore current loading of a feeder remains same along its length. It is designed mainly from the point of view of its current carrying capacity. Distributors are the conductors from which numerous

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tapping for the supply to consumers are taken. The current loading of distributor varies along its length. Distributors are designed from the point of view of the voltage drop. Service mains are the conductors which connect the consumer's terminals to the distributor.

3. REQUIREMENT OF A POWER SYSTEM

A considerable effort is mandatory to maintain the supply of electric power system within the requirements of many consumers.The necessary requirements of a good power system are:-

3.1 Availability of power demand

Power should be available to the consumers in large amount as per their requirement

3.2 Reliability

Present day industry is totally dependent on electric power for its operation. So there is an urgent need of a reliable service. If per chance there is a power failure it should be for the minimum possible time at every cost. Improvement in reliability can be made up to a considerable extent by Reliable automatic control system and providing additional reserve facilities.

3.3 Proper Voltage

Most important requirement of a distribution system is that the voltage variations at the consumer terminals should be as low a possible. The main cause of changes in voltage variation of load on system. Therefore, a distribution is said to be good, if it ensures that the voltage variations are within permissible limits at consumer terminals.

3.4 Loading

The transmission line should never be over loaded.

3.5 Efficiency

The efficiency of transmission lines should be maximum say about 90%.

4.0 POWER SYSTEM STABILITY

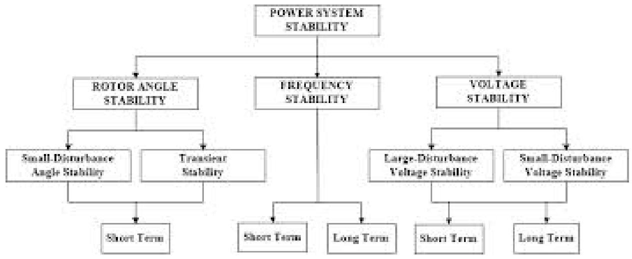

Fig.2. Power System Stability Chart

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. The power system is a highly nonlinear system that operates in a constantly changing environment; loads, generator outputs and key operating parameters change continually. When subjected to a disturbance, the stability of the system depends on the initial operating condition as well as the nature of the disturbance. The classification of power system stability proposed here is based on the following considerations.

- The physical nature of the resulting mode of instability as indicated by the main system variable in which instability can be observed.
- The size of the disturbance considered, which influences the method of calculation and prediction of stability.
- The devices, processes, and the time span that must be taken into consideration in order to assess stability.

Fig. 2 gives the overall picture of the power system stability problem, identifying its categories and subcategories. The following are descriptions of the corresponding forms of stability phenomena.

4.1 Rotor Angle Stability

Rotor angle stability refers to the ability of synchronous machines of an interconnected power system to remain in synchronism after being subjected to a disturbance. It depends on the ability to maintain/ restore equilibrium between electromagnetic torque and mechanical torque of each synchronous machine in the system. Instability that may result occurs in the form of increasing angular swings of some generators leading to their loss of synchronism with other generators.

4.2 Frequency Stability

Frequency stability refers to the ability of a power system to maintain steady frequency following a severe system upset resulting in a significant imbalance between generation and load. It depends on the ability to maintain/restore equilibrium between system generation and load, with minimum unintentional loss of load. Instability that may result occurs in the form of sustained frequency swings leading to tripping of generating units and/or loads.

4.3 Voltage Stability

Voltage stability refers to the ability of a power system to maintain steady voltages at all 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 occurs 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 other elements by their protective systems leading to cascading outages. Loss of synchronism of some generators may result from these outages or from operating conditions that violate field current limit. Considering simple bus system which can easily define the equation of the voltage stability.

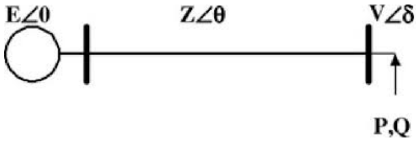

Fig.3. Voltage Stability Diagram

Real power transfer from bus is given by

$$P = \frac{EV}{X}\sin\delta$$

Reactive power transfer from bus is given by

$$Q = -\frac{V^2}{X} + \frac{EV}{X}\cos\delta$$

where, E = E ∠δ is the voltage
V = V ∠0 is the voltage
x = impedance of the line
δ = power angle.

5. TOOLS FOR VOLTAGE STABILITY ANALYSIS

Different methods exist in the literature for carrying out a steady state voltage stability analysis. The conventional methods can be broadly classified into the following types.

1. P-V curve method
2. V-Q curve method and reactive power reserve.
3. VSI Index method
4. Bifurcation analysis method

5.1 P-V curve method

When considering voltage stability, the relationship between transmitted P and Receiving end V is of interest. The process of voltage stability analysis involves the transfer of P from one region of a system to another, and monitoring the effects to the System voltages V. This type of analysis is commonly referred to as a P-V study. The P-V curves, real power-voltage curve, are used to determine the MW distance from the operating point to the critical voltage. Consider a single, constant power load connected through a transmission line to an infinite-bus. Let us consider fig-4 the solution to the power-flow equations, where P, the real p ower of the load, is taken as a parameter that is slowly varied, and V is the voltage of the load bus the parameter P. In the first region, the power flow has two distinct solutions for each choice of P; one is the desired stable voltage and the other is the unstable voltage. As P is increased, the system enters the second r egion, where the two solutions intersect to form on e solution for P, which is the maximum. If P is further increased, the power-flow equations fail to have a solution. This process can be viewed as a bifurcation of the power-flow problem. The method of maximum power transfer determines critical limits on the load bus voltages, above which the system maintains steady-state operation.

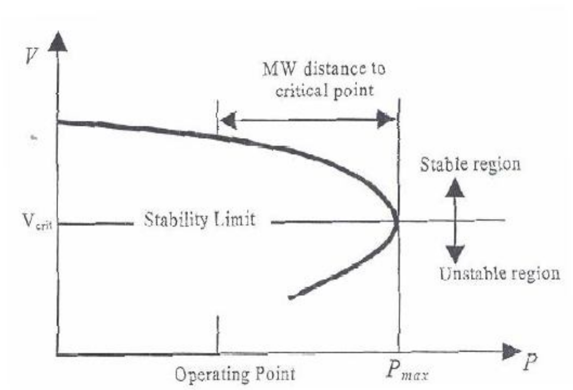

Fig. 4. Voltage Load vs Power Flow

The P-V curve is drawn for the load bus and the maximum transmissible power is calculated. Each value of the transmissible power corresponds to a value of the voltage at the bus until V = Vcrit after which further increase in powe r results in deterioration of bus voltage. The top portion of the curve is acceptable operation whereas the bottom half is considered to be the worsening operation. The risk of voltage collapse is much l ower if the bus voltage is further away, by an upper value, from the critical voltage corresponding to Pmax. Hence, the P-V curve can be used to determine the system's critical operating voltage and collapse margin.

5.2 V-Q Curve Method

The Q-V curves, reactive power - voltage curve, are used to determine the Mvar distance from the operating point to the critica l voltage. A typical Q-V curve is shown in Figure 5 It shows the sensitivity and variation of bus voltages with respect to reactive power injections or absorption s. Scheduling reactive loads rather than voltage produces Q-V curves. These curves are a more genera l method of assessing voltage stability. They are used by utilities as a workhorse for voltage stabilit y analysis to determine the proximity to voltage collapse and to establish system design criteria based on Q and V margins determined from the curves. Op erators may use the curves to check whether the vo ltage stability of the system can be maintained or no t take suitable control actions.

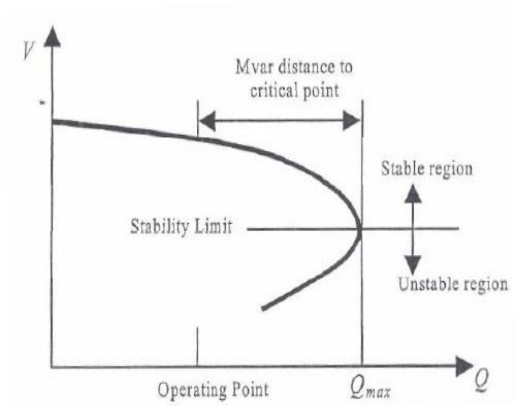

Fig.5. Voltage Load vs Reactive Power

In Figure 5, the Q axis shows the reactive power that needs to be added or removed from the bus to maintain a given voltage at a given load. The reactive power margin is the Mvar dista nce from the operating point to the bottom of the curve. The curve can be used as an index for voltage i nstability. Near the nose

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of a Q-V curve, sensitivities get very large and then reverse sign. Also, it can be seen that the curve shows two possible values of voltage for the same value of power. The power system operated at lower voltage value would require very high current to produce the power.

That is why the bottom portion of the curve is classified as an unstable region; the system cannot be operated, in steady state, in this region. The top portion of the curve represents the stability region while the bottom portion from the stability limit indicates the unstable operating region. It is preferred to keep the operating point far from the stability limit.

5.3 VSI Index method

To accurately predict the operating condition of a power system need a fast and accurate voltage stability index (VSI) to help them monitoring the Voltage stability index is numerical solution which helps operator to monitor how close the system is to collapse or to initiate automatic remedial action schemes to prevent voltage collapse. The main objective of VSI is to find the distance from current operating point to the marginally stable point. The purpose of finding VSI is to find most sensitive node of the system. Voltage collapse starts at the most sensitive node and then spread out to other sensitive nodes. system condition for identifying the node, which is most sensitive to voltage collapse. Fig.6 shows the electrical equivalent of radial distribution system.

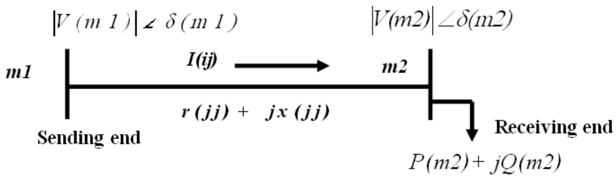

Fig. 6. Electrical Equipment Radial Distribution System

From Fig. 6, the following equation can be written:

$$I(ij) = \frac{V(m1) - V(m2)}{r(jj) + jx(jj)}$$

Where
Jj =branch number.
m1 = sending end node,
m2 = receiving end node,
I (ij) = current of branch ij,
V (m1) = voltage of node m1,
V (m2) = voltage of node m2,
P (m2) = total real power load fed through node m2,
Q (m2) = total reactive power load fed through node m2.

The node at which the value of the stability index is minimum, is more sensitive to the voltage collapse. Different load models, i.e., constant power, constant current, constant impedance and composite load modeling are considered for the purpose of voltage stability analysis.

5.4 Bifurcation analysis method

In any system with the change in parameters there is some change in the dynamic behavior. Most of the time, these changes are only quantitative in nature. But there may also be situations, where a small change in parameters may result qualitative change in steady state behavior of a dynamic system. Such events are called Bifurcations.

The number of attractors in a non – linear dynamic system can change when the system parameter is changed. This change is called Bifurcation. It is accomplished by a change of stability of an attractor. In a bifurcation point, at least one Eigen value of the Jacobian matrix gets a zero real part. The sudden change in the behavior of the system as a parameter passes through a critical value called a bifurcation point.

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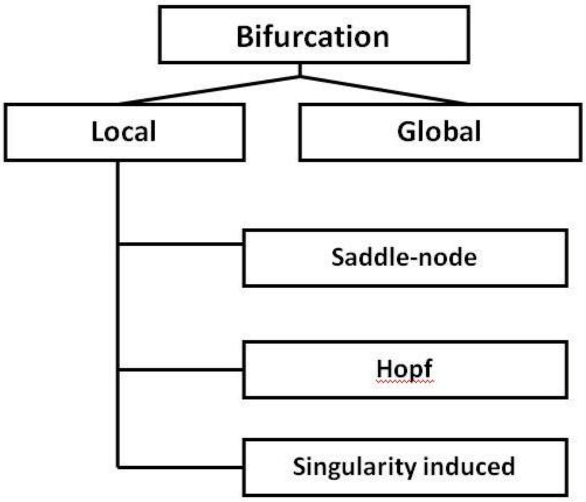

In general there are two types of bifurcation such as global and local bifurcation. Global bifurcation often occurs when larger invariant sets of the system collide with each other or with equilibrium of the system. They cannot be detected purely by a stability analysis of the equilibrium. Local bifurcation can be analyzed entirely throughout changes in the local stability property of equilibrium, periodic orbits or other invariant sets as parameters cross through critical thresholds. Then further Local Bifurcation in divided into three different types such as saddle-node, Hopf and Singularity induced bifurcation.

6. CONCLUSION

A precise definition of power system stability that is inclusive of all forms is provided .A salient feature of the report is a systematic classification of power system stability, and the identification of different categories of stability behavior. This paper explains all the methods of improving voltage stability assessment briefly. According to this paper take any form of method to explain the voltage stability briefly by using different types of software such as VST toolbox, power flow simulate software and different types of numerical solving methods. The report also includes a rigorous treatment of definitions and concepts of stability from mathematics and control theory. This material is provided as background information and to establish theoretical connections.

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