# Voltage Collapse: Causes and Prevention

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***Abstract*—Power system stability of large interconnected power system is the major issue the world is facing in order to obtain a secure operation of power system. Recent major blackouts across the world illustrate this issue for secure operation. Voltage collapse is the process by which the sequence of events accompanying voltage instability leads to an unacceptable voltage drop in a significant part of power system. Catastrophic decrease in voltage leads to loss of stability in large interconnected power system causing blackout. In this paper we will discuss the various causes and the prevention methods for power system collapse.**

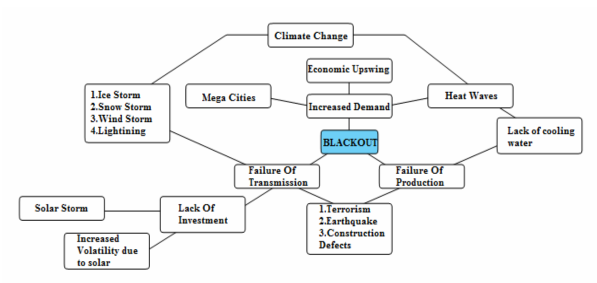
***Keywords*—Stability;Voltage Regulation;SVC**

## I. INTRODUCTION

The important operating work of power system utilities is to keep voltage within an allowable range limit in order to provide a high quality customer service. Day by day increase in power demand results in more and more pressurized transmission lines. Such systems are usually subjected to voltage instability and eventually a voltage collapse. Now-a-days voltage collapse is becoming an increasing threat to system security and stability. Power systems are expected to become more heavily loaded in the next decade as the demand for electric power rises while economic and environmental concerns limit the construction of new transmission and generation capacity. Heavily loaded power systems are closer to their stability limits and voltage collapse blackouts will occur if suitable monitoring and control measures are not taken. It is important to understand the mechanisms of voltage collapse so that voltage collapse blackouts may be effectively prevented.

### *A.) Causes of voltage collapse*

- Increase in loading
- Generators, synchronous condensers, or SVC reaching reactive power limits
- Action of tap changing transformers
- Load recovery dynamics
- Line tripping
- Generator outages




POTENTIAL CAUSES OF BLACKOUT

Fig. 1. Potential causes of Blackout

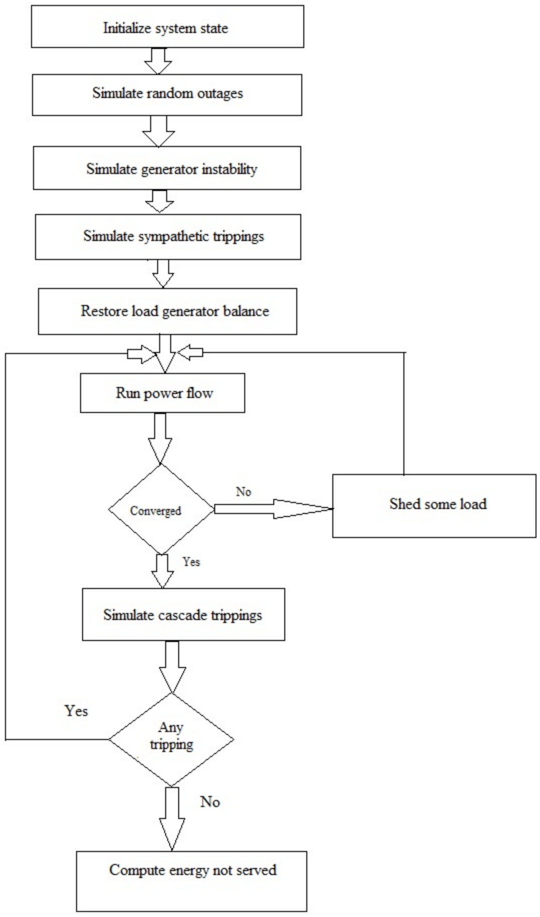



Fig. 2. Flow Chart for Cascading Failure Power System Model

## II. LOAD SHEDDING

Load shedding is an option that is becoming more widely used a final means of avoiding system wide voltage collapse. This option is only considered when all other effective means of avoiding collapse are exhausted. This option may be the only effective option for various contingencies, especially if the collapse is in the transient time frame, and if load characteristics result in no effective load relief by transformer load taps changer control. Load shedding results in high costs to electricity suppliers and consumers; therefore, power systems should be designed to require such actions only under very rare circumstances. Load may be shed either manually or automatically depending on the rate of voltage drop.

*A. Voltage collapse prediction index (VCPI)*

The voltage collapse and precisely voltage collapse prediction index accurately predict the points of voltage collapse and determines the voltage stability allocation for each bus. It indicates how far the bus is from its collapse point. This is derived from the basic load flow equation,

$$S_k = V_k * I_k^* \qquad (1)$$

Here $S_k$ is the complex power at bus k, $V_k$ is the voltage phasor at bus k and $I_k$ is the current phasor at bus k. The equation (1) can be separated into its real and imaginary parts as follows.

$$f_1(V_k,\delta)=IV_kI^2-\left|V_K\right|^2-\sum_{\substack{m=1\\ m\neq k}}^{n}\left|V_m\right|\left|V_K\right| \cos\delta_k \qquad (2)$$

$$f_2(V_k,\delta)=\sum_{\substack{m=1\\ m\neq k}}^{n}\left|V_m\right|\left|V_k\right| \sin\delta_k \qquad (3)$$

Solving equation (1) and (2), we get:

$$VCPI_{k^{th}bus}=\left|1-\frac{1}{V_k}\sum_{\substack{m=1\\ m\neq k}}^{n}\left|V_m\right|\right| \qquad (4)$$

The values of VCPI determine the proximity to voltage collapse at a bus. The value of VCPI varies from 0 to 1, where, [4]

VCPI=0, the bus is stable

VCPI=1, the bus is unstable

*B. Sensitivity Analysis*

The voltage stability at a bus can also be determined from the sensitivity analysis. Here voltage to reactive load sensitivity is calculated. This expresses the slope of a curve, where the voltage is given as a nonlinear function of reactive power at the same bus. The number will increase to an infinite value when the critical voltage is approached. Due to the nonlinearity in the network behavior, the sensitivity figure is valid only in the close vicinity of the actual voltage. The changes in real and reactive powers with respect to change in voltage magnitudes and voltage phase angles for a power system can be computed from the linearized power flow equations given below: [2]

$$\frac{\Delta V}{\Delta R}=J_R^{-1}=\{J_{QV}-(J_QJ_PJ_V)\}^{-1}$$

The $J_R^{-1}$ is reduced to *V-Q* Jacobian matrix [5]. The $i^{th}$ diagonal element of the reduced Jacobian matrix gives the sensitivity at $i^{th}$ bus.

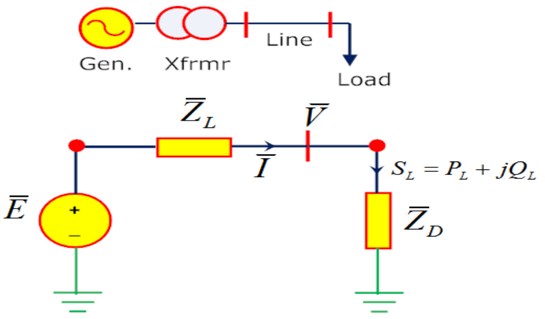



Fig. 3. A simple machine system

Voltage stability may occur in different ways. A simple case of voltage stability can be explained by considering the two terminal network of Fig. 3. In this system, the network is represented by an equivalent generator that can be modeled in the steady state by an equivalent voltage source E behind the equivalent impedance $Z_g$. In general, the generator, transformer and line impedances are combined together and represented as $Z_L$. The load impedance is $Z_D$ and $V$ is the receiving end or load voltage. The current I in the circuit is given by;

$$\bar{I}=\frac{\bar{E}}{\bar{Z_l}+\bar{Z_d}}$$

$$=\frac{\bar{E}}{Z_l\angle\theta+Z_d\angle\phi}$$

$$=\frac{\bar{E}}{(Z_l\cos\theta+Z_d\cos\phi)+j(Z_l\sin\theta+Z_d\sin\phi)}$$

The magnitude of current is

$$I=\frac{\bar{E}}{\sqrt{(Z_l\cos\theta+Z_d\cos\phi)^2+(Z_l\sin\theta+Z_d\sin\phi)^2}}$$

Which may be written as,

$$I=\frac{E}{Z_l\sqrt{F_L}}$$

Where $F_L$ is

$$F_L=1+\left(\frac{Z_d}{Z_l}\right)^2+2\left(\frac{Z_d}{Z_L}\right)\cos(\theta-\varphi)$$

Thus the magnitude of voltage is given by

$V=Z_D * I$

$$=\frac{E}{\sqrt{F_L}}\cdot\frac{Z_d}{Z_L}$$

And power is given by $P_L=V\,I\cos\varphi$

$$P_L=\frac{Z_d}{F_l}\cdot\left(\frac{E}{Z_l}\right)^2\cos\varphi$$

The plots of I, V and $P_L$ are shown in Fig. 6.10 as a function of $Z_l/Z_d$ ratio for a specific value of φ and θ.

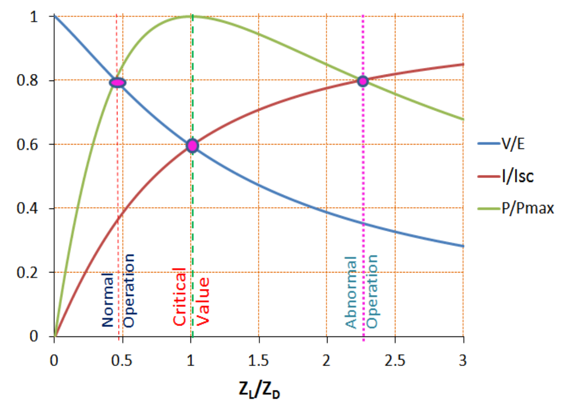



Fig 4: curve between $Z_L/Z_D$ and various parameters.

An explanation of the characteristics of Fig.4 is as follows:

1. As the load demand is increased by reducing $Z_D$, the load power $P_L$ increases rapidly at first and then slowly, before reaching a maximum value and then starts decreasing. There is thus, a maximum value of active power that can be transmitted through impedance from a constant voltage source.
2. The transmitted power reaches a maximum when the voltage drop in the line is equal to the load voltage V. This occurs, when the load impedance $Z_D$ is equal to line impedance $Z_L$. As $Z_D$ is gradually reduced, current in the line I increases and load voltage V decreases. Initially, for high values of $Z_D$, the enhancement in I is more than the reduction in V, and hence load power $P_L$ increases rapidly with reduction in $Z_D$. As $Z_D$ approaches $Z_L$, the effect of the enhancement in I is only slightly greater than that of the reduction in V, hence increase in $P_L$ is slow. Finally, when $Z_D$ is quite less than $Z_L$ the reduction in V dominates over increase in I and h ence, $P_L$ decreases.

## III. EFFECT OF LOAD TYPE ON VOLTAGE STABILITY

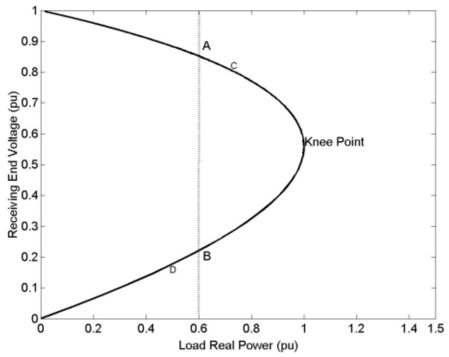



Fig.5. P-V Curve

Consider the P-V curve shown in Fig. 5. For a given real power consumed by the load there are two possible receiving end voltages. As can be seen from operating points A and B from Fig. 5, for a real power of 0.6*pu* there are two receiving end voltages of 0.85*pu* and 0.20*pu,* approximately. If the load is a constant MVA load, then the operating point A is stable, whereas the operating point B is unstable. In fact for a constant MVA load any operating point below the knee point is unstable. This phenomenon can be understood from the Fig. 5. Suppose due to some disturbance the operating point moves from point A to C. At the operating point C the real power is more than the real power at operating point A. Since, the load is constant MVA load the current will decrease and therefore the operating point move back from C to A. The operating point may not stop immediately at operating point A but may oscillate around it and will settle down with enough damping. Hence, the operating point A is a stable operating point. Now consider the operating point B. Again let the operating point move to point D due to disturbance. At operating point D the real power is less than that at operating point B. Since the load is a constant MVA load at operating point D the current increases, as compared to operating point B, which leads to a further voltage drop and further increase in the line current. This phenomenon continues till the voltage at the receiving end becomes zero and hence called as voltage collapse. Therefore, the operating point B is unstable operating point. It can be observed from P-V curve that the curve above knee point has $dV_R/dP_L$ negative that is the change in real power and voltage are in opposite direction, for a increase in power voltage decreases and for a decrease in power voltage increases. The curve below the knee point has positive $dV_R/dP_L$ and at the knee point $dV_R/dP_L$ is zero.[1]

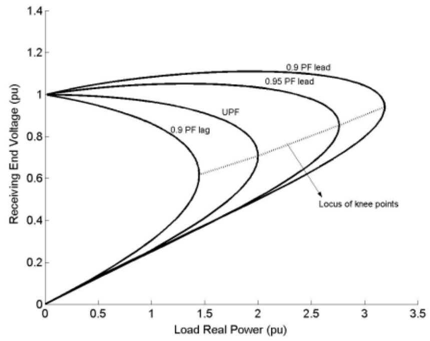



Fig.6 P-V curve for different pf(s)

Figure 6 show the P-V curves for loads with different power factors. It can be observed from the figure that as the load power factor moves from lagging to leading the knee point is shifted towards higher real power and higher voltage. This shows that the voltage stability improves as the power factor moves from lagging to leading loads.

## IV. LOSS OF SYNCHRONISM

Any unbalance between the generation and load initiates a transient that causes the rotors of the synchronous machines to “swing” because net accelerating (or decelerating) torques are exerted on these rotors. If these net torques are sufficiently large to cause some of the rotors to swing far enough so that one or more machines “slip a pole,” synchronism is lost. To assure stability, a new equilibrium state must be reached before any of the machines experience this condition. Loss of synchronism can also happen in stages, e.g., if the initial transient causes an electrical link in the transmission network to be interrupted during the swing. This creates another transient, which when superimposed on the first may cause synchronism to be lost.

Now consider a severe impact initiated by a sizable generation unbalance, say excess generation. The major portion of the excess energy will be converted into kinetic energy. Thus most of the machine rotor angular velocities will increase. A lesser part will be consumed in the loads and through various losses in the system.

However, an appreciable increase in machine speeds may not necessarily mean that synchronism will be lost. The important factor here is the angle difference between machines, where the rotor angle is measured with respect to a synchronously rotating reference.

## V. SELF RESTORATION MECHANISM IN THE NEW CONCEPT OF FRAMEWORKING A NEW MODEL

It is observed that whenever a cascading failure occurs, it leads to a split of phase in the system. When a system splits its one part becomes power deficient and a frequency decrease takes place there whereas for the other part a power surplus takes place in the other part with the frequency increase. The part with power surplus might be slightly elevated in frequency which could retard the merging process. So to overcome this device called AUFLS1 which responds to the frequency decrease or the rate of its variation stops the frequency fall. Owing to the time delays in the operation of automatic devices, during this operation other stages begun to act which additionally disconnects the consumers' lines, as a result of power surplus the frequency slightly increases. The restoration of frequency to the normal level is performed by the AUFLS2 whose successful operation is ensured by the retiming setting at the rated frequency level.

## VI. PREVENTION MEASURES

Some of the control actions used as counter measures against voltage collapse is as follows:

- Switching of shunt capacitors
- Blocking of tap-changing transformers
- Re-dispatch of generation
- Rescheduling of generator and pilot bus voltages
- Secondary voltage regulation
- Load shedding

## VII. CONCLUSION

This paper on the techniques for the prevention of voltage system collapse provides a preventive plan to minimize the chances of failure in the power system as possible. To identify the system vulnerability in the network, the power system simulations are performed. Many aspects are analyzed to understand the constraints on the system and select the appropriate methods to solve the problem efficiently. This paper is a case study of power system study and implementation on the preventive measures to enhance the stability, reliability and security of the power system.

## VIII. FUTURE SCOPE

There is an international tendency to increase the power transfer limit in the network and to improve the efficiency of existing power plants. The reasons are on the one hand the huge economic cost of new investments and the growing environmental concern, and on the other hand the considerable economic benefit be gained. This will raise the requirements for more sophisticated plan and models and there will be ongoing efforts to maintain and to improve the reliability of the power system. Therefore, the need to improve planning and operation in power system, underline the importance of future work in the voltage stability field.

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