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# Power System Grid Blackout Mitigation Using Branch Participation

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**Abstract**

Considering a lot of precautionary methods still all over the world an existing loss is not mitigated yet. A new technique is needed with computational intelligent to mitigate the power system blackout. Instead of cutting a line totally we can insert a resistance in the line to reduce the receiving end power and hence a delay in cascading with avoidance overloading of the other lines. Complete system is a mitigated from blackout. For this we attempted a methodology by inserting a resistance in the most effected lines to decrease the load on line to avoid from reply operation as well as cascaded process leading to total collapse. Although method seems to be economical small loss but a mitigated blackout will overcome this loss million folds.

**Key Words:** Power system, Blackouts, branch participation

## Introduction

Analytical work includes development of various voltage collapse indices for predicting system performance during the structural and topological changes in the power system. The impact of these changes leads to progressive and uncontrollable event of voltage degradation causes voltage instability of the power system. The problem may occur over a period of minutes to hours starting with a gradual decrease in system voltage. These phenomena have been observed in many countries like Belgium, Japan, France, and Sweden and even in US. These incidents are caused by large and small disturbances. Large disturbances consist of the loss of generators, transmission lines and transformers. Small disturbances on the other hand consist of slow variation in system load. The common techniques used for voltage stability assessment during these disturbances are discussed in the literature.

## VOLTAGE STABILITY AND BLACKOUT:

Voltage stability is concerned with 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. 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 protections leading to cascading and ultimately blackout.

The main factor contributing to voltage instability is usually the voltage drop that occurs when active and reactive power flow through inductive reactance associated with the transmission network; this limits the capability of transmission network for power transfer. The power transfer is further limited when some of the generators hit their field or armature winding time-overload capability limits. The driving force for voltage instability is the load; in response to a disturbance, power consumed by the loads tends to be restored by the action of distribution voltage regulators, tap changing transformers, motors, and thermostats. Restored loads increase the stress on the high voltage network causing further voltage reduction. A run-down situation causing voltage instability occurs when load dynamics attempt to restore power consumption beyond the capability of the transmission network and the connected generation, leading to a condition with sustained imbalance in reactive power [3, 4, 5].

Small-disturbance voltage stability is concerned with a system's ability to control voltages when subjected to small perturbations such as incremental changes in system load. This form of stability is determined by the characteristics of loads, continuous controls, and discrete controls at a given instant of time. This concept is useful in determining, at any instant, how the system voltage will respond to small system changes. System equations can be linearized for analysis thereby allowing computation of valuable sensitivity information useful in identifying factors influencing stability. Voltage instability may occur in several different ways. From figure a constant voltage source (Es) supplying a load (ZL) through a series impedance Z. This is representative of a simple radial feed to load or a load area served by a large system through a transmission line.

The critical condition corresponding to maximum power represents the limit of satisfactory operation. For higher load demand, control of power by varying load would be unstable; that is, a decrease in load impedance reduces power. Whether voltage will progressively decrease and the system will become unstable depends on the load characteristics. With constant-impedance static load characteristics, the system stabilizes at power and voltage levels lower than the desired values. On the other hand, with a constant-power load characteristic, the system becomes unstable through collapse of the load bus voltage.

**REDUCED JACOBIAN MATRIX BASED INDICATOR:**

Motivated Parameters based on measurement of system conditions are useful for planning and operating purposes to avoid the situation where a system collapse might occur. The problem with P-V and Q-V curves is that, although reliable, they are rather time consuming to be computed. Hence other indices that do not require exhaustive calculations and derive the parameters in real time have been sought and proposed. Rapid derivation and analysis of these parameters is important to initiate automatic corrective actions fast enough to avoid collapse under emergency conditions which arise due to topological or very fast load changes. Appropriate effective indicators could be based on reduced load flow Jacobian matrix. The general load flow analysis can be formulated as:

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = [J] \begin{bmatrix} \Delta\theta \\ \Delta V \end{bmatrix} \quad (1)$$

$$[J] = \begin{bmatrix} J_1 & J_2 \\ J_3 & J_4 \end{bmatrix} \quad (2)$$

$$J_1=\partial P/\partial\theta,\ J_2=\partial P/\partial V,\ J3=\partial Q/\partial\theta,\ J4=\partial Q/\partial V \quad (3)$$

where J represents the load flow Jacobian matrix. It contains the first derivatives of active and reactive power mismatch equations, ∆P=∆P (θ, V) and ∆Q=∆Q (θ, V), with respect to the voltage magnitude V and angles θ. In [9], it is proposed to reduce the Jacobian to the first derivative of reactive power equations in relation to voltage magnitude by assuming that the generator and load buses present no active power variation, i.e. ∆P=0. Jacobian matrix J in (1) can be reduced as follows:

$$\Delta Q=J_R.\Delta V \quad (4)$$

$$J_R=J_4-J_3J_1^{-1}J_2 \quad (5)$$

where $J_R$ is reduced Jacobian matrix. The singular value of this reduced matrix can be used to determine proximity to voltage collapse. As demonstrated in [2] and [6], these singular values provide better indications than the ones obtained from J matrix. It is valuable to mention that sub-matrix $J_3$ is quasi symmetric, due to small value of transmission system resistances. Therefore one expects a similar attribute for JR, making the singular values and eigenvalues practically identical, since symmetric matrices have similar singular value and eigenvalue decomposition.

**Q-V SENSITIVITY INDICATORS**

It is quite valuable if a few critical parameters that can be directly measured could be used in real time to quickly indicate proximity to collapse. An example of such indicator is sensitivity of the generated reactive powers with respect to load parameters and voltage magnitude. Q-V sensitivity analysis calculates the relation between voltage change and reactive power change.

$$\Delta V= J_R^{-1}\Delta Q \quad (6)$$

where

∆V incremental change in bus voltage magnitude

∆Q incremental change in bus reactive power

$J_R^{-1}$ reduced Jacobian matrix

The elements of the inverse of the reduced Jacobian matrix JR-1 are Q-V sensitivities. The diagonal components ∂Vi/∂Qi are the self-sensitivities and the nondiagonal elements ∂Vk/∂Qi are the mutual sensitivities. The sensitivities of voltage-controlled buses are equal to zero. For a quite stable system when Q decreases at specified bus or buses, its effect on the voltage magnitude of the system buses should be minor. The sensitivity indices are interpreted as follows:

Positive sensitivities: Stable operation; the smaller the Sensitivity, the more stable the system. As stability decreases,

The magnitude of the sensitivity increases, becoming infinite at the stability limit (maximum loadability).

Negative sensitivities: Unstable operation. The system is not controllable, because all reactive power control devices are designed to operate satisfactorily when an increase in Q is accomplished by an increase in V.

**Q-V MODAL INDICATOR**

Modal analysis approach has the added advantage that it provides information regarding the instability procedure. Voltage stability characteristics of the system can be identified by computing the eigenvalues and eigenvectors of the reduced Jacobian matrix JR.

$$JR = \xi \Lambda \eta \quad (7)$$

$$\xi = \eta^{-1} \quad (8)$$

where,

Λ diagonal eigenvalue matrix

ξ right eigenvector matrix

η left eigenvector matrix

$\xi_i$ ith right eigenvector, ith column of right eigenvector matrix

$\eta_i$ ith left eigenvector, ith row of left eigenvector matrix

Using modal analysis technique, equation (6) is transformed to:

$$v = \Lambda^{-1} . q \quad (9)$$

where,

$v = \eta \bullet \Delta V$ vector of modal voltage variations

$q = \eta \bullet \Delta Q$ vector of modal reactive power variations

The difference between equations (6) and (9) is that $\Lambda^{-1}$ is a diagonal matrix whereas the reduced Jacobian matrix in general is nondiagonal. The inverse transformation is given by:

$$\Delta V = \xi . \ v \quad (10)$$

$$\Delta Q = \xi . \ q$$

Eigenvalues obtained from Q-V modal analysis can be interpreted as follows:

Positive eigenvalue: The system is voltage stable. The smaller the magnitude, the closer the ith modal voltage is to become unstable. The magnitude of the eigenvalues can provide a relative measure of the proximity to instability.

Zero eigenvalue: The ith modal voltage collapses because any change in that modal reactive power causes infinite change in the modal voltage.

Negative eigenvalue: The system is voltage unstable.

In addition, some other useful indices could be extracted from Q-V modal analysis. In certain conditions of the system due to variations and disturbances one or more modes, which are diagonal elements of Λ, may be excited. According to these modes, Q-V modal based indices present good insight about of voltage instability weak points and indicate how the system elements respond to certain variations and which areas are more influenced. These indices are as follows:

Bus participation factor: The relative participation of a bus in a certain mode is given by the bus participation factor. Bus participation factors determine the areas associated with each mode. Thus, weak voltage areas or unstable (not controllable) areas are identified. The sum of all the bus participation factors for each mode is equal to unity. The size of bus participation in a given mode indicates the effectiveness of remedial actions applied at that bus in stabilizing that mode. Branch participation factor: The relative participation of branch j in a certain mode is given by the participation factor defined by:

$$P_j = \Delta Q_{loss\_j} / \max[\Delta Q_{loss\_j}] \quad (11)$$

Branch participation factors indicate that for each mode, which branches consume the most reactive power in response to an incremental change in reactive load. Branches with high participations are either weak links or are heavily loaded. Branch participations are useful for identifying remedial measures to alleviate voltage stability problems and for contingency selections.

Generator participation factor: The relative participation of machine m in a certain mode is given by the generator participation factor defined by:

$$P_m = \Delta Q_m / \max[\Delta Q_m] \quad (12)$$

Generator participation factors indicate that for each mode, which of the generators supply the most reactive power in response to an incremental change in system reactive loading. Generator participations provide important information regarding proper distribution of reactive reserves among all the machines in order to maintain an adequate voltage stability margin.

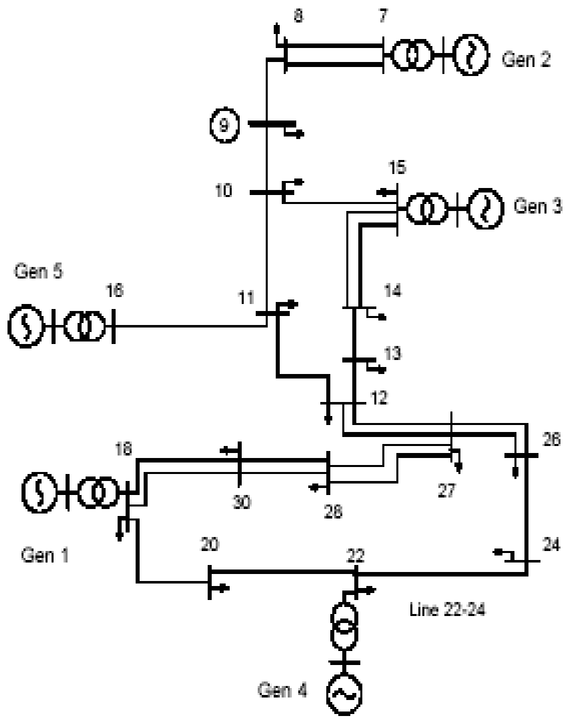


**Figure 1: Studied complex power system**

Fig. 1 shows the power system simulated for studying voltage collapse indices introduced in this paper. NEPLAN software is used to model this system. The system includes five generators Gen-1 to Gen-5, which in total delivers 800 MW to loads as the reference normal operating condition. The main load centers are located at buses 12, 13, 26, 27 and 28. Different scaled load (based on the reference normal load) are considered for the power system and for each condition a load flow study is performed. Obtained results from these studies are used to determine P-V and Q-V based indices.

The highest branch participation factor

An important result reveals that line 22-24 consumes the most reactive power.

Hence, the line 22-24 and buses 9, 24, 26 and 28 are weak parts of the system. To increase system reliability and prevent voltage collapse, these parts should be supported by adding new transmission lines or reactive power resources. To simulate a voltage collapse case, load of bus-9 can be increased until collapse point is reached. Variations of the voltage collapse proximity indices can be evaluated during this load increase.

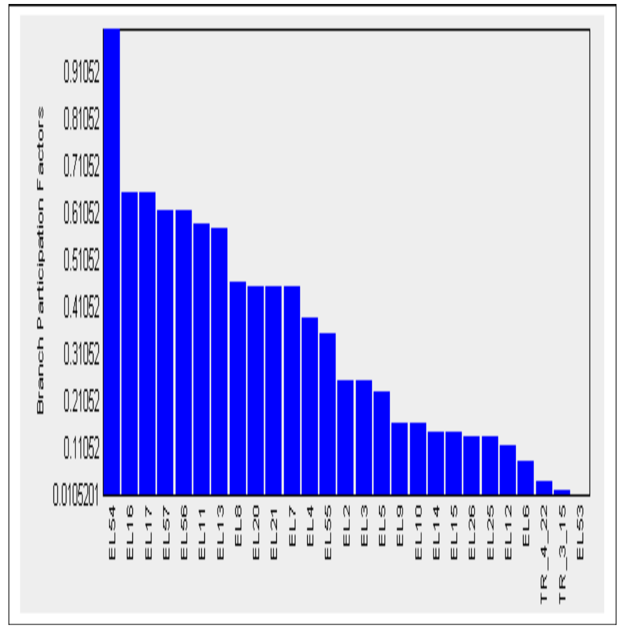


**Figure 2: Branch participation factor**

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To increase system reliability and prevent voltage collapse, these parts should be supported by adding new transmission lines or reactive power resources.

To simulate a voltage collapse case, load of bus-9 can be increased until collapse point is reached. Variations of the voltage collapse proximity indices can be evaluated during this load increase. Most effected branch EL54 is on verge of disconnect as highest loaded branch. By inserting a resistive compensation in the highest loaded branch will cause the reduction of the apparent power from this branch. This will increase the line loss. But the new situation of loading is in very important to be analysis. Compensation causing more branches to participate Comparison before and after compensation Addition of new compensation in the line caused the participation of power to other buses but with less difference.

Now important factor is that new line taking highest participation is EL11. This line is not on the verge of collapse as power loss is only 0.31 MW in comparison to line EL 54 where power loss is 9.19 MW. Before compensation loss on EL 11 was 0.23 MW and loss on EL 54 was 1 MW.

This method is very effective if broadly analysis the losses occurred due to power system blackout with the losses due to increased resistive load. For a temporary moment sudden insertion may divert the power from most effected line to other line which is not having much burden. After fault removal the system can come to normal operating stages. As this line EL 11 is not overloaded even though highest participation is taking place. If without requirement this branch is tried to be compensated then again branch EL 54 is getting highest participation, which is dangerous thing for the system leading to collapse.

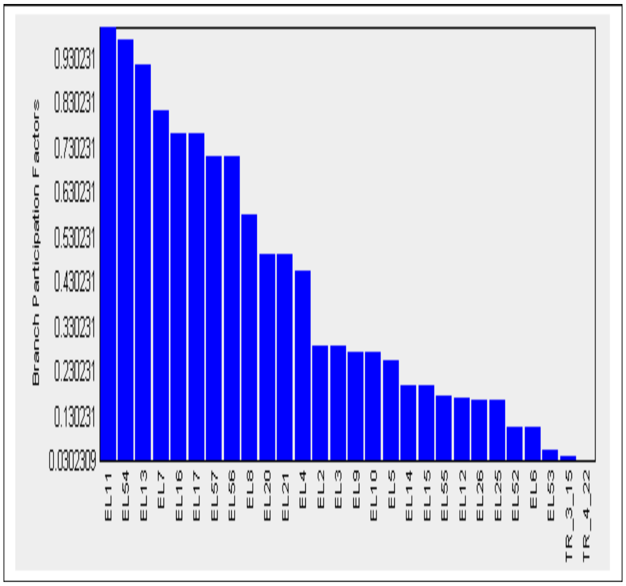


**Figure 3: Branch participation factor after line resistance increased**

Hence this resistive sudden compensation is most effective for mitigation of blackout just by adding only overloaded branches if they are also in the highest participation stage.

**CONCLUSION:**

Changing the resistance to high value angle reduces and causes the stability of the line. Because receiving power reduction is avoiding the relay operation to trip the line. Tripping of the line causes other lines to be over loaded. Other lines getting tripped to crossing of load limit. Instead of cutting a line totally we can insert a resistance in the line to reduce the receiving end power and hence a delay in cascading with avoidance overloading of the other lines. Complete system is mitigated from blackout.

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