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Reliability Analysis of Power Systems Using Neural Network

Fouzul Azim Shaikh

JMI, New Delhi, India

gaibimadad@gmail.com

Abstract

Stability is a condition of equilibrium between opposing forces. Depending on the network topology, system operating mode and the form of disturbance, different sets of opposing forces may experience sustained imbalance leading to different forms of instability. Using artificial neural network heterogeneous voltage instability problem analysis is shown in this paper along with modal analysis for voltage stability.

Keywords: Neural Networks, Reliability, Voltage Stability, Complex Power System

INTRODUCTION

The 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 this paper.

Voltage Instability

Voltage instability is concerned with the inability 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.

Reliability of supply has been considered implicitly since the beginnings of power supply in that planners chose network topologies, which were tolerant of frequent equipment failures. Such plausibility considerations continue to be used in network planning to this day in the form of the (n-1) criterion. The principle behind the (n-1) criterion is that the not improbable failure of an item of equipment must not be allowed to result in an unacceptable interruption in the power supply. A certain amount of discretion is applied in the use of this "principle of simple reliability" since it is assumed that the failure of a number of groups of elements is unlikely (e.g. such assumptions are often made for buses), and these are therefore excluded from the failure study. On the other hand, the judgment as to the permissible length of a short-term interruption in the context of switchovers depends on the philosophy of the utility company concerned. The (n-1) criterion therefore requires specific interpretation guidelines in order to be applied in practice. When using the (n-1) criterion, the planner investigates all failures manually and ascertains whether the existing resources in the network are sufficient to reestablish the supply to customers within an acceptable time. If this is not the case, the scope for enhancing the network is reviewed. 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 [4] and [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.

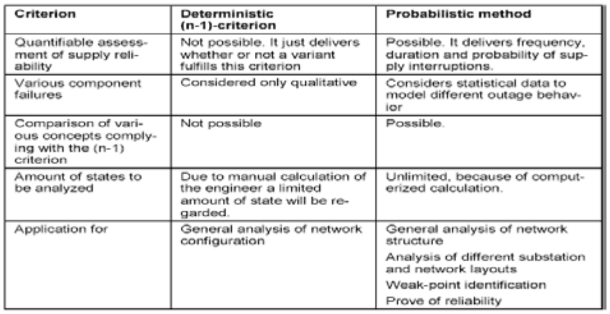
Artificial Neural Networks

In the recent years, ANN has been proposed as an alternative method for solving certain difficult problems where conventional techniques have not achieved the desired speed, accuracy and efficiency [2]. The artificial neural network consists of an input layer, an output layer and at least one hidden layer, with each layer consisting of a set of neurons. The neurons are interconnected. It is a feed forward network composed of an organizing topology of interconnected processing element (PE) called neurons or nodes. Nodes of each layer are fully connected to those of the succeeding layer through connection weights. The input layer serves only to transfers its input information, without processing to the next layer. The transfer function can be a sigmoid or a hyperbolic tangent function. With supervised learning, pairs of input-output data are presented to the output layer through the hidden layers. At the output layer, the error between the desired and computed value is determined. The error is back propagated and weights adjusted according to the gradient descent technique. The whole procedure is repeated until the root mean square (RMS) at the output layer falls below a small-prespecified value, usually between 0.1 and 0.01. The RMS error is obtained by summing squares of the errors for each PE in the output layer, dividing by the number of PEs and taking the square root of the average. Weight connections are randomly generated between –0.1 and 0.1 at the initiation of the learning phase. Learning and momentum coefficients are incorporated in the weight adjustments to speedup the convergence process while reducing error oscillations. Input-output data are usually scaled between 0 and 1 or –1 and 1, depending on the type of transfer function employed. To test the trained network generalization ability, the mean absolute error (MAE) is used.

Probabilistic Reliability Calculation

Reliability calculation constitutes an enhanced and automated procedure for applying the (n-1) criterion. However, there are essential differences are (a) In contrast to the (n-1) criterion; in reliability calculation a large number of system states are investigated. The number of states examined is limited by the maximum number of elements simultaneously affected by the failure or the minimum probability of the state. (b) The examination of the consequences due to occurring faults runs automatically. Therefore the network model needs to comprise the protection devices and switching possibilities in the case of failures. (c) It is not just independent single failures in the network that are examined; all types of failure, which have proved in the past to be significant sources of problems, are examined. The advantages of probabilistic methods are shown in the following Table 1.

Table 1: Advantages of Probabilistic Methods



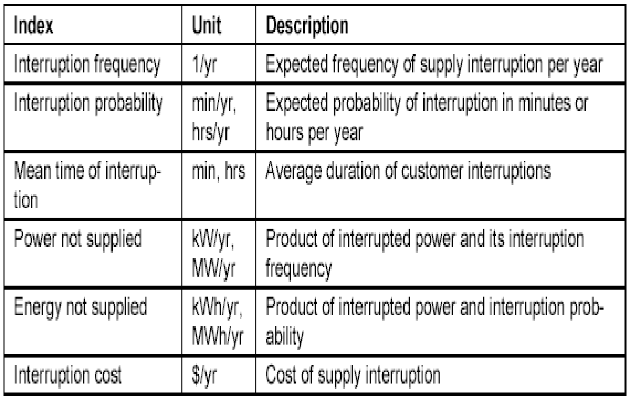
Criterion	Deterministic (n-1)-criterion	Probabilistic method
Quantifiable assessment of supply reliability	Not possible. It just delivers whether or not a variant fulfills this criterion	Possible. It delivers frequency, duration and probability of supply interruptions.
Various component failures	Considered only qualitative	Considers statistical data to model different outage behavior
Comparison of various concepts complying with the (n-1) criterion	Not possible	Possible.
Amount of states to be analyzed	Due to manual calculation of the engineer a limited amount of state will be regarded.	Unlimited, because of computerized calculation.
Application for	General analysis of network configuration	General analysis of network structure Analysis of different substation and network layouts Weak-point identification Prove of reliability

Reliability data of components comprises a crucial part of the input data for the probabilistic reliability calculation. This outage data describes the frequency and mean duration of component failures.

Reliability Calculation Results

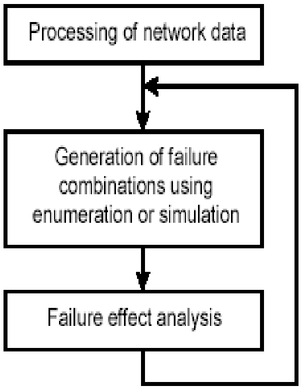
The indices of reliability calculation results are shown in the following Table 2

Table 2: The Indices of Reliability Calculation Results



Index	Unit	Description
Interruption frequency	1/yr	Expected frequency of supply interruption per year
Interruption probability	min/yr, hrs/yr	Expected probability of interruption in minutes or hours per year
Mean time of interruption	min, hrs	Average duration of customer interruptions
Power not supplied	kW/yr, MW/yr	Product of interrupted power and its interruption frequency
Energy not supplied	kWh/yr, MWh/yr	Product of interrupted power and interruption probability
Interruption cost	$/yr	Cost of supply interruption

In reliability calculation, the smallest contributors to problems are failure combinations. Such a failure combination describes the components, which are out of service at the same time due to either stochastic (as a result of failure) or determinate (as a result of maintenance activity) overlapping. The aim of reliability calculation is to determine and quantify the contribution made by all relevant failure combinations to the interruption in supply to the load nodes. Like the manual procedure used by the planner, this entails two major steps: generation of the failure combinations and investigation of the effects on the supply in the network (failure effect analysis, FEA). The first method of generating failure combinations is enumeration. This entails defining all possible combinations of elements above a specified minimum probability or up to a maximum number of components affected simultaneously. The alternative to enumeration is simulation, in which the affected components are determined randomly on the basis of their characteristic data.



Sequence of operations performed during reliability calculation

Fig. 1: Sequence of Operations Performed

Generating combinations of outages

The crucial part of these sequential operations is to generate failure combinations up to a certain order, i.e. the number of simultaneous failing components. For each combination the program determines the various "events" leading to this certain combination. Thus, e.g. a single order outage of a circuit breaker could occur due to protection over-function or false manual tripping by operation personnel. Double order contingencies might occur due to unlikely simultaneous independent component failures of failure overlapping component maintenance.

Failure effect analysis (FEA)

Failure effect analysis is performed on each failure combination. First, the tripping range of the components affected by the failure, as determined by the network protection system, is deactivated. The software then determines whether the supply of the loads is restricted in this state. If it is, an attempt is made to re supply the loads at least partially. Processing of a failure combination produces a value for the contribution of that combination to the reliability characteristics of the network, expressed as a probability. For each load node, figures are generated for the frequency and duration of non-supply or undersupply. The contribution of this failure combination is added to the factors already identified, so that after processing all relevant failure combinations, a detailed picture is obtained of the interruptions occurring at each load node.

Evaluation of Results

To make proper use of reliability calculation, criteria for analyzing the results are required. There are two different, complementary aspects to consider here. The first form of evaluation entails the categorization of the failure combinations on the basis of their effect on supply in the network. This categorization into acceptable and non-acceptable failure combinations is possible with both deterministic criteria and probabilistic criteria. The (n-1) criterion is an example of a deterministic criterion. Probabilistic criteria include the Zollenkopf criterion or the specification of a maximum interrupted power output, depending on the expected interruption frequency and duration.

The second aspect of the evaluation, which is only possible with probabilistic methods, is the categorization of the overall failure picture at each load node. If the customer's specific requirements are known, it is possible to categorize situations as either acceptable or unacceptable. However, the ideal way of evaluating supply reliability is to evaluate it in monetary terms. In network planning, in particular, this approach makes it easy to focus on investment and operating costs. Normally the costs taken are the costs incurred by the customer as a result of interruptions to the power supply. The main disadvantages of this approach are the great effort required to calculate these costs and the fact that in the case of public power supply these represent external costs for the utility. In Europe, penalty clauses are becoming increasingly widespread, such that, if minimum standards are not met, the utility company has to pay a fine to a regulatory agency, for example. In addition, as a result of deregulation, supply contracts under which utility companies are required to pay compensation in the event of interruptions to supply will be increasingly common. In these cases, only reliability calculation allows the possible benefits of different supply concepts and different local automation measures to be evaluated.

Reliability Calculations

Systems have to be modeled in detail for reliability calculations. E.g. switch bay topologies and durations for manual and remote switching play an important part during contingencies. Based on the load flow model a system needs additional data input for reliability analysis. A reliability study may typically include the following steps:

1. Model the study system for load flow calculations
2. Define topology of switchgear assemblies (incl. durations of switching operations)
3. Specify protection configuration of switchgear assemblies
4. Specify system grounding
5. Input and assign reliability data
6. Input load and generation characteristics (see calculation parameters); assign characteristics to load and generator elements
7. Possibly define failure groups
8. Adjust calculation parameters
9. Start calculation
10. Visualize results in the network diagram, by tables and charts
11. Possibly make additional evaluations
12. Possibly repeat steps 9. to 12. in order to analyze different study cases.

Tripping zones of circuit breakers needn’t to be defined by the user. The program automatically identifies them.

Reduced Jacobian Matrix Based Indicator

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 [5[. The general load flow analysis can be formulated as:

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

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

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

where J represents the load flow Jacobian matrix. It contains the first derivatives of active and reactive power mismatch equations, $\Delta P=\Delta P\ (\theta,\ V)$ and $\Delta Q=\Delta Q\ (\theta,\ V)$, with respect to the voltage magnitude V and angles θ [4]. In, 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. $\Delta P=0$. 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 [4], 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 J_R, 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
ΔV incremental change in bus voltage magnitude
ΔQ incremental change in bus reactive power
J_R^{-1} reduced Jacobian matrix

The elements of the inverse of the reduced Jacobian matrix J_R^{-1} are Q-V sensitivities. The diagonal components $\partial Vi/\partial Qi$ are the self sensitivities and the nondiagonal elements $\partial Vk/\partial Qi$ 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 Indicators

The 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 J_R.

$$J_R=\xi.\Delta.\eta \quad (7)$$

$$\xi_i=\eta_i^{-1} \quad (8)$$

where,
Δ diagonal eigenvalue matrix
ξ right eigenvector matrix
η left eigenvector matrix
ξi ith right eigenvector, ith column of right eigenvector matrix
ηi ith left eigenvector, ith row of left eigenvector matrix

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

$$\nu=\Delta^{-1}.q \quad (9)$$

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 Λ^{-1} is a diagonal matrix whereas the reduced Jacobian matrix in general is nondiagonal. The inverse transformation is given by:

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

$$\Delta Q=\xi.\nu \quad (11)$$

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:

$$P_j = (\Delta Q_{loss\_j})/(\max(\Delta Q_{loss\_j}) \qquad (11)$$

Branch participation factor It indicates 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:

$$P_m = (\Delta Q_m)/(\max(\Delta Q_m) \qquad (12)$$

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.

Simulation Studies

Fig. 1 shows the power system simulated for studying voltage collapse indices introduced in this paper.

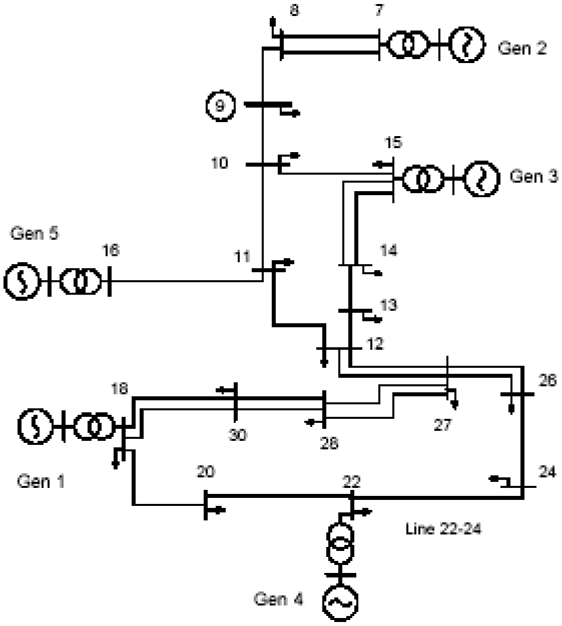


Fig. 2: Studied 23-bus Swiss system

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 26, 27, 12, 28 and 13. 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. Fig 2 shows bus participation factors. In this study, it is found that voltage of buses 26, 27, 12, 28 have the most sensitivity to reactive power variations, respectively.

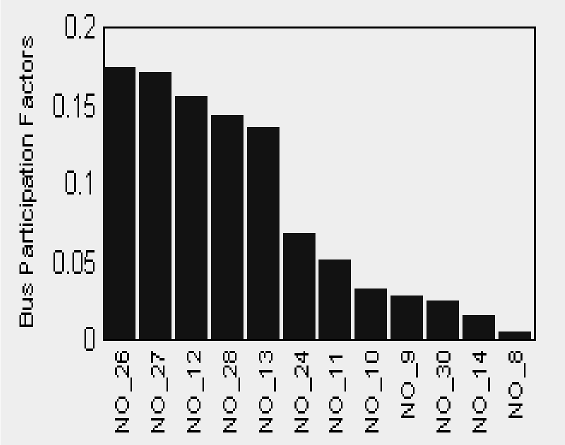


Fig. 3: Bus Participation Factor

The highest sensitivity corresponds to bus-26 which is far from generation and load centers. Hence, this bus is a weak point in the network.

Fig. 3 shows Q-V curves for the most sensitive buses. The distance between minimum points of the curves and voltage axis is defined as reactive power margin, which is an effective indicator for proximity to collapse. As shown in Fig. 3, this index is also minimum for bus-26. Consequently, referring to the mentioned analysis, bus-26 has a high potential for collapse and therefore, the voltage collapse indices are calculated by focusing on this bus.

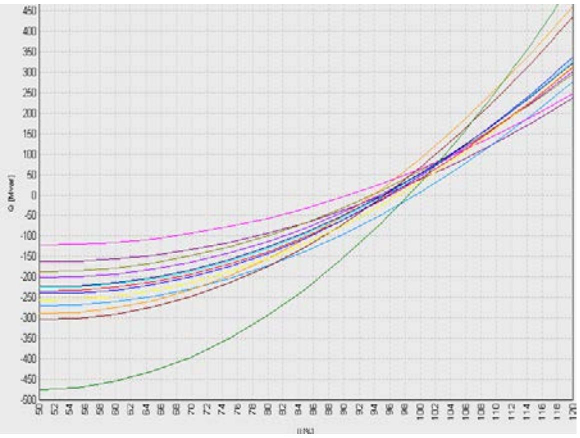


Fig. 4: Q-V curves for most sensitive buses

Table 3: The Smallest Modal Eigen Values of the studied Power System

Mode	Mode1	Mode2	Mode3	Mode4
Value	2.076	4.41	9.987	10.94

Table 3 depicts the results obtained from Q-V modal analysis. In Table 1 four smallest eigenvalues of the system are presented. The smallest eigenvalue of the system is for Mode-1. When this mode is excited, as shown in Fig. 5 below, Gen-3 is the most responsible generator for providing adequate reactive power change. According to Fig. 3, bus-26 has the highest bus participation factor and therefore the area around buses 26 and 27 is the most sensitive area when Mode-1 is excited.

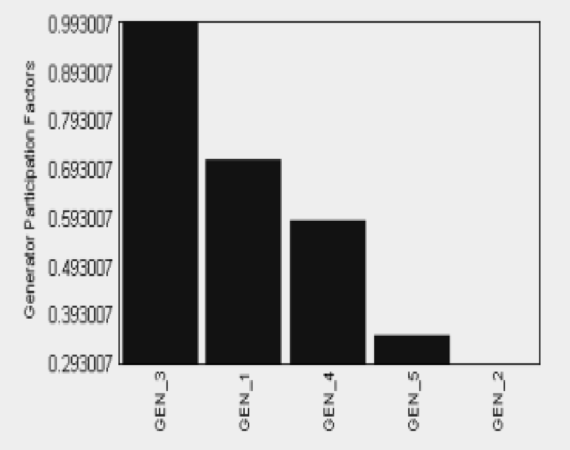


Fig. 5: Generator participation factor for Mode-1

Similarly, it is observed that for Mode-2, Mode-3 and Mode-4; Gen-2, Gen-1 and Gen-4 have the highest generator participation factors, respectively.

The area related to each mode can also be determined. An important result reveals that again for Mode-3 and Mode-4, line 22-24 consumes the most reactive power. Hence, the line22-24 and buses 9, 24, 26 and 28 are weak parts of the system.

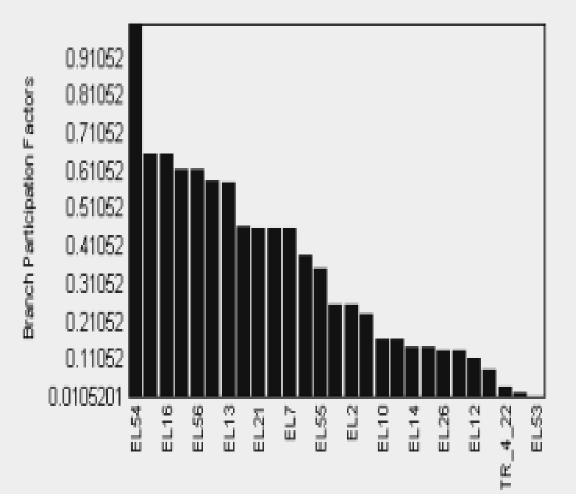


Fig 6: The highest branch participation factor for Mode-1

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-26 can be increased until collapse point is reached. Variations of the voltage collapse proximity indices can be evaluated during this load increase.

Applications of ANN and Results

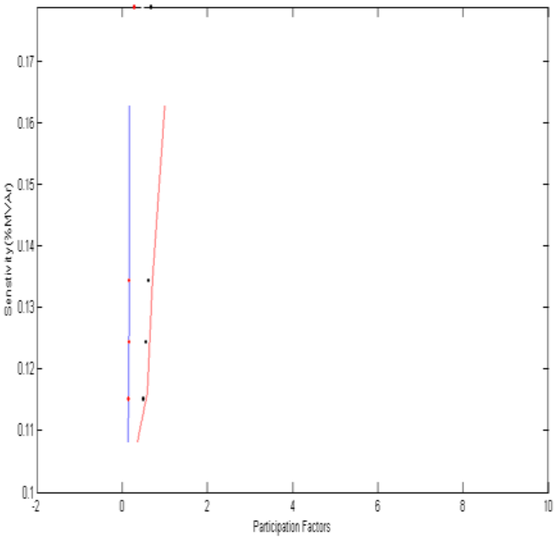


Fig. 7: Comparison between ANN and actual results for bus participation factor and self sensitivity

Table 4: Various Participation Factors.

S No.	Bus Participation Factor	Generator Participation Factor	Branch Participation Factor
1	0.174	1	1
2	0.1704	0.7151	0.6539
3	0.156	0.5898	0.6539

Now values of two participation factors namely bus participation factor and generator participation factor are taken from Table 4 as input to ANN model and respective sensitivity is taken as target to train the ANN model. Once ANN is trained some test values (as show in Table 5) are used to check the working of ANN.

Table 5 Random Test Values

S No.	Bus participation factor	Branch participation factor
1	0.148	0.163
2	0.203	0.363
3	0.484	0.556

As shown in Fig. 7 the actual result and result obtained by trained ANN are approximately equal (with in acceptable limits of error).

Conclusion

In this paper loadability of a sampled power system is studied and results obtained from this study is implemented and verified with ANN. The study could provide a good indication for possibility of a voltage collapse. ANN is used successfully for analyzing the power system's normal or abnormal condition

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REFERENCES

1. F. A. Shaikh, R. Balasubramanian, "Evaluation of Voltage Stability of Power Systems Using Neuro-Fuzzy Techniques", in *Proc., Workshop on Soft Computing,* International Conference on High Performance Computing (2002).
2. C. Canizares et. al.," Comparison of Performance Indices for Detection of Proximity to Voltage Collapse" , IEEE Trans. on Power System, vol.
3. S. Chen, B. Mulgrew, and P. M. Grant, "A clustering technique for digital communications channel equalization using radial basis function networks," *IEEE Trans. Neural Networks*, vol. 4, pp. 570–578, July 1993.
4. P. Kundur, *Power System Stability and Control*, McGraw-Hill, 1994.
5. G.K. Morison, B. Gao, P. Kundur, "Voltage Stability Analysis Using Static and Dynamic Approaches", IEEE Trans. On Power Systems, Vol. 8, No. 3, pp. 1159-1171, August 1993.
6. B. Gao, G.K. Morison, P. Kundur, "Towards The Development of a Systematic Approach for Voltage Stability Assessment of Large-Scale Power Systems", IEEE Trans. On Power Systems, Vol. II, No. 3, pp. 1314-1324, August 1996