International Journal for Innovative Engineering and Management Research
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IJIEMR Transactions, online available on 23rd Nov 2019. Link :http://www.ijiemr.org/downloads.php?vol=Volume-08&issue=ISSUE-11

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Volume 08, Issue 11, Pages: 263–272.

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# USE OF LOCAL MEASUREMENTS TO ESTIMATE VOLTAGE STABILITY MARGIN (VSM)

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## ABSTRACT

Estimating the proximity of power system to voltage collapse in real time still faces difficulties. Beside the data management and computational issues, any central-control method is subject to the reliability of long-distance data communications. On-line determination of the maximum permissible loading of a power system is essential for operating the system with an adequate security margin. A very simple and straightforward method of determining the maximum permissible loading and voltage stability margin of a power system using information about the current operating point is proposed. The method simply requires some locally measurable quantities, such as bus voltage magnitude, and active and reactive components of load power. The measured data are carefully processed to estimate the maximum permissible loading and voltage stability margin of a system.

## INTRODUCTION

Voltage instability has been regarded as one of the primary threats to the security of modern power network operation during the past few decades. Power system disturbances such as a continuous load increase and/or a major change in network topology can result in voltage collapse. The voltage collapse problem, which is characterized by the loss of voltage magnitude at certain locations of the power grid, has caused several severe blackout events worldwide. A number of planning and operation technologies have been proposed to mitigate the risk of voltage collapse. Among these technologies, phasor measurement unit (PMU) based schemes to secure power systems have become one of the enabling techniques which are under active investigations.

in the maintaining of quality and security of power supply due to ever-increasing interconnections and loading in large power system networks. Economic constraint has forced the utilities to operate generators and transmission systems very near to maximum loadability point. One of the major problems that may be associated with such a stressed system is voltage instability or collapse and that causes a steady-state security problem. To operate a power system with an adequate security margin, it is essential to estimate the maximum permissible loading of the system using information about the current operating point. The maximum loading of a system is not a fixed quantity but depends on various factors, such as network topology, availability of reactive power reserves and their locations etc. this paper deals with maximum permissible loading of a power system using some locally measurable quantities. When the loading of a power system approaches the maximum power or voltage collapse point, the voltage magnitude of a particular bus (or area) decreases rapidly. However, the voltage magnitude itself may not be a good index for determining the imminence of voltage collapse.

The voltage magnitude decreases because of inadequate local reactive power support to meet local demand and losses. Importing large amounts of reactive power from remote buses (or areas) may further deteriorate the voltage collapse. Determining the maximum permissible loading, within the voltage stability limit, is becoming a very important issue in power system operation and planning studies. The conventional P-V or V-Q curve is usually used as a tool for assessing voltage stability and hence for finding the maximum loading at the verge of voltage collapse. these curve are generated from the results of repetitive load flow simulations and thus involve a significant amount of computations.

Such an assumption is not very realistic. Also, the equivalent system used to estimate the maximum loading of the bus may not faithfully represent the original system over the entire operating range: several other methods, such as bifurcation theory, energy methods,A few studies have used static voltage stability limit for evaluating reliability indices. The Eigen value (or singular value) method, the multiple load flow solutions method, etc have been reported in the literature for assessing the voltage stability or for determining the maximum permissible loading of a system. All the methods described above require a considerable amount of calculations and thus cannot be candidates for on-line application.

The method used the complex voltage and current of a particular load bus to determine the relative strength or weakness of the transmission network connected to that bus. The measured voltage and current can also be used to design a digital relay for preventing voltage collapse by load shedding. The voltage stability of the system is then assessed through an extrapolation technique based on tangent vector behavior. The method described in this article is quite simple and does not require off-line simulation and training. Based on local measurement (voltage, active and reactive power it produces an estimation of the strength/weakness of the transmission system connected to the bus.

With the growing demand for electricity, several studies related to the planning and operation of electrical systems has increased its importance to guaranty the system voltage security. In addition to the increased demand, some factors such as the transfer of large amounts of power in the transmission and distribution networks, combined with the economic and environmental requirements conduces the system to operate in stressful conditions. Recent trends towards scale penetration of intermittent renewable energy sources into the grid exacerbate this situation making power systems mucho more vulnerable to stability and security issues.

This variability in generation, in addition to the existent load variability requires faster and efficient algorithms for monitoring of the power system. Voltage stability and security monitoring with continuation power flow (CPF) and methods based on the CPF are being incorporated in energy control centers. These methods allow the P-V curve drawing and the computation of the system's maximum loading point (MLP). This is important for the knowledge of voltage stability margin and modal analysis studies; this point provides information for determining effective measures for strengthening the system, since the MLP defines the boundary between regions of stable and unstable operation. The voltage stability has been considered a static phenomenon, due to slow variation of voltage over a long period until it reaches to the MLP and then it decreases rapidly to the voltage collapse. Static voltage stability can be analyzed by using saddle-node bifurcation theory.

Modern power grids are extremely difficult and widespread. Surges in power lines can cause massive network failures and permanent damage to multimillion dollar equipment in power generation plants. After electricity is generated at power plants it has to get to the customers that use the electricity. The transmission and distribution system delivers electricity from the generating site (electric power plant) to residential, commercial, and industrial facilities. The electricity first goes to a transformer at the power plant that boosts the voltage up to 400 kVA for transmission through extra-high voltage (EHV) transmission lines. When electricity travels long distances, it is improved to have it at higher voltages since the electricity can be transferred more efficiently at high voltages. High voltage transmission lines carry electricity long distances to a substation.

At transmission substations a decrease in voltage occurs for distribution to other points in the system through high voltage (HV) transmission lines. Further voltage reductions for commercial and residential customers take place at distribution substations, which connect to the primary distribution network. Transformers are a crucial link in the electric power distribution system. Utility transformers are high-voltage distribution transformers typically used by utilities to step down the voltage of electricity going into their customers' buildings. Distribution transformers are one of the most widely used elements in the electric distribution system.

They convert electricity from the high voltage levels in utility transmission systems to voltages that can safely be used in businesses and homes. Distribution transformers are either mounted on an overhead pole or on a concrete pad. Most commercial and industrial buildings require several low-voltage transformers to decrease the voltage of electricity received from the utility to the levels used to power lights, computers, and other electric-operated equipment. Distribution System The part of power system which distributes electric power for local use is known as distribution system. In general, the distribution system is the electrical system between the substation fed by the transmission system and the consumers' meters. It usually consists of feeders, distributors and the service mains.

## LITERATURE

**M. Kezunovic, J. D. McCalley, and T. J. Overbye (2012)** P-V or Q-V curve are commonly used to determine the maximum permissible load or static voltage stability limit of a power system. Voltage versus current relation approximation is presented as a tool to assess. The voltage stability limit. determination of the maximum permissible loading of a power system is essential for operating the system with an adequate security margin. A very simple and straightforward method of determining the maximum permissible loading and voltage stability margin of a power system using information about the current operating point is proposed. The method simply requires some locally measurable quantities, such as bus voltage magnitude, and current data at present operating point. The measured data are carefully processed to estimate the maximum permissible loading and voltage stability margin of a system. The proposed method is tested on IEEE 6-bus and 14-bus system.

**C. Zheng and M. Kezunovic (2010)** Estimating the proximity of power system to voltage collapse in real time still faces difficulties. Beside the data management and computational issues, any central-control method is subject to the reliability of long-distance data communications. On-line determination of the maximum permissible loading of a power system is essential for operating the system with an adequate security margin. A very simple and straightforward method of determining the maximum permissible loading and voltage stability margin of a power system using information about the current operating point is proposed. The method simply requires some locally measurable quantities, such as bus voltage magnitude, and active and reactive components of load power. The measured data are carefully processed to estimate the maximum permissible loading and voltage stability margin of a system.

**C. Zheng and M. Kezunovic (2008)** The primary objective of this dissertation is the utilization of an integrated and effective framework for voltage stability assessment and control based on computational intelligence techniques. A method based on artificial neural network (ANN) was developed to estimate the voltage stability margin (VSM) of a power system in real time and used for initiating appropriate control actions. The developed ANN method should provide accurate estimation for any system condition. A new method for generating training samples for ANN was proposed in this dissertation in order to take correlation of loads at different locations and variation of control settings into consideration. The next focus of this thesis is the development of a black-box optimization algorithm requiring minimum human intervention. The algorithm has to be capable of handling practical engineering optimization problems with complex cost characteristics, mixed-integer variables and a large number of constraints.

**C. Zheng and M. Kezunovic (2012)** This paper presents a new approach for estimating and improving voltage stability margin from phase and magnitude profiles of bus voltages using sensitivity analysis of Voltage Stability Assessment Neural Network (VSANN). Bus voltage profile contains useful information about system stability margin including the effect of loadgeneration pattern, line outage and reactive power compensation, so it is adopted as input pattern of VSANN. In fact, VSANN establishes a functionality for VSM with respect to voltage profile. Sensitivity analysis of VSM with respect to voltage profile and reactive power compensation extracted from information stored in the weighting factor of VSANN is the most dominant feature of the proposed approach. Sensitivity of VSM helps one to select the most effective buses for reactive power compensation aimed enhancing VSM. The proposed approach has been applied to IEEE 39-bus test system which demonstrated applicability of the proposed approach.

**Y. She, X. She, and M. E. Baran (2011)** This paper proposes an online steady-state voltage stability assessment scheme to evaluate the proximity to voltage collapse at each bus of a load area. Using a non-iterative holomorphic embedding method (HEM) with a proposed physical germ solution, an accurate loading limit at each load bus can be calculated based on online state estimation on the entire load area and a measurement-based equivalent for the external system. The HEM employs a power series to calculate an accurate Power-Voltage (P-V) curve at each load bus and accordingly evaluates the voltage stability margin considering load variations in the next period. An adaptive two-stage Pade approximants method is proposed to improve the convergence of the power series for accurate determination of the nose point on the P-V curve with moderate computational burden. The proposed method is illustrated in detail on a 4-bus test system and then demonstrated on a load area of the Northeast Power Coordinating Council (NPCC) 48-geneartor, 140-bus power system.

## METHODOLOGY

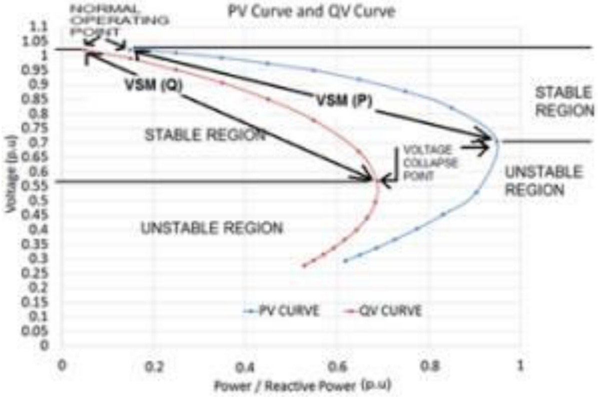
### Voltage Stability Margin (VSM)

Voltage stability margin (VSM) is defined as the distance between the normal/initial voltages operating point until the voltage critical/collapse point. VSM can be divided into two categories which are VSM for real power of load (P) and VSM for reactive power of load (Q). VSM (P) and VSM (Q) are obtained from PV and QV curve as shown in Figure. It can be seen that the smaller value of VSM, the closer the bus of the power system towards voltage instability and vice versa. VSM can be depicted by using Equation:

$$VSM = \text{hypotenuse distance} \mid v_{initial} - v_{critical} \mid$$

where, Vinitial is the bus voltage at normal operating point

Vcritical is the bus voltage at voltage collapse point



**Graph PV and QV curve**

## Load Power Margin (LPM)

Similar to VSM, load power margin (LPM) can be divided into two categories which are LPM for real power of load (P) and LPM for reactive power of load (Q).LPM (P)shows the distance of the real power (P) of load from the normal voltage operating point until the voltage collapse point as depicted in Figure.

$$LPM\ (P) = (P_{critical} - P_{initial})$$

where, Pcritical is the value of load (MW) at voltage collapse point

Pinitial is the value of load (MW) at normal operating point

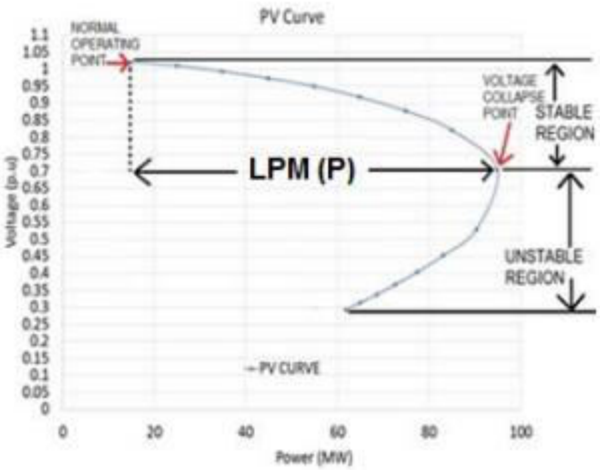


**Figure LPM (P) in PV curve**

LPM (Q) on the other hand is used to measure the distance of the reactive power (Q) of load from the base voltage operating point until the voltage critical point as shown in Figure. Equation (3) can be used to calculate LPM (Q).

$$LPM\ (Q) = (Q_{critical} - Q_{initial})$$

where, Qcritical is the value of load (MVAR) at voltage collapse point

Qinitial is the value of load (MVAR) at normal operating condition.

## Artificial Neural Network (ANN)

Type 1: Predicting VSM and LPM Values

The ANN model will be used in this approach to predict the values of VSM and LPM. Two ANN types which are the MLPBP ANN model and ANFIS model are chosen for this task. MLPBP networks are the most widely used of ANN model especially in data predictions, forecasting, pattern recognition and others. In this approach, an optimised MLPBP model is used to predict the values of VSM (P), VSM (Q), LPM (P) and LPM (Q). The inputsof the optimized MLPBP model for both VSM

(P) and VSM (Q) predictions are the values of Vinitial, Vcritical, load at normal operating point and load at collapse point. These values can be obtained in the PV and QV curve. Figure depicts the optimised MLPBP model. MATLAB is used to run the optimized MLPBP model as shown in Figure.

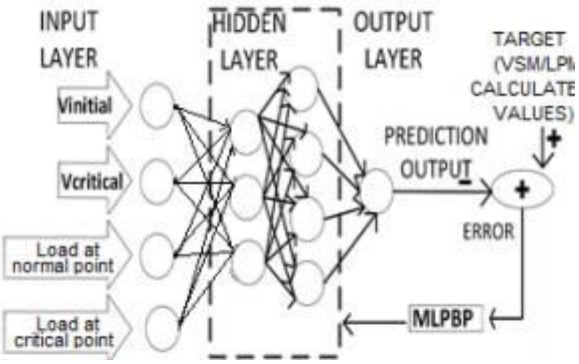


**Figure Optimised MLPBP ANN model**

Adaptive Neuro-Fuzzy Inference System or ANFIS is an architecture that consists a combination of ANN with Sugeno typed fuzzy logic. In ANFIS system, the ANN method such as backpropagation is used to improve the membership functions and rules of the fuzzy system. Figure shows the basic ANFIS structure.

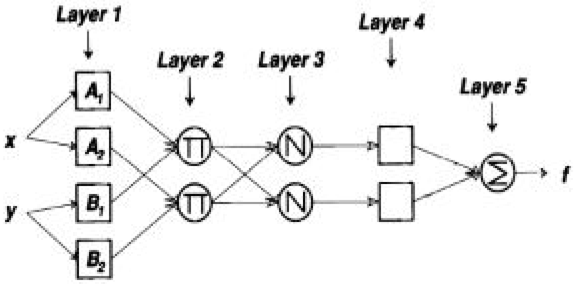


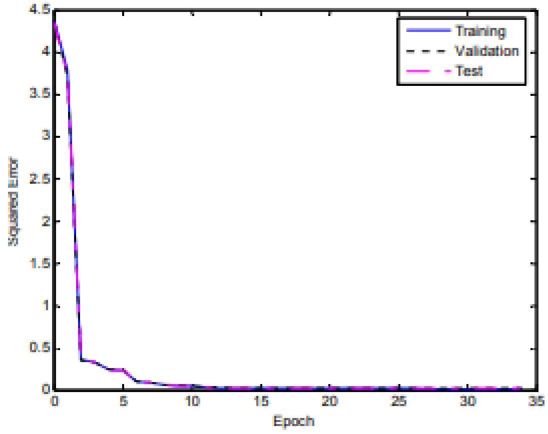
**Figure Basic ANFIS structure**

Figure depicts that there are five layers in an ANFIS structure. The first layer consists of the fuzzy's membership functions. At the second layer, the minimum value of two input weights from the first layer is chosen. Then, the chosen weights are normalized in the third layer. The fourth layer contains linear functions of the input signals. Finally, the fifth layer sums all the incoming signals to produce final output. MATLAB is used to run the ANFIS as shown in Figure.

### Type 2: Classification of VSM and LPM values

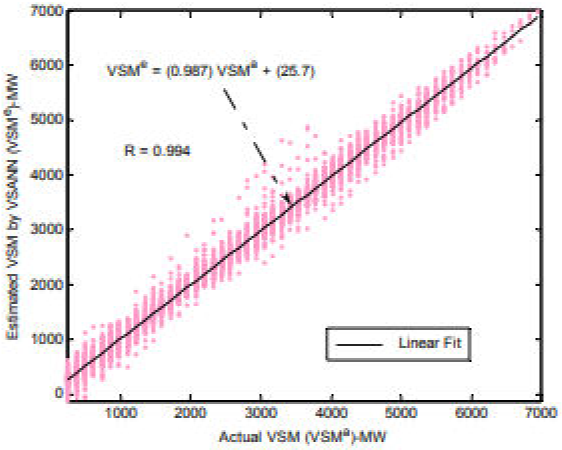
In this research, probabilistic neural network (PNN) is used to classify the calculated values of VSM and LPM. According PNN is best used for classification purposes. Figure shows the basic PNN structure. Basically, PNN has four layers. The input layer will be the data that need to be classified (in this research, the calculated values of VSM and LPM).

In order to prepare training data, 23 load increase patterns are adopted and by means of CPF calculation system load is incrementally increased until the point of loadability limit. Load increase patterns are chosen in such variety that corresponding loadability limits lie in the range of 7000 to 12800 MW. With respect to each loading pattern, during load increment toward voltage collapse various operating points with associated load level, voltage profile and VSM are created. In order to embed the effect of network topology and reactive power compensation into voltage profiles and corresponding VSM, for some loading patterns network topology is changed by line outages or reactive power are injected at some buses. By this way 10269 operating points with a wide variety in voltage profile and VSM are generated and used for training VSANN.



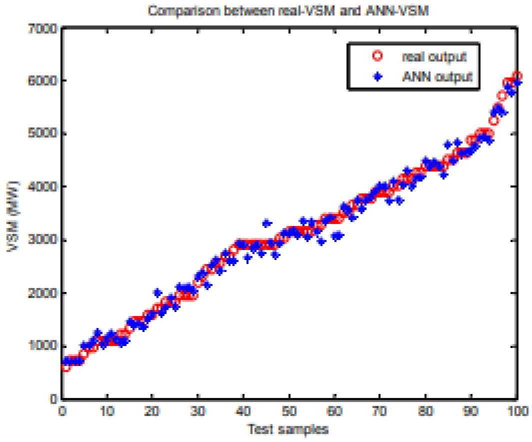
**Graph Trend of errors corresponding to training, validation and testing in 34 epochs of training**

After data preparation, 30% , 10% and 60% of total 10269 patterns are used for training, validating and testing VSANN respectively. The training patterns are selected from those operating points whose VSM cover the whole range of feasible variation of system conditions including the effect of line outage and reactive power compensation. For each training pattern, the original input variables are 78 variables consisting of voltage magnitudes and phase angles of 39 buses. By applying the PCA transformation on original 78 operating variables through 3081 training patterns, they are reduced to 8 main components.



**Graph Post regression analysis on TRAINLM.**

Fig. shows the trend of errors corresponding to training, validating and testing VSANN. At the end of training process of VSANN, Mean Square Error (MSE) and epoch reached 0.0113 and 34 respectively. In addition to training, validating and testing errors, another post-training analysis denoted as regression analysis has been performed relating VSANN response to the actual values to investigate the performance of the trained VSANN. For this purpose, linear regression between VSANN outputs and exact values is used to determine the accuracy of VSANN. In Fig, the outputs of VSANN are plotted versus the exact values, while its slope and correlation coefficient are about 0.987 and 0.994 respectively which are very close to 1 indicating good performance of VSANN.



**Graph Comparison between exact VSM and ANN output.**

## CONCLUSION

The techniques that allow us to identify these interconnected subsystems make use of the singular perturbation approach. Using Lyapunov's second method, we determine the necessary and sufficient conditions for achieving global asymptotic stability following large disturbances in such systems. We show that global asymptotic stability can be realized by damping oscillations based on control laws which only depend on local measurements. Furthermore, we infer by simulations on IEEE standard test beds that a better damping of oscillations is obtained if the control devices are installed on buses close to the boundaries of the control areas. Furthermore, regression models are developed between the available reactive power in a region with its local voltage stability margin.

Hence, in future research work, models may be enhanced with the path-dependent terms included. Another direction of research that can be explored for the development of decentralized stability analysis is the application of subsystem-wise spectral analysis schemes. Furthermore, current schemes are only implemented on IEEE standard test beds. A better approach consists in assessing the applicability of the method in a real utility power system by using the transmission system data of a large electric utility. The methods of uncertainty quantification of control decisions can be expanded to both local and global levels..

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