

# Voltage Stability Monitoring Using Adaptive Neuro-Fuzzy Inference System

V.Ramkumar, S.Baghya Shree

PG Scholar, Anna University Regional center Madurai, India

Assistant Professor, Department Of E.E.E, University College of Engineering, Dindugul, India

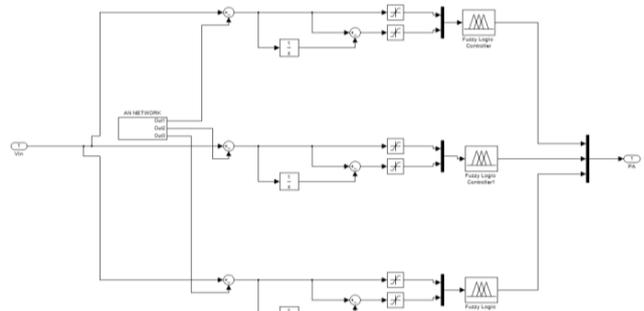
**ABSTRACT**-This paper presents an application of (ANFIS) for monitoring power system voltage stability. The training of ANFIS is accomplished by adapting information received from local and remote measurements as inputs and fast indicators providing voltage stability information of the whole power system and one at each particular bus as outputs. The use of feature reduction techniques can decrease the number of features required and thus reduce the number of system quantities needed to be measured and transmitted. In this paper, the effectiveness of the proposed algorithm is tested under a large number of random operating conditions on the standard IEEE 14-bus system and the results are encouraging. Fast performance and accurate evaluation of voltage stability indicators have been obtained. Finally, the idea of applying load shedding based on voltage stability indicator as one of potential countermeasures is described.

**KEYWORDS**-Neurofuzzy;Upfc;Ivdr

## 1. INTRODUCTION

Voltage stability has been of the keen interest of industry and research sectors around the world since the power system is being operated closer to the limit whereas the network expansion is restricted due to many reasons such as lack of investment or serious concerns on environmental problems. There are several works previously proposed to predict the voltage stability and proximity to voltage collapse based on conventional approach, for example PV and QV curves, sensitivity based indices and continuation methods. Other methods, such as bifurcation theory, energy function singular value decomposition, etc have been also reported in the literature. These methods provide complete and accurate results but they are usually hampered by the fact that they consume long computing time because of the requirement for repetitive power flow calculations. To suit the online

monitoring requirement, fast, accurate and easily interpretable indicators are desired. Few examples of pioneering but still popular indicators are the L-index and Voltage Collapse Proximity Index (VCPI). These indicators provide sufficiently accurate assessments but, however, they usually require complete topological information of the system under consideration. W. Nakawiro and I. Erlich are with the Institute of Electric Power System, University of Duisburg- Essen, Bismarckstr. 81, 47057 Germany .Recently, the wide area monitoring system consisting of phase measurement units (PMUs) and high-speed communication links provides snapshots of current power system variables where PMUs are connected. Based on the simple method proposed in for determining Thevenin equivalent parameters, few voltage stability indicators can be determined based only on voltage and current information provided by PMU at local buses. Examples of those are Power Transfer Stability Index (PTSI), Power based Voltage Stability Margin (PVSM). This method is very suitable for implementing on a protective device because no communication for system data acquisition is required and its action can be autonomously undertaken.



Online voltage security assessment is a very useful but not yet becomes a widely used tool that measures the distance from the current operating condition at any time

to the critical point. ADAPTIVE NEURO FUZZY INFERENCE SYSTEM have recently received widespread attention from researchers for this application. Most of ANFIS applications have been implemented using multi-layered feed-forward neural networks trained by back propagation because of their robustness to input and system noise, their capability of handling incomplete or corrupt input data. However, in typical power systems there are voluminous amount of input data. Then, the success of ANFIS applications also depends on the systematic approach of selecting highly important features which will result in a and brief summary of considered indices are presented in some Section compact and efficient ANFIS. Different feature reduction methods are compared in this paper. This paper is organized as follows. The method of real-time tracking of Thevenin equivalent presents the design of the proposed method. Simulation results are given in section IV and section V concludes the paper and suggests the future work.

**II. DETERMINATION OF FAST VOLTAGE STABILITY INDICATORS**

In this part, several voltage stability indicators are calculated. It should be mentioned here that this paper aims at implementing these already proposed indicators by ANFIS. The capability of monitoring proximity to voltage collapse was tested beforehand, but unfortunately due to space limitation and scope of this paper the complete results cANFISot be presented. However, the corresponding references given in the earlier section will enable the avid readers to regenerate the same results.

**2.1 Tracking Thevenin Equivalent (TTE)**

Consider a load bus k having a load demand of  $S_k = P_k + jQ_k$  connected to the rest of power system. The voltage equation at bus k at time t taken from measurement j can expressed as;

$$U_{TH}^t = U_{k,j}^t + Z_{TH}^t I_{k,j}^t$$

**2.2 Minimum Singular Value (MSV)**

The proximity to voltage collapse can be traced by monitoring zero-convergence of the smallest singular value. For the real n x n Jacobian matrix, the singular value decomposition is given by,

$$J = U \Sigma V^T = \sum_{i=1}^n u_i \sigma_i v_i^T$$

**2.3 Voltage Collapse Proximity Index (VCPI)**

The voltage collapse proximity index (VCPI) can be calculated based on the voltage phasor information of participating buses and topological data of the system. The VCPI of bus k can be found from,

$$VCPI_k = \frac{1 - \sum_{m=1, m \neq k}^N U_m}{U_k}$$

**2.4 L – Index**

The Line (L) index can be derived from information of a normal power flow solution. It can be calculated for each bus j according to,

$$L_j = 1 - \sum_{i \in \alpha G} F_{ji} \frac{U_i}{U_j}$$

**2.5 Power Transfer Stability Index (PTSI)**

The power transfer stability index (PTSI) represents the ration of load bus apparent power to maximum allowable one with the knowledge of Thevenin equivalent parameters, PTSI can be determined from,

$$PTSI = \frac{2S_L Z_{TH} (1 + 2 \cos(\beta - \phi))}{U_{TH}^2}$$

**2.6 Power based Voltage Stability Margin (PBVSM)**

Based on the fact that the magnitude of load impedance becomes equal to the magnitude of Thevenin impedance at the maximum load ability point, the power based voltage stability margin (PVSVM) can be expressed as,

$$PVS = \frac{(Z_{L-} Z_{TH})^2}{Z_{TH}^2 + Z_{L+} 2Z_{TH} Z_{L} \cos(\beta - \phi)}$$

Voltage stability has been of the keen interest of industry and research sectors around the world since the power system is being operated closer to the limit whereas the network expansion is restricted due to may reasons such as lack of investment or serious concerns on environmental problems. There are several works previously proposed to predict the voltage stability and proximity to voltage collapse based on conventional approach, for example PV and QV curves, sensitivity based indices and continuation methods Other methods, such as bifurcation theory, energy function singular value decomposition ,etc have been also reported in the literature. These methods provide complete and accurate

results but they are usually hampered by the fact that they consume long computing time because of the requirement for repetitive power flow calculations. Online voltage security assessment is a very useful but not yet becomes a widely used tool that measures the distance from the current operating condition at any time to the critical point. ADAPTIVE NEURO FUZZY INFERENCE SYSTEM have recently received widespread attention from researchers for this application. Most of ANFIS applications have been implemented using multi-layered feed-forward neural networks trained by back propagation because of their robustness to input and system noise, their capability of handling incomplete or corrupt input data. However, in typical power systems there are voluminous amount of input data. Then, the success of ANFIS applications also depends on the systematic approach of selecting highly important features which will result in a compact and efficient ANFIS. In this part, several voltage stability indicators are calculated. It should be mentioned here that this paper aims at implementing these already proposed indicators by ANFIS. The capability of monitoring proximity to voltage collapse was tested beforehand, but unfortunately due to space limitation and scope of this paper the complete results can't be presented.

### III. PROPOSED METHODOLOGY

#### 3.1 Proposed ANFIS – Based Method

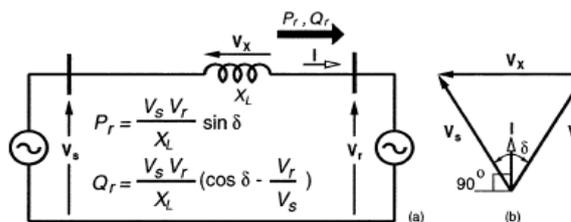
Training data sets for ANFIS training are generated by varying both real and reactive loads at all the buses randomly in the range of 60% –120% of their base case values at the constant power factor and utilizing the corresponding power flow solutions. All generators in the system share the additional generation needed to meet the increased load demand equally. Power flow program is conducted at all steps and corresponding voltage stability indicators are calculated. The Power System Analysis Toolbox (PSAT) was used as a computing tool. Collection of these data constitutes the training data set.

#### 3.2 UPFC Description:

UPFC is the most comprehensive multivariable flexible ac transmission system (FACTS) controller. Simultaneous control of multiple power system variables with UPFC poses enormous difficulties. In addition, the complexity of the UPFC control increases due to the fact that the controlled and the control variables interact with each other. The Unified power flow controller (UPFC) enables independent and simultaneous control of a transmission line voltage, impedance, and phase angle. This has far reaching benefits: in steady state, the UPFC can be used to regulate the power flow through the line and improve utilization of the existing transmission

system capacity; and, during power system transients, the UPFC can be used to mitigate power system oscillations and aid in the first swing stability of interconnected power systems

Electric power flow through an ac transmission line is a function of the line impedance (R, XL), the magnitudes of the sending-end voltage Vs, and the receiving-end voltage Vr, and the phase angle δ, between these voltages as shown in Fig.2. The expressions for power flow at the receiving-end of the line are shown, considering the line is represented in its simplest form with a reactance XL.



**Fig.2 (a) Simple power transmission, (b) Phasor diagram.**

An uncompensated active and reactive power flow in a transmission line is typically not optimal. If the reactive power flow in the line is reduced, the freed up capacity of the line can be effectively utilized to carry an increased amount of active power. As a consequence, the generator is no longer required to supply the reactive power.

The efficiencies of the generator and its coupling transformer also increase. Therefore, the independent control of active and reactive power flow in a transmission line delivers the most revenue from an ac transmission system.

Due to the recent increases in their variety and ratings, an increasing number of high power semiconductor devices are available for power system applications; particularly in flexible ac transmission systems (FACTS) apparatus. The unified power flow controller (UPFC) is one of the FACTS devices. The invention of the unified power flow controller has seeded research in two directions. One direction is concerned with its applications. The second direction is concerned with the power electronic realization of the UPFC and its performance characteristics. The UPFC has three independent degrees of freedom, by which the real power through a radial line and the reactive powers at both ends of the line can be simultaneously controlled. It has also the reassuring internal flexibility that its shunt converter can be used as a stand-alone STATCOM its series converter as a stand-alone series capacitor compensator (SSSC) or combinations of the two. With this device, the real and reactive power flows in a transmission line can rapidly and precisely be controlled. The UPFC consists of

two voltage-sourced converters (VSCs) using thyristors which operate from a common dc-circuit consisting of a dc-storage capacitor. The UPFC could be described as consisting of a parallel and a series branch. Each converter can independently generate or absorb reactive power. This arrangement enables free flow of active power in either direction between the ac-terminals of the two converters. The function of the parallel converter is to supply or absorb the active power demanded by the series branch. This converter is connected to the ac-terminal through a parallel-connected transformer. If required, it may also inject leading or lagging reactive power directly into the connection busbar. The second (series connected) converter provides the main function of the UPFC by injecting an ac-voltage with controllable magnitude and phase angle. The transmission line current flows through this voltage source, resulting in an active and reactive power exchange with the ac-system.

### 3.3 UPFC connected to a transmission line.

The real power coordination discussed in this project is based on the known fact that the shunt converter should provide the real power demand of the series converter. In this case, the series converter provides the shunt converter control system an equivalent shunt converter real power reference that includes the error due to change in dc link capacitor voltage and the series converter real power demand. The control system designed for the shunt converter in cause's excessive delay in relaying the series converter real power demand information shunt converter.

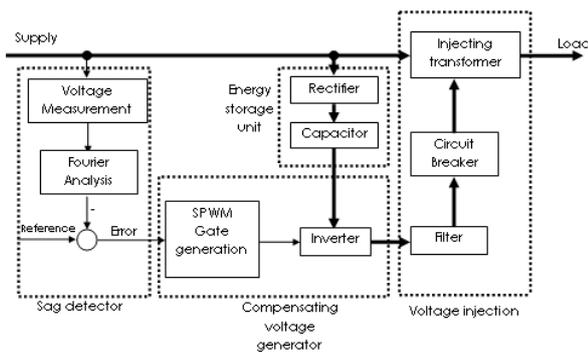


Fig 3 : IVDR

The reference voltage is the supply 11 kV with certain tolerance. The DVR will not operate on small voltage variation events to keep the operational losses to a minimum. In this study, a tolerance of 550V (5% of rated voltage) is considered.

Computation of the compensating voltage is done using a comparator with one input as the variable system voltage and the other input being the fixed reference voltage. The comparison (subtraction) is done for magnitude only, since the compensation strategy is the In-phase method. The output of the comparator determines the voltage

required to be injected by the DVR, and is called the error signal.

### 3.4 Generation of the Compensating Voltage

The inverter is the core component of the DVR, and its control will directly affect the performance of the DVR. In the proposed DVR, a sinusoidal PWM scheme will be used. The inverter used in this study is a six-pulse inverter, the carrier waveform is a triangular wave with high frequency (1000 Hz in the study). The modulating index will vary according to the input error signal.

The basic idea of PWM is to compare a sinusoidal control signal of normal 50 Hz frequency with a modulating (or carrier) triangular pulses of higher frequency. When the control signal is greater than the carrier signal, three switches of the six are turned on, and their counter switches are turned off. As the control signal is the error signal, therefore, the output of the inverter will represent the required compensation voltage.

## IV. SIMULATION RESULTS AND DISCUSSION

The standard IEEE 14-bus system is used to test the ability of the proposed ANFIS-based voltage stability monitoring system. It has a slack bus (bus 1), 4 voltage controlled buses (buses 2,3,6,8), 9 load buses without attached generation (buses 4,5,7 and 9-14) and 2 additional loads are connected to voltage controlled buses 2 and 3. The base load of the test system is 385.95 MVA. In this paper, real and reactive power demand ( $P_d, Q_d$ ), real and reactive power generation ( $P_g, Q_g$ ) and voltage magnitude and angle of each bus ( $U_b, \delta$ ) are obtained from power flow calculations of random operating states and constitute as a full set of measured quantities.

Reactive power limits are imposed at all PV buses except bus 1 which is assumed to be an infinite bus. The entire data set consists of 3000 samples, with 20% validation and 20% testing. The performance of the proposed ANFIS-based method is presented in terms of errors which are defined as the maximum error ( $em_{ax}$ ) and RMS error ( $er_{ms}$ )

$$em_{ax} = \max\{|Tq - Oq|\}, q = 1, 2, \dots, NO$$

$$er_{ms} = \sqrt{\frac{1}{p_{max}} \sum_{q=1}^{p_{max}} \frac{1}{NO} \sum_{q=1}^{NO} [t_{qp} - o_{qp}]^2}$$

In this paper, a fast method for monitoring voltage stability margin using ANFIS is proposed. Several indicators were used to define the proximity of the system to voltage instability.

The proposed ANFIS-based system was successfully implemented to predict the voltage stability indicators for random operating conditions of the IEEE 14-bus system. The simulation results reveal the followings;

1. The variation of the indicators presented in section II with respect to change in system load is so smooth and predictable that the system security can be periodically monitored. It should be emphasized here that only one or few indicators may be chosen in real practice. This papers aims at comparing some of those already proposed in literatures.

2. Feature reduction is crucial for the success of ANFIS application, although each has its own merit and demerit. Feature selection based on clustering technique can identify important parameters directly measurable from the power system. In this paper, 14 out of 49 features (28%) are shown to be adequate in describing the problem. This method has some drawbacks in that those 14 features were selected from different clusters sharing the same characteristics. These chosen features may not necessarily be to characterize the whole system. On the other hand, feature extraction is fast and highly accurate. However, this method requires full set of system information which may not be obtainable in practical cases.

3. The results of voltage stability indicators predicted by the proposed ANFIS-based method are very close to the actual values calculated. Additionally, the response time of the ANFIS model is extremely fast.

The proposed method is quite promising for real world application. Further studies can focus on artificial intelligence methods, such as particle swarm optimization or evolutionary programming, applying to optimize preventive and corrective controls with minimum cost while ensuring system security and reliability. Incomplete and noise contained input data which represent practical situation scan be considered.

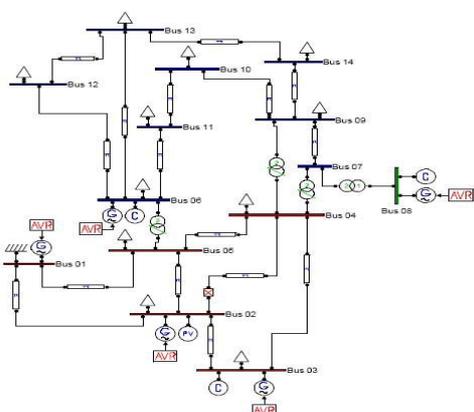
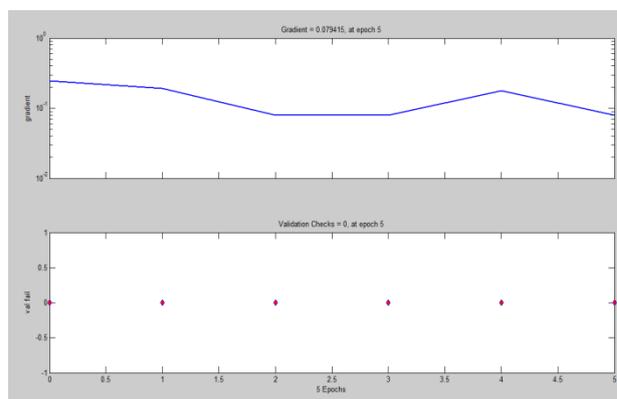


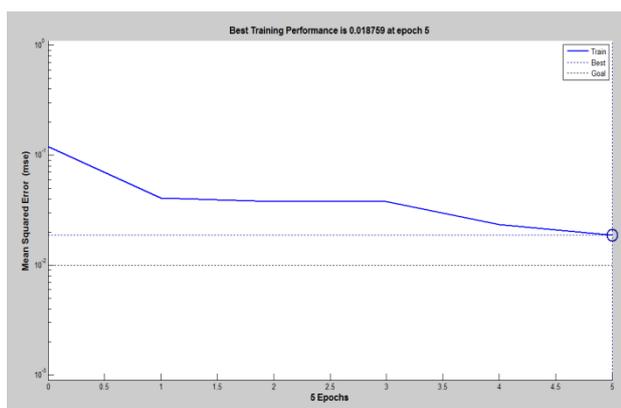
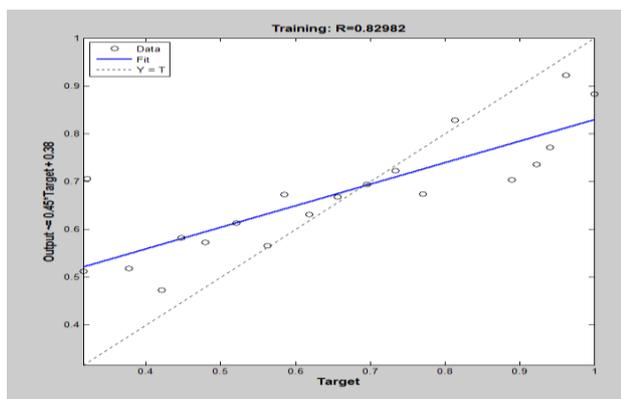
Fig:4 IEEE 14 BUS SYSTEM

## V. CONCLUSION

A fast method for monitoring voltage stability margin using ANFIS is proposed. several indicators were used to define the proximity of the system to voltage instability. The proposed ANFIS-based system was successfully implemented to predict the voltage stability indicators for random operating conditions of the IEEE 14-bus system. The simulation results reveal that the variation of the indicators presented with respect to change in system load is so smooth and predictable that the system security can be periodically monitored. It should be emphasized here that only one or few indicators may be chosen in real practice. Feature reduction is crucial for the success of ANFIS application, although each has its own merit and demerit. Feature selection based on clustering technique can identify important parameters directly measurable from the power system. This method has some drawbacks in that those 14 features were selected from different clusters sharing the same characteristics. These chosen features may not necessarily be to characterize the whole system. On the other hand, feature extraction is fast and highly accurate. However, this method requires full set of system information which may not be obtainable in practical cases. The results of voltage stability indicators predicted by the proposed ANFIS-based method are very close to the actual values calculated. Additionally, the response time of the ANFIS model is extremely fast. The proposed method is quite promising for real world application. Further studies can focus on artificial intelligence methods combined fussy applying to optimize preventive and corrective controls with minimum cost while ensuring system security and reliability.



## Voltage Stability Monitoring Using Adaptive Neuro-Fuzzy Inference System



- [8]. **R.P.Klump&T.J.Overbye** 1996 The simplest way of evaluating the impact of contingencies on long-term voltage stability is by computing the post contingency long term equilibrium.
- [9]. **D.Maratakulam** 1992 The locations for electricity generation are based on the presence of energy sources availability. If the reactive power along the line is reduced the freed up capacity of the line can be used to increase the flow of active power.
- [10]. **L.Gyugyi** 1994 The wave form of voltage at the buses of a power system to be a constant frequency and dynamic compensation of A.C. Transmission lines.

## REFERENCE

- [1]. WorawatNakawiro and IstvánErlich, *Senior Member, IEEE*, "Online Voltage Stability Monitoring using ADAPTIVE NEURO FUZZY INFERENCE SYSTEM", Electric Power System, April 2008.
- [2]. M. R. Sayed, A.S.Attia, M.A.Badr, "Automated Monitoring of Power System Disturbances Using Wavelet Transform", Mepcon'2003, Vol.1, Dec2003, pp.453-458.
- [3]. T. Van Cutsem, "A method to compute reactive power margins with respect to voltage collapse" IEEE Trans. Power Systems, February 1991, Vol. 6, No. 1, pp. 145-156.
- [4]. J. Lu, C. W. Liu, and J. S. Thorp, "New methods for computing a saddle-node bifurcation point for voltage stability analysis". IEEE Trans. Power Systems, May 1995, Vol.10, No.2, pp. 978-989.
- [5]. C. J. Park, I. F. Morrison, and D. Sutanto, "Application of an optimization method for determining the reactive margin from voltage collapse in reactive power pANFISing," IEEE Trans. Power Systems, August 1996, Vol.11, No.3, pp. 1473-1483.
- [6]. **T.Vancutsem** 2008 Voltage regulation restores voltage-sensitive loads. Voltags drop mainly due to reactive power transfer.
- [7]. **A.R.Bergen** 1986 Power system stability models to simulate system dynamic behaviors and direct methods have held the promise of providing real time stability assessments.