Voltage Stability Prediction in Power System using Artificial Neural Network

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Abstract – Voltage instability has become one of the sudden interest in modern power system industry since it can initiate a critical event called voltage collapse or blackout in a system. Therefore, voltage stability management is vital in order to avoid loss of power and operating cost. This paper presents an application of Fast Voltage Stability Index (FVSI) and Artificial Neural Network (ANN) in determining the voltage stability for IEEE 30 Bus System. In this paper, different load variations will be implemented which based on reactive power for voltage stability analysis. FVSI for each line will be calculated and the weakest line which has high value of FVSI and bus which has the lowest voltage will be identified. Next, the overall data from FVSI analysis will be collected and undergo training and testing in a multi-layer Feed Forward ANN for voltage stability determination. The simulation of FVSI and ANN is executed by using MATLAB R2011a software.

Keywords – Fast Voltage Stability Index, Voltage Stability, Artificial Neural Network

I. INTRODUCTION

Voltage stability can be defined as the capability of the power system to maintain a satisfactory range due to sudden interference [1]. Interference can be caused by insufficient amount of reactive power supplied and outages of line and generator in the system. This type of interference can contribute to voltage collapse or power system blackout. For the past decade, many developed countries have encountered a major blow for their system blackout for example 2003 in Italy [2] where Italian Power system have encountered a major loss where it affects an area with an estimated of 60 million people. In 2006, a bigger problem was encountered which it involves the whole Europe to experience power blackout [3].

The company in recent years has increased its concern on voltage stability based on the previous incident in order to avoid the same problem occurred in the future. As a precaution, it is vital to monitor the voltage profile of the system regularly in order to avoid sudden increase in reactive power demands to voltage instability and voltage collapse. Thus, a sufficient and quick reactive power supplies is essential to avoid total system breakdown.

Over the past years, different techniques were proposed for voltage stability analysis. Modal analysis was proposed in [4] where voltage stability determination is based on generating bus participation factors for the critical mode to determine the most critical buses. Verification of weak buses is also needed by comparing Q-V curves and the relative stability margins at each bus. Power system load ranking for voltage stability analysis has also been proposed in [5] where the classification of loads is based on the most contributing factor that can lead to voltage instability. A method called probabilistic assessment for voltage stability or VSPA has also been introduced in where contingent factor such as load level, generation patterns and network topology which gives high probability for outages in a system is analyzed in VSPA through MCSM (Monte Carlo Simulation Method) [6].

The previous years have showed that ANN is widely used for voltage stability analysis and load forecasting because of its intelligence in classification and clustering a problem with highly non-linear relationship data. An analysis for IEEE 6-Bus System has been conducted in [7] where L index is used as the indicator for voltage stability monitoring. The results showed that ANN successfully predicts the desirable output of L index itself where the targeted output is close enough to the actual output. An estimation for long term voltage stability margin has also been tested in [8] by using ANN. Results showed that prediction of ANN is more accurate when each ANN is constructed for each loading conditions rather than one ANN for whole network configuration.

II. FAST VOLTAGE STABILITY INDEX (FVSI)

Fast Voltage Stability Index (FVSI) is one of the voltage stability assessment technique in order to determine the most critical buses in a power system. There are several techniques which are similar proposed in [9] where line stability index equation or Lmn is derived based on typical one-line diagram of a transmission line. [10] also proposes an equation based on concept of power transmission called LQP. FVSI is introduced in [11] ,where FVSI is derived based on the relationship between a two-bus power system representations consist of sending and receiving end.

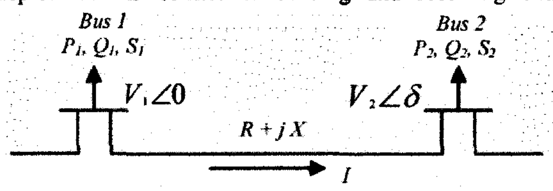

Figure 1: Two-bus power system representation

Source: S.K.Nandha Kumar (2010)

Where:

P_1, P_2 = Real power for sending and receiving buses
Q_1, Q_2 = Reactive power for sending and receiving buses
S_1, S_2 = Apparent power for send and receiving buses
δ = Difference angle between sending and receiving buses

From the figure, current flowing through the line can be denoted as:

$$I = \frac{V_1 < 0 - V_2 < \delta}{R + jX} \tag{1}$$

As the reference voltage has the angle 0, therefore we can obtain the apparent power at bus 2 as:

$$S_2^* = V_2 I^* \tag{2}$$

Rearranging (2), we can obtain:

$$I = \frac{P_2 - jQ_2}{V_2 < -\delta} \tag{3}$$

Bring (1) and (3) into one equation,

$$\frac{V_1 < 0 - V_2 < \delta}{R + jX} = \frac{P_2 - jQ_2}{V_2 < -\delta} \tag{4}$$

Multiply at both sides,

$$V_1 V_2 < -\delta - V_2^2 < 0 = (R + jX)(P_2 - jQ_2)$$

It becomes: (5)

$$V_1 V_2 < -\delta - V_2^2 < 0 = RP_2 - jRQ_2 + jXP_2 + XQ_2$$

Separating the real and imaginary part of the equation,

Real: $$V_1 V_2 \cos\delta - V_2^2 = RP_2 + XQ_2 \tag{6}$$

Imag: $$-V_1 V_2 \sin\delta = XP_2 - RQ_2 \tag{7}$$

From (6) and (7), voltage quadratic equation at the receiving bus can be formed by rearranging (7) into:

$$P_2 = \frac{-V_1 V_2 \sin\delta + RQ_2}{X} \tag{8}$$

Substitute (8) into (6), we can obtain the quadratic equation as:

$$V_2^2 - \left(\frac{R}{X}\sin\delta + \cos\delta\right) V_1 V_2 + \left(X + \frac{R^2}{X}\right) Q_2 = 0 \tag{9}$$

Discriminant of the equation is set greater or equal to 0, so it becomes:

$$\left[\left(\frac{R}{X}\sin\delta + \cos\delta\right) V_1\right]^2 - 4\left(X + \frac{R^2}{X}\right) Q_2 \geq 0 \tag{10}$$

Rearranging (10) becomes:

$$\frac{4Z^2 Q_2 X}{V_1^2 (R\sin\delta + \cos\delta)^2} \leq 1 \tag{11}$$

Since δ is relatively small, so it can be negligible. Therefore FVSI equation is formed:

$$FVSI_{ij} = \frac{4Z^2 Q_j}{V_i^2 X} \tag{12}$$

Where Z = line impedance
X = line reactance
Q_j = receiving end reactive power
V_i = sending end voltage

FVSI ranges from 0 to 1 where it indicates that voltage are closer to stability when it approaches 0 and unstable when it approaches 1.

III. ARTIFICIAL NEURAL NETWORK (ANN)

ANN is one of the branches of Artificial Intelligence where its computational models is basically based on the human brain system that consists of many neurons interconnected with each other [12]. Neuron is the most basic or fundamental unit of the human brain system where it functions as to transmit or receive information throughout the brain.

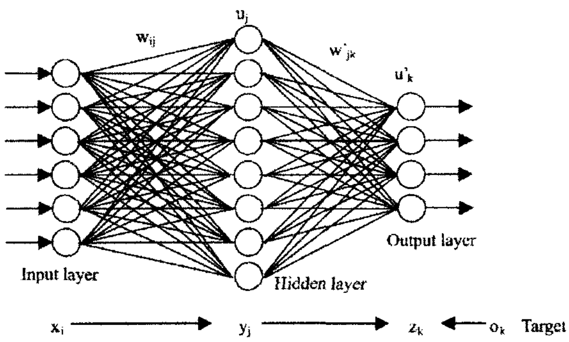

Figure 2: Structure of ANN that inspired by the human brain system [13]. It consists of three layers which are input, hidden and output layer.

Source: Paulo Priore (2003)

ANN is mainly used for prediction and forecasting analysis because of its capability to learn the pattern recognition of mostly non-linear characteristics data through training and testing [14, 15]. There are several training algorithms that can be used in ANN but in this paper, the technique that will be used is Multi-Layer Feed-Forward technique introduced in [16].

IV. METHODOLOGY

Analysis of voltage stability is based on load variations in the system. In this paper, the analysis is started with FVSI analysis on the IEEE 30 Bus system by increasing reactive power on each bus by adding the existing reactive power with additional load varies from 0.2 to 2.4 MVar.

Next, FVSI at each line will be calculated based on the load variations by modifying a current load flow program created by Hadi Saadat. Load flow program is a program used to analyze the change in voltage, real and reactive power and also power loss in the power system. Basically, Newton-Raphson algorithm is used for the load flow analysis because of its efficiency for a typical large system. [17]

The modification process is by inserting an additional code for the FVSI calculation just after the load flow analysis in the program. At the end of load flow analysis, FVSI of each line and voltage profile at each bus of the system will be determined. Two graphs will be constructed for each case based on FVSI and voltage profile during the load variations. Then, the critical buses and lines will be determined based on the two highest FVSI values and two lowest voltage profiles value.

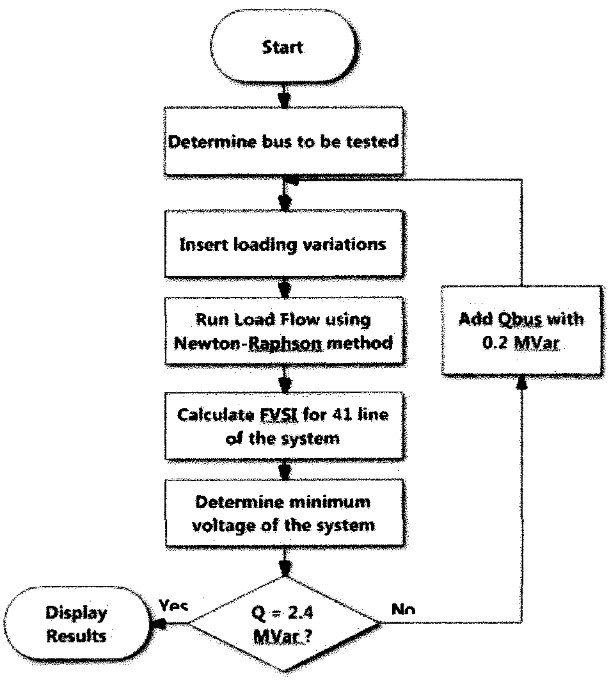

Figure 3: FVSI analysis Flow Chart

To construct an ANN network, it requires a raw data which can be obtained by collecting data as many as possible from an analysis. In this paper, the data is collected based on the value of FVSI in each line for every load variations and also the value of reactive power as the rare input data and the minimum voltage for the system as the target output for ANN.

In this paper, FVSI values at each line will be used as an input variable and minimum voltage in the system for training and testing in ANN. The data is collected based on different load variations and load conditions as mentioned before. Then, the historical data will be separated into two, 60% data for training and other 40% data for testing. For the pattern data, load variations are a little bit different with FVSI analysis. For each case, only one bus is injected with reactive power at one time. The number of buses that will be tested also will be different with the previous analysis that is 17 which all consists of load buses. At each case, 10 MVar will be inserted on the following test bus.

Minimum voltage of the system is taken as the target output for ANN is because it indicates the most critical bus in the system so that ANN can use it for training and testing to determine the permissible minimum voltage for the system. For analysis, 17 columns of pattern data is collected. Next, 10 columns of data will go through training process and another 7 into testing process for regression analysis. The ANN configuration for this paper is set to [8,5,1] which consists of 8 input layer, 5 hidden layer and 1 input layer for the network. Next, three figures below shows the three flowcharts of ANN analysis throughout this paper for implementation, training and testing.

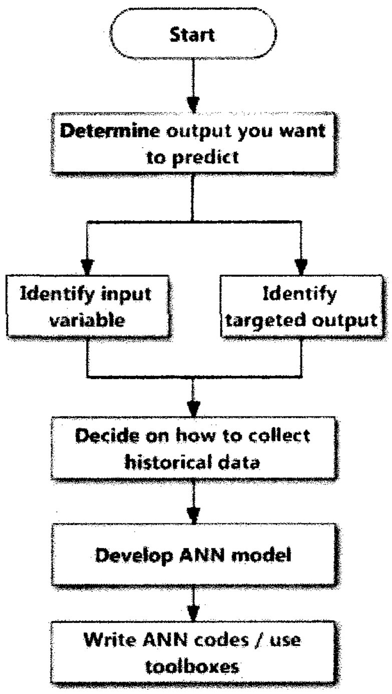

Figure 4: Implementation for ANN Flow Chart

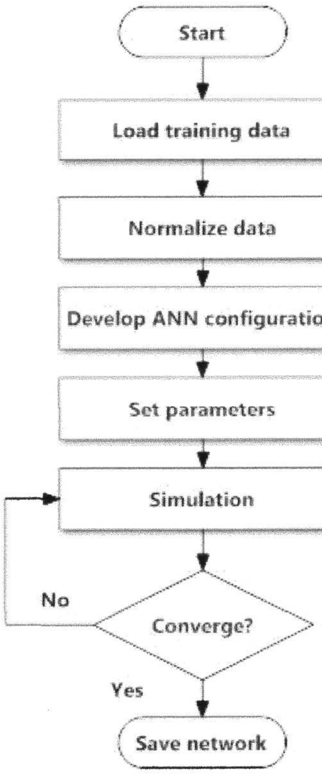

Figure 5: Training program for ANN flow chart

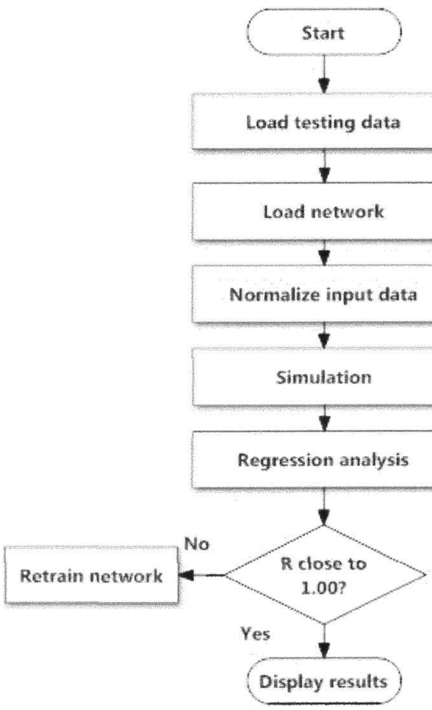

Figure 6: Testing program for ANN flow chart

V. TEST SYSTEM

Voltage stability analysis is tested on IEEE 30 Bus System [18] which consists of six generator buses, 21 load buses and 41 lines as in figure below:

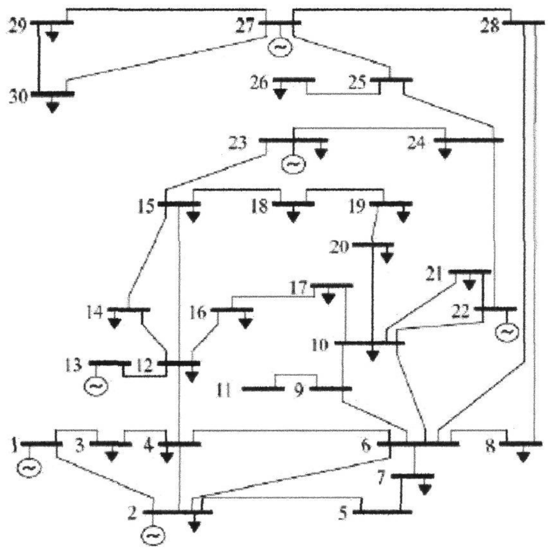

Figure 7: IEEE 30 Test Bus System

Source: http://www.ee.washington.edu/research/pstca/

VI. RESULTS AND DISCUSSIONS

(i) FVSI analysis

After the FVSI analysis has been conducted, the results is as expected where the increase amount of reactive power at each bus affects the voltage profile of the system becoming less stable. FVSI of each line also increasing rapidly as the load increases.

The graph below shows the results of FVSI value at each line and also the voltage profile at each bus for IEEE 30 Bus System for load variations 0.2, 0.8, 1.4, 2.0 and 2.4 MVar inserted at each bus. The two most critical FVSI and voltage value is determined.

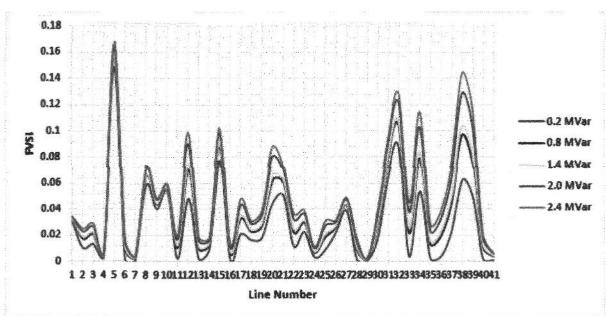

Figure 8: FVSI value at each line on different load variations

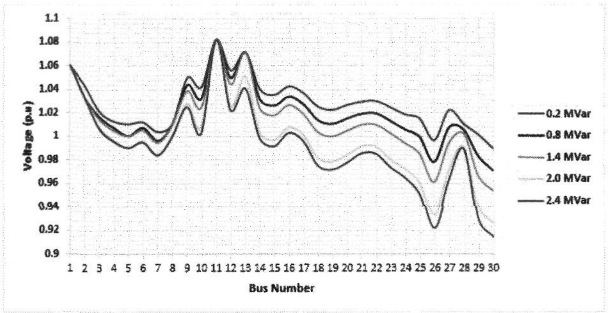

Figure 9: Voltage profile at each bus on different load variations

Based on the two graphs above, the first and second highest value of FVSI is from line 5 and line 38. Line 5 consists of bus 2 as its sending end, and bus 5 as its receiving end. Line 38 consists of bus 27 as its sending end and bus 30 as its receiving end. Line 5 has FVSI value of 0.1681 and line 38 has FVSI value of 0.1437. This two lines denotes as the most critical line in IEEE 30 Bus System. As for the voltage profile of the system, bus 26 and bus 30 has the lowest voltage recorded at load of 2.4 MVAR which was the highest load variations set in this analysis. Voltage at bus 26 is 0.9215 and for bus 30 is 0.9143. Therefore, these two buses denotes as the most critical buses in IEEE 30 Bus system. IEEE has set the optimum range of voltage profile in the system which is ranges from 0.9 to 1.1 p.u. Based on the analysis, the lowest voltage recorded is 0.9143 p.u which is almost close to lowest permissible voltage in IEEE standards. Therefore, it can be concluded that at this type of load variations, the permissible voltage for the system is 0.9143 p.u.

(ii) ANN analysis

Results of ANN in training gives positive results on the performances where it only requires 6 epochs to reach the goal performance. It indicates that the overall 17 patterns of data is not hard to train since it requires only small amount of time to reach the best training performances.

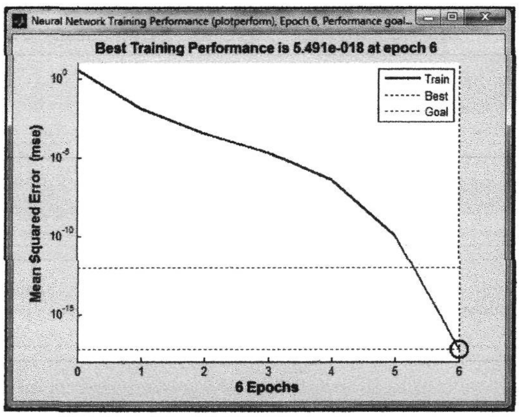

Figure 10: Results of training performances and convergence

Next, the figure below shows the results of regression analysis of another 7 pattern data use for testing process. To indicate that results is accurate, the targeted output must close to the actual output of the data. The regression analysis indicates as the closer the correlation coefficient, R to the value 1 or unity, the more accurate the developed network will be. Regression analysis is tested on data set which has two types of input variables. At first try, the results is not as satisfying because of the coefficient value is too low. So, the data must be retrained until the results shows that R is close to 1. The best results of testing are obtained at 23rd try, R = 0.96968.

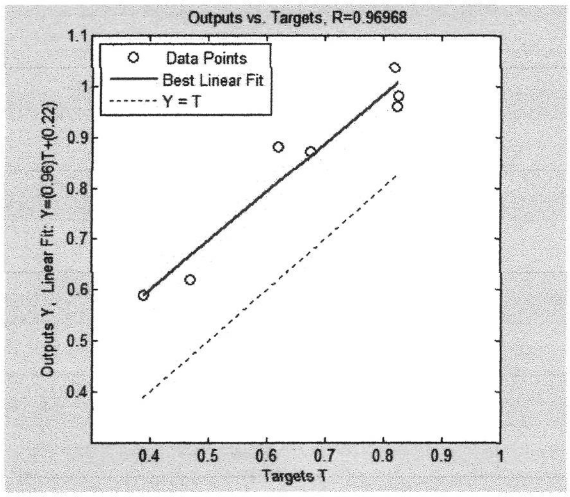

Figure 11: Best regression analysis for first data set at 23rd try where R = 0.96968

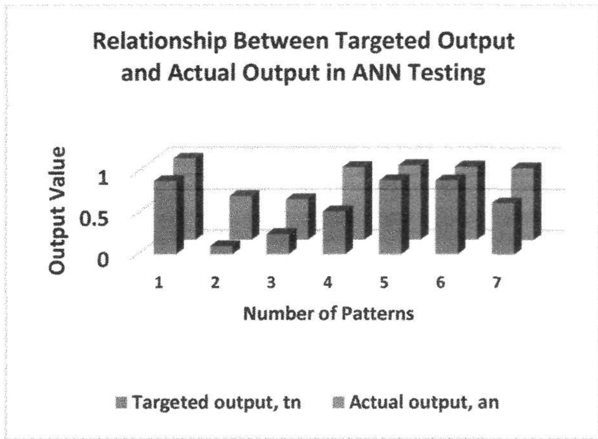

Figure 12: Graph of relationship between the targeted output, tn and actual output, an in ANN testing at R = 0.96968

The graph above shows the relationship between the targeted output and the actual output in every single pattern *in 10 patterns of testing data at 96 percent prediction* accuracy. It can be seen that the value is almost equal to each other except for pattern number 2 which it has difference about 0.4309 which is quite a big margin. Analysis of FVSI has been successful where it able to determine the critical buses and lines in the power system and same goes to ANN where the accuracy of the prediction is almost close to 1 which is 96% out of 100%.

VII. CONCLUSION

Implementation of FVSI on this project has showed that this method is efficient to identify the most critical lines and buses in IEEE 30-Bus System. Based on different load variations, line 5 which consist of Bus 2 as sending end and Bus 5 as receiving end has FVSI value of 0.1681 at 2.4 MVar which is identified to be the most critical line in the system. Bus 30 is identified as the most critical bus in the system which gives the voltage profile of 0.9143 at 2.4 MVar load which is the lowest among all the voltages at the other buses. This following line and bus has to be monitored regularly to avoid any voltage collapse in the system. ANN also has showed its intelligence for voltage stability prediction for the system based on different input variables which is R = 0.96968 which indicates that ANN successfully predicts 96% out of 100% of the targeted output which is the minimum voltage of the system and the actual output executed in ANN. Finally, it can be concluded that there is some limitations or permissible amount of load in the power system. Therefore, voltage profile has to be maintained at satisfactory range to avoid voltage breakdown when contingency occurs.

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