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Artificial Neural Network Based Voltage Stability Analysis of Radial Distribution System

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Abstract

Voltage instability is a big problem in modern power system. Increasing load demand on Distribution system gives lower voltage. This is the reason of voltage instability in Distribution system. So, analysis of voltage stability is very important. Different techniques can be used for voltage stability analysis. In this paper a new indicator is developed for analysis of line stability. The proposed indicator depends on apparent power and voltage magnitude of the bus and on the line impedance. The effectiveness of the proposed indicator is tested on standard IEEE 33 bus Radial Distribution System. By using the required parameters in the Matlab coding the values of proposed indicator for different Lines of the system under consideration have been calculated. The value of the indicator was considered as the pointer of weakest line. The line having highest value of indicator will be the weakest line of the system. Another standard line stability indicator named FVSI is also calculated for the same system. The highest value of FVSI indicator indicates the weakest line. The results obtained from the proposed indicator are verified by the results obtained from FVSI. Both indicators give same ranking of weak Lines. So, the proposed indicator effectively is able to find the weak lines of the system. Artificial Neural Network technique has also been used to predict voltage stability of power system.

Keywords: artificial neural network; distribution system;equivalent two bus network; impedance apparent power indicator; voltage stability.

INTRODUCTION

The demand of electric power is growing rapidly. So, the power system is facing more challenge. This situation has led the power system to operate at low voltage. This arise the problem of voltage instability [1]. When the power system supplies a huge amount of power, it becomes heavily stressed and this type of power system is weak. So, they suffer from voltage stability problem. Other reasons of voltage instability are generator control limits, load characteristics, reactive power supplying devices and voltage control devices [2]. For proper protection of distribution system the measuring and controlling schemes needs improvement and in appropriate voltage control voltage profile estimation is required [3]. To work in power system the operator should have knowledge about the voltage stability condition of the system. Voltage stability analysis is of two types: static and dynamic [4]. Voltage collapse generally occurs in a heavily loaded system. Then the power system is not able to meet the reactive power demand. So, it is important to analyze and detect voltage instability before its occurrence [5] - [7]. Radial distribution system having high resistance to reactance ratio is weak in character. In voltage instability problem the power system is not able to provide or consume uniform power. Radial distribution system has high power loss and suffers from voltage instability [8]. Researchers have developed many methods for stability analysis of power system namely P-V and Q-V curve based indices, singularity indices, L-index etc. [9]. Different approaches such as supervised and unsupervised algorithms of ANNs, multi objective approach based on minimization of power loss maximization of voltage stability, real time voltage stability monitoring by artificial neural network and on-line assessment of voltage security by radial basis function were used for voltage stability analysis [10]-[13].

Khyati Mistry et al. increased Voltage stability index of distribution system by network reconfiguration [14]. R.S. Al Arbi et al. used proper size of distributed generation system at appropriate position to improve stability level of distribution system [15]. Mohamed M. Hamada et al. proposed a new indicator taking into account different parameters affecting steady state voltage stability of distribution system. So, it gives better analysis of the system [16].

This paper proposes a new method for weakest line identification by the developed indicator. The indicator can be calculated from bus voltage, bus apparent power and line impedance which provides a technique for analysis of voltage stability. MATLAB coding is developed to find the indicator value for the lines of the standard IEEE 33 Bus Radial Distribution System. Another standard indicator, FVSI is also calculated for the above mentioned system. The results obtained from the proposed indicator are verified by those obtained from standard FVSI indicator. Comparison shows that the proposed indicator is efficient in finding the weakest line. A multilayer feed forward neural network can act for function approximation. In the present work the input values

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are given to neural network and the output is proposed indicator. The network is trained by error back propagation learning algorithm. The ANN method is tested on IEEE 33 node Radial Distribution System.

INDICATOR FORMULATION

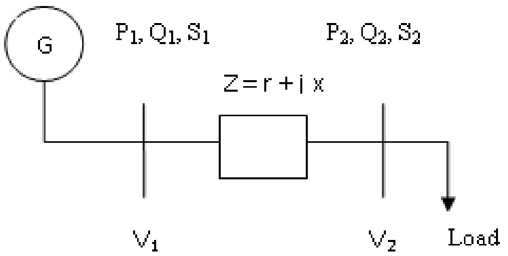

Figure 1. Two-bus equivalent network

A Multi-bus Distribution system can be simplified by an equivalent two bus netwok comprising of one slack bus and one load bus. Such a system is shown in Fig. 1. The sending end side bus has voltage magnitude V_1 where generator is connected and the receiving end side bus has voltage magnitude V_2. The two buses are connected by a distribution line having impedance Z = r + j x and line current is I. In the sending end side bus real power is P_1, reactive power is Q_1 and apparent power is S_1. The similar parameters in the receiving end side bus are P_2, Q_2 and S_2 respectively [17].

For the given two- bus network, the active and reactive power loss of the system are respectively

$$P_L = r\,(P_2^2 + Q_2^2)/V_2^2 \qquad (1)$$

$$Q_L = x\,(P_2^2 + Q_2^2)/V_2^2 \qquad (2)$$

The relation between active power, reactive power and apparent power can be written as

$$S_L^2 = P_L^2 + Q_L^2 \qquad (3)$$

The relation between resistance, reactance and impedance of a line can be written as

$$Z^2 = r^2 + x^2 \qquad (4)$$

For a radial system the line current can be written as

$$I^2 = \frac{S_L^2}{(V_1 - V_2)^2} \qquad (5)$$

Using equation (1), (2), (3) and (4) in equation (5) and after simplification the above equation can be written as

$$I^2 = \frac{Z^2 S_2^4}{V_2^4 (V_1 - V_2)^2} \qquad (6)$$

Again, the line current can be written as

$$I^2 = (V_1 - V_2)^2 / Z^2 \qquad (7)$$

Equating equation (6) and (7) we get

$$\frac{(V_1 - V_2)^2}{Z^2} = \frac{Z^2 S_2^4}{V_2^4 (V_1 - V_2)^2}$$

Or, $V_2^2 (V_1 - V_2)^2 = Z^2 S_2^2 V_2^2 (V_1 - V_2)^2 = Z^2 S_2^2$

Or, $(V_1 V_2 - V_2^2)^2 = Z^2 S_2^2$

Or, $V_1 V_2 - V_2^2 = Z S_2$

Or, $V_2^2 - V_1 V_2 + Z S_2 = 0$

The above equation is of the form

$$a x^2 + b x + c = 0$$

So, a root of the equation is

$$b^2 - 4\,a\,c \geq 0$$

i.e. $V_1^2 - 4 Z S_2 \geq 0$

So, $\dfrac{4\,Z\,S_2}{V_1^2} \leq 1$

The proposed indicator can be written as

$$Indicator = \frac{4\,Z\,S_2}{V_1^2}$$

VERIFICATION OF THE PROPOSED METHOD

A standard indicator named FVSI is used for stability analysis of line is dependent on the idea of power flow through a single line. For a line having impedance Z, Reactance X, receiving end side reactive power Q_j and sending end side voltage V_i, FVSI can be calculated as

$$FVSI = \frac{4\,Z^2\,Q_j}{V_i^2\,X}$$

The line for which the value of FVSI is nearer to 1 will be the weakest line [18].

Line ranking obtained by proposed indicator and FVSI is shown in Table I and the indicator value of lines are shown in Table II.

Table 1: Comparison of Stability Ranking

Line No.	Proposed Indicator Value	Stability Ranking obtained by Proposed indicator	FVSI Value	Stability Ranking obtained by FVSI
29	0.0150	Weakest	0.0308	Weakest
24	0.0148	Weaker	0.0131	Weaker
23	0.0146	Weak	0.0129	Weak

From Table I it is clear that the two methods give same stability ranking of Lines. So, the proposed indicator can effectively identify the weak portion of the system.

Table 2: Proposed Indicator and FVSI Values

Line Number	Proposed Indicator value	FVSI value
1	0.0004	0.0004
2	0.0018	0.0016
3	0.0020	0.0025
4	0.0010	0.0010
5	0.0024	0.0012
6	0.0055	0.0026
7	0.0064	0.0092
8	0.0031	0.0017
9	0.0032	0.0018
10	0.0004	0.0008
11	0.0012	0.0020
12	0.0055	0.0049
13	0.0053	0.0037
14	0.0020	0.0005
15	0.0025	0.0017
16	0.0057	0.0001
17	0.0039	0.0080
18	0.0007	0.0023
19	0.0067	0.0040
20	0.0021	0.0011
21	0.0035	0.0020
22	0.0019	0.0016
23	0.0146	0.0129
24	0.0148	0.0131
25	0.0006	0.0006
26	0.0008	0.0008
27	0.0034	0.0016
28	0.0039	0.0045
29	0.0150	0.0308
30	0.0094	0.0056
31	0.0046	0.0026
32	0.0019	0.0024

Table II shows that the value obtained for the proposed indicator is highest in Line number 29. So, it is the weakest Line. The result obtained by the proposed indicator has been compared with the result of standard FVSI indicator. From FVSI indicator value it can be said that Line number 29 is the weakest Line. The comparison of stability ranking obtained by using the two methods is shown in Table II.

As the load on the power system increases, the power flow in the line increases and the result is low voltage at the buses. With the increase in active power the value of proposed indicator also increases. This is true for increase in reactive power loading also. The change in indicator value in Line number 29 for increasing active power in that line is shown in Fig. 2 and the change in indicator value in Line number 29 due to increase in reactive power in that line of the system is shown in Fig. 3.

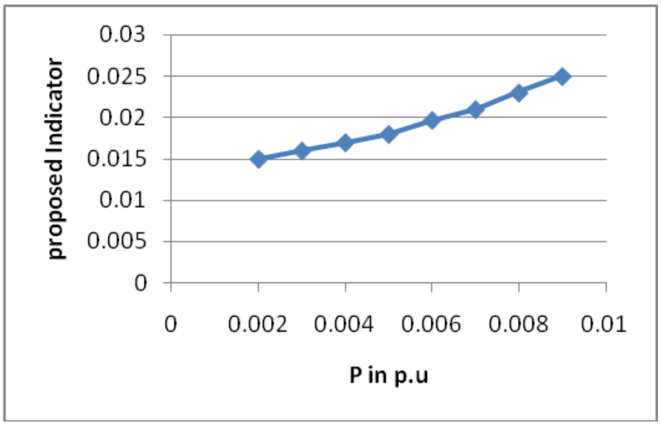

Figure 2. Graph of Proposed Indicator in Line no. 29 agaainst increase in active power loading

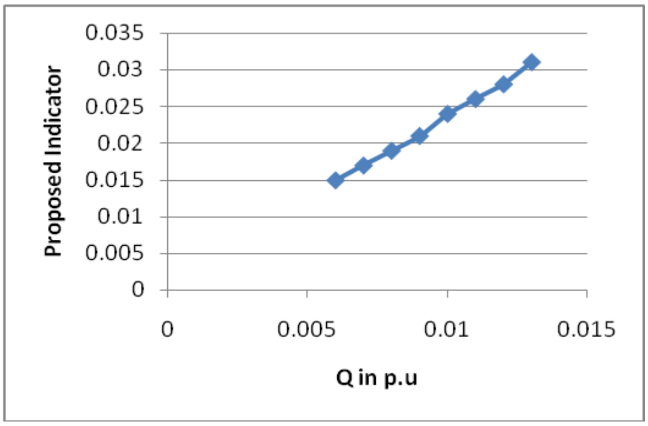

Figure 3. Graph of Proposed Indicator in Line no. 29 against increase in reactive power loading

From Fig. 2 and Fig. 3 it is clear that the proposed indicator shows almost linear characteristics with increase in active power or reactive power.

ANN ARCHITECTURE FOR PROPOSED INDICATOR

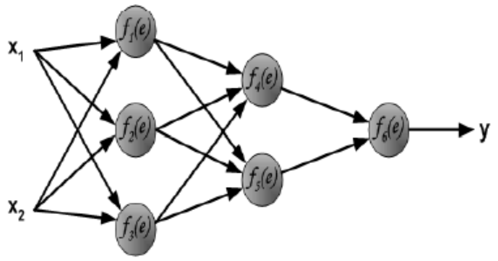

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Figure 4. A multilayer feed forward network

By using a feed forward neural network the output function can be approximated by using input data. ANN structure does not require continuous data for finding the output function. ANN is able to find the ooutput function from disccrete values. A multilayer feed forward neural network is shown in Fig.4.

A. Preparation of Training Data Set

The proposed indicator is tested on standard IEEE 33 node Radial Distribution System. The input data set for the training purpose in this case is obtained from load flow solution considering all possible loading, single and double contingencies. This data preparation also includes single and double outages of lines connected to the weakest, weaker and weak buses. For 2-bus equivalent system the proposed indicator is calculated. Indicator value is calculated under all cases of the equivalent system which are used as output for training purpose. For this purpose 500 samples of data are obtained, out of which 450 was used for training and 50 for testing. Each data contains line number, apparent power, bus voltage, line impedance and the corresponding proposed indicator value as target.

B. Architecture of the ANN Used

To obtain the ideal configuration of ANN for this case a large number of trials are performed. The optimum ANN structure requires 4 input layer neurons which use line number, bus apparent power, bus voltage, line impedance and 3 hidden layers having 7, 4 and 6 neurons. The output layer has one neuron which gives the value of proposed indicator.

C. Training of the ANN Structure

A continuous function is at first sampled to find the mathematical function by using neural network. From the sampled data the original function is formulated. The neural network is trained with the available data information. In this case the ANN pattern recognition engine was trained with the line number, bus apparent power, bus voltage and line impedance and proposed indicator value as output. The ANN structure was able to achieve the desired value in 125 epochs and generalized the result. The accuracy of the proposed ANN structure was verified on IEEE 33 node Radial Distribution system. Proposed indicator value for each unobserved condition is assessed by ANN and compared with the actual value of proposed indicator. The test result is shown in Table III.

Table 3: Test Result using ANN

Line No.	Actual Value of Proposed Indicator	Indicator Value estimated by ANN	% error in estimation
29	0.0150	0.0151	0.66
24	0.0148	0.01474	-0.40
23	0.0146	0.01463	0.21

From Table III it is experiential that the error in estimation lies between +0.66 to -0.40, which is brilliant and sufficient for this purpose.

CONCLUSION

The Proposed Indicator provides a technique of voltage stability analysis which is tested on IEEE 33-bus Radial Distribution system for Line stability analysis. The weak lines of the system can be identified by the proposed indicator which is verified by the standard FVSI indicator. Both the indicators give same stability ranking of lines. So, the proposed indicator efficiently indentifies the weakest segment of the distribution system. The proposed indicator is very simple to calculate, require less number of input variables, needs less effort and time to manipulate. It helps the power system operator to assess the weakest Line of the multi bus system very easily. ANN pattern recognition engine is also applied for line stability assessment. The results shows higher degree of accuracy. The proposed approach has proved to be efficient and fast for the assessment of voltage security of the system for any unknown load patterns and contingencies which will help the power system operator.

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