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Artificial Neural Network based FACTS in a Contingency Situation

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ABSTRACT- The two biggest issues facing today's energy management systems are the ongoing monitoring of online voltage stability and the improved loadability of the transmission lines for the current electrical power system. As a result, it is highly difficult and time-consuming to assess online voltage stability under diverse loading conditions. This study describes a practical voltage stability monitoring system that automates online voltage monitoring and alerts the operator before voltage drops by computing line voltage stability indices using an ANN. This study compares evaluations of system voltage stability and loadability at the load with FACTS devices. The results suggest increase in system loadability while ensuring the security of power system operation.

Keywords: Line voltage stability indices, FACTS Devices, ANN, Power system security.

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1. INTRODUCTION

The world's power systems are [1-6] operating under extraordinarily stressful conditions as a result of a lack of reactive power, which could push the systems closer to their operational limits. It is difficult to keep a power system in a safe operating mode because of the following reasons:

- Electricity demand has significantly grown.
- A limited growth of the transmission network is the result of social and environmental constraints

All of these factors contribute to stability issues in the power system. When under stress, a power system performs differently than when it is not under stress. The system may lose stability in response to a relatively little perturbation because it is so near to the stability limit. The electricity system is often a connected system, which will have a substantial impact on its functionality and stability.

Discussion is had regarding the basic principles of operating and modeling power systems [1]. Problems with voltage stability and rotor angle stability arise simultaneously and are thus related. Despite their connections, one form of instability predominates in many situations [2]. Using a modal analysis technique, the voltage stability study of large power systems is done. A reduced Jacobian matrix's allied eigenvectors and explicit range of its minimal Eigen values are computed using a gradual state system model. The Eigen values, each of which is connected to a certain way. The eigenvectors are used to define the mode form and to provide information about the network components and generators involved in each mode [3]. Static voltage stability analysis uses a variety of methodologies. Calculating system load margin is the method used the most frequently to indicate the voltage stability limit. Real and reactive power margins are the two most often utilized indicators [4]. The method for measuring the influence of a system on voltage stability through net testing in the outline of an indicator L that fluctuates between zero (no load on the system) and one (voltage collapse) is in [5-7]. Due to the rapid nature of voltage collapse, quick voltage stability evaluation technologies are required to ensure the safe operation of modern power systems. Thus, a new online method based on ANN that requires the least amount of input to estimate the voltage [8]. Utilizing the method of condensing an influence system network into a single line, voltage stability factors are introduced and regularly used to assess system stability [9], the techniques for using voltage stability indices to identify essential bus/branch and the improvement in voltage stability achieved by FACTS devices [10-13].

2. PROBLEM FORMULATION AND MATHEMATICAL ANALYSIS

2.1 Line Voltage Stability Index (L_{mn}) under Single Line Contingency

The apparent power at the receiving and transmitting ends is given by *equations (1)* and *(2)* below.

$$S_r = \frac{|V_s||V_r|}{z}\angle(\theta - \delta_1 + \delta_2) - \frac{|V_r|^2}{z}\angle\theta \qquad (1)$$

$$S_s = \frac{|V_s|^2}{z}\angle\theta - \frac{|V_s||V_r|}{z}\angle(\theta + \delta_1 - \delta_2) \qquad (2)$$

As a result, in order to qualify as stability criteria, the following requirements must be met:

$$\frac{4XQ_r}{[V_S \, sin(\theta-\delta)]^2} = L_{mn} \leq 1.00 \qquad (3)$$

2.2 Proper location to install FACTS Device and check the enhancement in stability margin

The Mathematical Analysis of SVC is given below based on the *figure 1*. The voltage sources are provided for a transmission line of T-type. The capacitance is providing the reactive power which connected at shunt and middle of the transmission line.

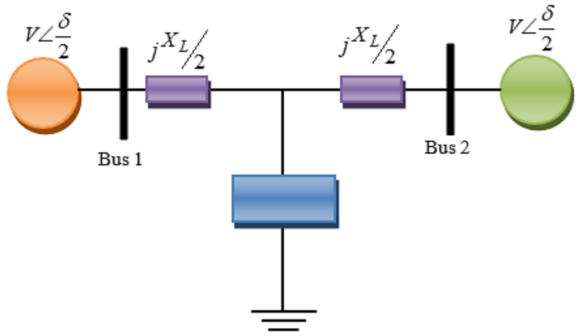

Figure 1: Single line diagram of Transmission line with SVC

Equation (4), which is shown below, is used to determine the reactive power that the capacitor injects in order to control the transmission line's voltage:

$$Q_C = 4\frac{V^2}{X_L}(-\,cos\frac{\delta}{2}) \qquad (4)$$

Series capacitor banks boost the efficiency of power transmission, enhance system stability, lower system losses, enhance line voltage profiles, and maximize the distribution of current among parallel lines.

$$Q_C = 2\frac{V^2}{X_L}\frac{k}{(1-k^2)}(1 - cos\,\delta) \qquad (5)$$

2.3 Artificial Neural Network (ANN) Technique for Predicting Proper Location for Online Stability Applications

Individually neurons in ANN receives a high number of inputs (Each input has a weight). Bias is added to the summation. Net output is produced with the help of inputs, weights and bias. An activation perform is applied to those inputs which ends up in activation level of neuron. Then the output is obtained.

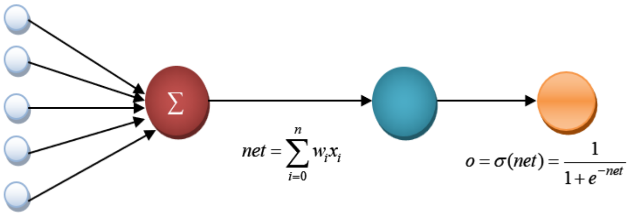

Figure 2: ANN Functional Overview

Accuracy of the network is given below;

$$\text{Accuracy} = \frac{\text{Number of correct classifications}}{\text{Total number of test cases}}$$

2.4 General Procedure to ANN

Step 1: The inputs like number of neurons, computation weights and activation functions are provided.
Step 2: Forward propagation.
Step 3: Check the error with in and out and the desired output.
Step 4: Modify the network weights and the network based on the errors.
Step 5: Update weights and modify the input and output.

2.4.1 Learning process

The flowchart or the procedure of training and testing of the neural network is given in *figure 3*.

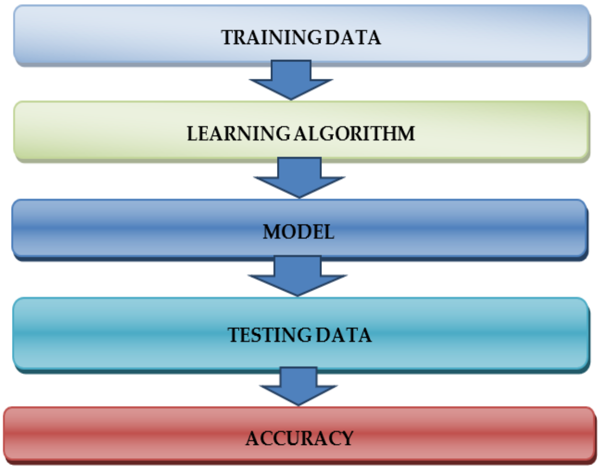

Figure 3: Training Procedure for Artificial Neural Network with FACTS

3. RESULTS AND DISCUSSION

3.1 Proposed Algorithm

The proposed algorithm [12] is provided below for determining the line, bus and L_{mn} respectively.

Read the system's line and bus data; the load (MW & MVAR), generator (MW & MVAR, Q_{min} & Q_{max}), and system angle (MW & MVAR) data are assumed to be constants.

Perform load flow for potential line outages as the baseline. For each line outage, determine the L_{mn}.

Under every line outage with a maximum L_{mn}, rank the more sensitive line.

Connect SVC to the system and determine $L_{mn's}$ value.

Compare L_{mn}. with and without SVC.

3.2 Case Study and Results

There are 42 input variables consisting of 14 bus voltages, 6 reactive power limits, 1 reactive power loss, 20 transmission lines and 1 SVC parameters. If SVC is not considered, 41 input variables are considered. To choose the best ANN for the given problem a number of trial-and-error simulations were carried out and an input layer with 41 neurons, 2 hidden layers with 21 and 5 neurons and an output layer with one neuron have given the best performance. The ANN with and without connecting SVC is given in *table 1*.

Table 1: ANN for IEEE-14 Bus System with and without SVC

Type of ANN Parameter	Without SVC	With SVC
Number of input neurons	41	42
Number of hidden layers	2	2
Number of neurons in hidden layers	21 and 5	22 and 5
Number of output neurons	1	1
Error goal	0.00015	0.00015
Learning rate	0.425	0.445
Minimum performance gradient	1e-7	1e-7
Maximum number of epochs	60	60

3.2.1 Case 1: ANN using prediction of weak buses/branch

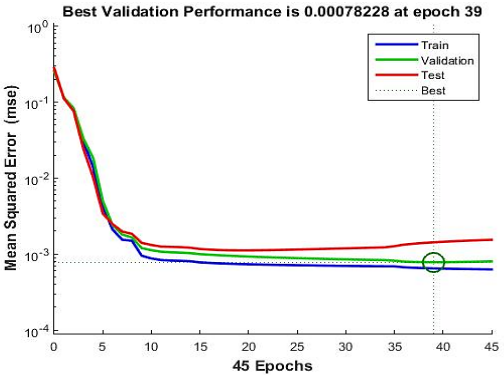

Figure 4: ANN for L_{mn} in outage scenario

Line Ranking for contingency case in *figure 4* shows that epoch 39 yields the greatest validation performance of 0.00078228.

3.2.2 Case 2: SVC Compensation

Table 1 displays the Bus Ranking with SVC. SVC for 100%, 160%, and Lmn are 14, 12, and 0.34416, respectively.

Table 2: **Bus Ranking with SVC**

BR	100% Loading			160% Loading		
	Bus No.	Cont. No.	Lmn	Bus No.	Cont. No.	Lmn
1	14	20	0.24992	12	10	0.34416
2	8	7	0.23867	13	10	0.33942
3	9	19	0.23857	11	10	0.31652
4	11	18	0.23549	14	10	0.25755
5	13	20	0.229705	10	10	0.25744
6	10	20	0.22665	9	20	0.25487
7	6	20	0.22513	7	7	0.25310
8	7	7	0.21815	8	7	0.23493
9	2	20	0.20980	6	20	0.20903
10	14	19	0.20955	4	7	0.20319
11	1	2	0.20856	2	20	0.19257
12	4	20	0.19346	5	20	0.1858
13	5	20	0.19272	1	20	0.17620
14	3	20	0.18283	3	20	0.16340

3.2.3 Case 3: SVC Compensation with ANN

Table 2 shows the Bus Ranking with SVC with ANN. For 100%, 160% is 4, 4 and the value is 0.249571, and 0.480814 respectively. From *figure 4* it is observed that the best validation performance 6.8146e-05 at epoch 8 is obtained.

Table 3: ANN Bus Ranking with SVC

BR		100% Loading			160% Loading	
	Bus No.	Cont. No.	Lmn	Bus No.	Cont. No.	Lmn
1	4	17	0.24957	4	17	0.48081
2	9	17	0.20096	9	17	0.39465
3	14	17	0.12403	14	17	0.24577
4	13	17	0.12306	13	17	0.24297
5	10	17	0.10935	10	17	0.21345
6	5	17	0.09578	5	17	0.18026
7	12	17	0.09127	12	17	0.18022
8	11	17	0.08245	11	17	0.16153
9	7	17	0.06796	7	17	0.13011

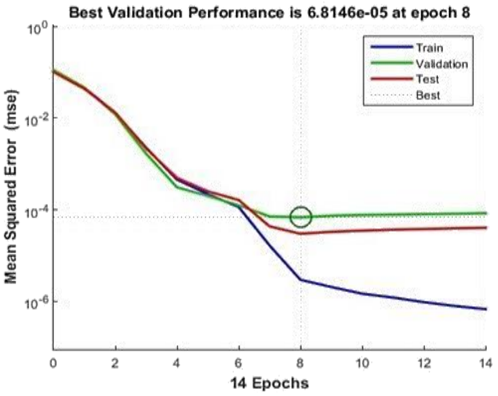

Figure 5: SVC Compensation with Lmn with ANN

From *figure 5* it is observed that the best validation performance for Lmn with SVC is 6.8146e-05 at epoch 8 is obtained Lmn. The comparison of various indices is given in *table 4* and it can be observed that the proposed algorithm has given the best performance comparatively.

Table 4: Comparison of Indices for IEEE-14 Bus System

Rank	CN		APPI		VCPI		Lmn	
	Line No.		Line No.		Bus No.		Bus No.	
	Conventional Method	ANN	Conventional Method	ANN	Conventional Method	ANN	Conventional Method	ANN
1	3	3	2	2	11	11	4	4
2	2	2	3	3	9	9	9	9
3	14	14	11	11	13	13	14	14
4	9	7	14	14	10	10	13	13
5	7	4	7	7	12	12	10	10
6	5	9	9	9	7	7	5	5
7	4	5	4	4	8	8	12	12
8	6	6	5	5	14	14	11	11
9	10	10	13	13	6	6	7	7

4. CONCLUSION

In this study, the interpretation of the maximum load ability limit takes voltage stability into account. The bus and branch in the system are located using voltage stability indices, and voltage instability is felt at various loading margins. These indices are close to 0 when the system is voltage stable and gradually increase closer to 1 as the system approaches the point. The estimated voltage stability indices are compared with various loading scenarios.

Reactive power compensation devices are located where the important bus or branch is predicted by artificial neural networks (ANN). The most powerful devices for controlling voltage and enhancing the stability of the power system are FACTS devices.

Author Contributions

Rachakonda Venkata Raghavendra Rao is contributed to resource data and analysis data, implementation of proposed method, the conduct of experiments and N.C Kotaiah and RadhaRani.K, guided to frame the paper and concept.

Conflicts of Interest

The author declares no conflict of interest

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