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FAST CONTINGENCY ANALYSIS AND RANKING FOR POWER SYSTEM SECURITY ASSESSMENT

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Abstract- Economic and environmental pressures have caused the modern power system to operate more close to its limit of stability. Maintaining power system security in such scenario is one of the challenging tasks for the power system engineers. An essential task is security assessment which gives the idea about the system state in the event of contingency. Practically, only selected contingencies will lead to severe conditions in power system. In this paper, contingency analysis and ranking technique for single line outage has been explained. Further the contingency analysis suited especially for online environment has been done by using Multilayer Perceptron Network (MLP) and Probabilistic Neural Network (PNN). This provides an effective mean to rank the contingencies for various loading in a power system.

Keywords- Contingency Analysis, FVSI, Loadability Margin, Neural Network. Security Assessment

I. INTRODUCTION

In recent times, a lot of voltage collapse incidents in many parts of the world have occurred. These were mainly caused due to system operating close to its stability limit as well as contingency caused by the unpredicted outages of line or transformer. Because power systems are operating closer to their limits, voltage stability assessment and control, although not a new issue, is now receiving a special attention. As defined in, voltage stability is the ability of a power system to maintain steady acceptable voltages at all buses in the system under normal operating conditions and after being subjected to a disturbance. The study of voltage stability can be analysed under different approaches, but specially, the assessment of how close the system is to voltage collapse can be very useful for operators. Up until now we have been mainly concerned with minimizing the cost of operating a power system. An prevailing factor in the operation of a power system is the desire to maintain system security. System security involves practices intended to keep the system operating when components fail. For example, a transmission line may be damaged by a storm and taken out by automatic relaying. If in committing and dispatching generation, apposite consider for transmission flows is maintained, the left over transmission lines can take the increased loading and still remain within limit. If any event occurs on a system that leaves it operating with limits desecrated, the event may be followed by a series of further actions that switch other equipment out of service. If this process of cascading failure continues, the entire system or large parts of it may entirely collapse. This is usually denoted as a system blackout. Transmission-line failures cause changes in the flows and voltages on the transmission equipment remaining connected to the system. Therefore, the analysis of transmission failures requires methods to predict these flows and voltages so as to be sure they are within their respective limits. Operations personnel must know which line or generation outages will cause flows or voltages to fall outside limits. To envisage the effects of outages, contingency analysis techniques are used. Contingency analysis procedures model single failure events one after another in sequence until “all credible outages” have been considered. For each outage screened, the contingency analysis procedure checks all lines and voltages in the network against their respective limits. A security analysis study which is run in an operations centre must be executed very quickly in order to be of any use to operators. As power systems have grown in size and complexity, full analysis of every possible contingency has become a tedious and costly process. Even with fast load flow techniques, such as a fast decoupled load flow, and linearized ac load flow, contingency analysis is still burdensome. Therefore, a method of determining a smaller set of critical contingencies to be studied is sought-after. A critical contingency is an outage which causes a bus voltage violation or a transmission line overload in the system. Rather than depend on a preselected list of critical contingencies, an automatic method can be developed to create a list of critical contingencies for a system.

An automatic contingency selection method ranks the contingencies of a system in order from most severe to least severe based on bus voltage and transmission line power flow requirements.

There have been a number of incidents in the past few years which were diagnosed as voltage instability problem due to the increase in loading and decrement of stability margin. The stability margin can be specified as the distance between the base loading of the system and the maximum loading limit of the system. This paper mainly emphasis on determining which line contingency is most critical and which bus is weakest in the system at a given load pattern. Previous researches have shown that contingency analysis can be time consuming particularly for a bulk power system. Human factor is mainly the reason for the long execution time. Time can be minimized by automatic contingency analysis and ranking. Rodrigues et. al. described the automatic contingency algorithm which is capable of identifying potential harmful contingency. Musirin et. al. has described a line stability index which can be used for finding of maximum load that a load bus can supply without stability problem.

II. LINE OUTAGE SEVERITY INDICATOR

While contingency analysis focus on a particular operating point, loadability limit determination deals with how far a system can move from this operating point and still remain in a stable state. In voltage stability analysis, it is helpful to assess voltage stability of power systems by means of voltage stability indices (VSI). System variable based VSI use direct measurements, such as bus voltages and elements of the admittance matrix. These require less computational efforts and are suitable for a fast diagnosis of system condition and contingency ranking. These indices have been classified in two groups: bus voltage computation indices (or nodal voltage stability indices) and line stability indices. One of such pre-developed line stability index termed as Fast Voltage Stability Index (FVSI) is used.

$$FVSI_{ij} = \frac{4Z^2 Q_j}{V_i^2 X}$$; for a line between node i and j

Where,

Z = line impedance

X = line reactance

Q_j = reactive power at the receiving end

V_i = sending end voltage

In order to maintain a stable voltage condition, the value of FVSI must be kept less than 1.00. The value of FVSI greater than 1.00 indicates that the voltage at bus j will have imaginary roots reflecting that the line has exceeded its voltage stability limit.

III. MAXIMUM LOADABILITY MARGIN AND CONTINGENCY ANALYSIS

In order to determine weakest bus of the system and maximum loadability margin, reactive power at load buses are increased gradually. The following procedure has been implemented:

1) Newton-Raphson load flow method is used to calculate FVSI value for every line in the system.
2) For FVSI value less than 1, reactive power load at a chosen load bus is increased till either FVSI value reaches 1 or load flow solution diverges. FVSI values are calculated for every load variation.
3) The line having maximum value of FVSI is flagged as most critical line with respect to a bus.
4) Step 1 to 3 is repeated for every load bus in the system.
5) The corresponding maximum reactive power loading for maximum FVSI value for every load bus is determined from step 3.
6) Maximum reactive power loading determined from step 5 is sorted in ascending order. The bus having lowest maximum loading is ranked highest and it is the weakest bus in the system.

Above algorithm will give the idea about how much reactive power loading can be increased on a particular load bus.

Contingency analysis and ranking can be done by using following procedure for single line contingency:

1) Run the newton-raphson load flow for single line outage by modifying admittance matrix for the removal of that line.
2) Compute FVSI for others line and find the maximum value of FVSI.
3) Repeat step 1and 2 for every line outage.
4) Sort out the maximum FVSI value obtained from step 2 in descending order with their respective line number.
5) The line on the top of the ranking is called most critical line of the system.

By using above algorithm analysis of contingency and ranking can be done very quickly and efficiently. This method is fast and hence reduces human error due to long execution time.

Artificial neural networks can be trained for these contingency analysis and ranking and then can be used to detect the most critical line in a very short time.

These methods can be used on line as these are very fast and can give real time solution.

In this work, two types of neural network named as multilayer perceptron model and probabilistic neural network has been trained from the data available from contingency analysis and ranking algorithms discussed above and are tested.

These show very fast response when executed.

IV. RESULTS AND DISCUSSION

Tests have been performed on IEEE 14-bus and IEEE 30-bus test system. Results have been shown in various tables. Table 1 shows the results of maximum loadability search for IEEE 14-bus test system having 9 load buses. The bus with minimum loading is placed at the top of the table and this bus is identified as weakest bus in the system. So, bus 9 is the weakest bus in the system.

Table 1: Qmax at load bus in ascending order for IEEE 14-Bus Test system

Bus No	Qmax (in p.u)(base value=100 MVA)
9	0.4760
13	0.7230
14	0.7400
12	0.9760
5	1.1860
11	1.2580
4	1.2910
7	1.3050
10	4.8080

There are 24 load buses in the IEEE 30 bus system. The results for maximum loadability search for IEEE 30-bus test system has been calculated for load buses and has been tabulated and are given in Table 2.

Below table shows the result for maximum loadability of IEEE 30-bus test system for various load buses in ascending order. The bus with minimum loading is placed at the top of the table and this bus is identified as weakest bus in the system. So, bus 30 is the weakest bus in the system.

Table 2: Qmax at load bus in ascending order for IEEE 30-Bus Test System

Bus No	Qmax (in p.u)(base value=100 MVA)
30	0.449
10	0.660
26	0.678
27	0.695
29	0.714
15	0.750
25	0.770
12	1.040
24	1.047
14	1.051
28	1.180
9	1.280
18	1.299
20	1.347
23	1.366
16	1.388
6	1.390
4	1.411
3	1.577
17	1.603
7	1.899
22	1.965
19	3.214
21	5.057

Automatic contingency analysis is done to find the most critical line in the system. Outage of this line will affect system severely and may cause voltage collapse and further cause system blackout. Outage of every line is considered and system performance is checked by Fast Voltage Stability Index (FVSI). Lines are arranged in descending order according to the FVSI value. The line having highest FVSI value is put on the top of table and is identified as most critical line of the system. Criticality of line decreases according to order in table.

There are 20 lines in the IEEE 14 bus test system. Outage of every line has been considered and tabulated. Loading change at a load bus can change the criticality of lines and other line may become critical so, some different loading than base case has also been considered and their results are also tabulated in Table 3.

Below table gives the most critical line. At base case lines 14 and 1 are critical but at the reactive loading of 50 MVAR at bus 14 line 20 becomes more critical than 1. This is because line 20 is directly connected to bus 14 and any change that occurs to this bus will give an impact on this line. Similarly, increase of reactive loading at other buses will also give impact on lines directly connected to those buses and after a certain loading these lines may become more critical than others.

Table 3: Contingency ranking for IEEE 14-Bus Test System

Base Case			Q_{d14}=50 MVAR		
Rank	Line Outage	FVSI	Rank	Line Outage	FVSI
1	14	1.0000	1	14	1.0000
2	1	0.3801	2	20	0.7036
3	3	0.3650	3	1	0.6983
4	2	0.3628	4	17	0.6924
5	4	0.3586	5	3	0.6856
6	7	0.3579	6	2	0.6848
7	8	0.3565	7	18	0.6834
8	5	0.355	8	7	0.675

		9			7
9	10	0.3542	9	4	0.6740
10	9	0.3531	10	5	0.6734
11	15	0.3524	11	16	0.6731
12	13	0.3518	12	11	0.6728
13	16	0.3517	13	6	0.6728
14	20	0.3516	14	9	0.6721
15	19	0.3515	15	8	0.6714
16	12	0.3514	16	12	0.6705
17	11	0.3514	17	19	0.6686
18	18	0.3514	18	15	0.6682
19	17	0.3513	19	10	0.6592
20	6	0.3480	20	13	0.6492

There are 41 lines in the IEEE 30-bus test system. Outage of every line has been considered and tabulated. Loading change at a load bus can change the criticality of lines and other line may become critical so, some different loading than base case has also been considered and their results are also tabulated in Table 4.

Below table gives the most critical line. At base case lines 13,16,34 and 5 are critical but at the reactive loading of 80 MVAR at bus 20 line 25 becomes more critical than 5. This is because line 25 is directly connected to bus 20 and any change that occurs to this bus will give an impact on this line. Similarly, increase of reactive loading at other buses will also give impact on lines directly connected to those buses and after a certain loading these lines may become more critical than others.

Table 5.4: Contingency ranking for IEEE 30-Bus Test System

Base Case			Q_{d20}=80 MVAR		
Rank	Line Outage	FVSI	Rank	Line Outage	FVSI
1	13	1.0000	1	13	1.0000
2	16	1.0000	2	16	1.0000
3	34	1.0000	3	34	1.0000
4	5	0.1732	4	25	0.6803
5	1	0.1167	5	1	0.6404
6	4	0.0979	6	5	0.6325
7	2	0.0976	7	7	0.6303
8	8	0.0966	8	4	0.6270
9	9	0.0863	9	2	0.6268
10	3	0.0745	10	6	0.6264
11	6	0.0744	11	41	0.6249
12	41	0.0739	12	27	0.6243
13	11	0.0738	13	40	0.6223
14	36	0.07374	14	3	0.6209
15	25	0.07372	15	30	0.6205
16	14	0.0737	16	26	0.6194
17	38	0.07369	17	38	0.6181
18	37	0.07368	18	37	0.61804
19	39	0.073678	19	29	0.61802
20	28	0.073674	20	39	0.6179
21	31	0.073674	21	32	0.61747
22	20	0.07367	22	31	0.61742
23	17	0.073667	23	28	0.61742
24	12	0.073651	24	17	0.6173
25	27	0.073613	25	21	0.6172
26	35	0.073582	26	20	0.6169
27	24	0.073577	27	19	0.6168
28	26	0.073568	28	36	0.6136
29	33	0.073559	29	18	0.6131
30	29	0.073549	30	33	0.6130
31	32	0.073547	31	9	0.6122
32	23	0.073539	32	15	0.6121
33	22	0.073533	33	35	0.6118
34	30	0.073521	34	22	0.6100
35	21	0.073519	35	8	0.6096
36	19	0.073506	36	23	0.6095
37	18	0.073493	37	24	0.6089
38	40	0.07347	38	10	0.6087
39	15	0.073278	39	12	0.6057
40	7	0.072929	40	11	0.5995
41	10	0.072655	41	14	0.5798

Artificial Neural Networks (ANN) can be trained from historical data and this trained network can be used to know the output at some different input and once trained it gives very fast response when executed. Here, two ANN Multilayer Perceptron Model (MLP) and Probabilistic Neural Network (PNN) are trained from the data taken from contingency analysis for IEEE 14 and IEEE 30 bus test system at different loading pattern. This trained network is then tested at different load patterns to check their performance. These trained networks can give us the idea of most critical line at certain load pattern without going for the whole process of contingency analysis and ranking so that we can take precautions for the outage of that line.

Outage of some line may cause islanding of a bus therefore these lines are always critical. So, these lines are not considered in the training.

Contingency analysis using MLP

a. For IEEE 14-bus test system

Number of input = 9
Number of output = 1
Number of training pattern= 171
Number of test pattern = 50

After training, testing has been done to check the performance of the MLP. Line 14 is always critical so it is not taken in consideration.

Total number of misclassification = 6

Misclassification Rate =Total no of misclassification/No of test input =6/50 = 0.12 = 12% Elapsed time is 2.674896 seconds.

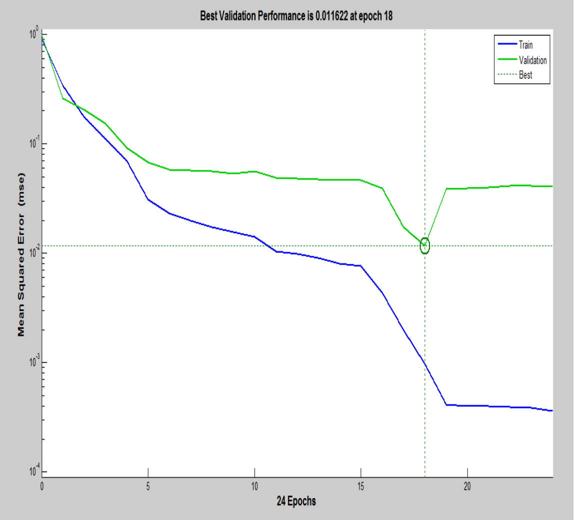

Fig. 1 MLP Performance plot for IEEE 14 bus system

b. For IEEE 30-bus test system

Number of input = 24
Number of output = 1
Number of training pattern= 247
Number of test pattern = 50

After training, testing has been done to check the performance of the MLP. Line 13, 16 and 34 are always critical so they are not taken in consideration.

Total number of misclassification = 7

Misclassification Rate =Total no of misclassification/No of test input
=7/50 = 0.14 = 14%
Elapsed time is 2.460742 seconds.

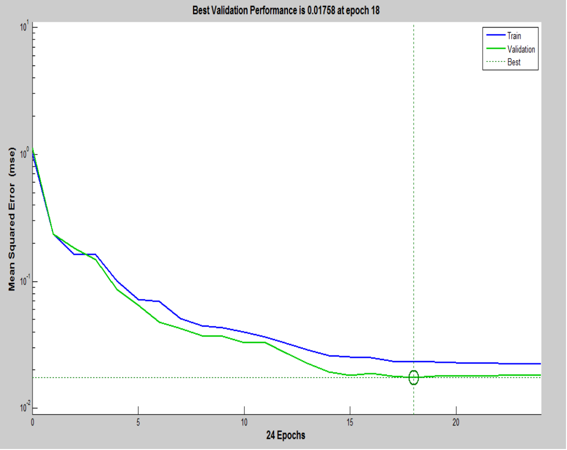

Fig. 2 MLP Training performance plot for IEEE 30-bus test system

Contingency analysis using PNN

a. For IEEE 14-bus test system

Number of input = 9
Number of output = 1
Number of training pattern= 171
Number of test pattern = 50

After training, testing has been done to check the performance of the PNN. Line 14 is always critical so it is not taken in consideration.

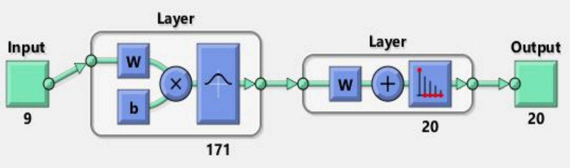

Fig. 3 PNN view for IEEE 14-bus test system.

Total number of misclassification = 2
Misclassification Rate =Total no of misclassification/No of test input
=2/50 = 0.04 = 4%
Elapsed time is 1.155316 seconds.

b. For IEEE 30-bus test system

Number of input = 24
Number of output = 1
Number of training pattern = 247
Number of test pattern = 50

After training, testing has been done to check the performance of the PNN. Line 13, 16 and 34 are always critical so they are not taken in consideration.

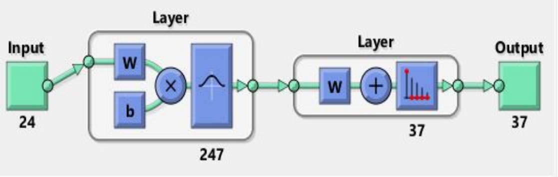

Fig. 4 PNN view for IEEE 30-bus test system

Total number of misclassification = 3
Misclassification Rate =Total no of misclassification/No of test input
=3/50 = 0.06 = 6%
Elapsed time is 1.310576 seconds.

CONCLUSION

Maximum loadability margin for IEEE 14 and IEEE 30 bus system has been identified and automatic contingency analysis and ranking algorithm based on voltage stability condition has been presented in this work. Contingency analysis for line outage in both the system has been done and most critical line is identified. Fast Voltage Stability Index (FVSI) has been used as a line stability parameter in automatic contingency analysis. Artificial Neural Network (ANN) has been modelled and trained for determination of most critical line with historical (simulated) data obtained from automatic contingency analysis. Automatic contingency analysis takes very less computation time in line outage analysis in compare to manual techniques which may cause error due to long computation time and human factor constraint.

Results show that once ANN has been trained it gives very fast response when executed.
Two types of neural network has been used and results shows that

1. Learning process of PNN is faster than MLP.
2. Misclassification rate is lower in PNN than MLP.
3. But PNN is not as general as MLP.

The conclusions from this study can easily identify the line outage severity without having to go through a long process as implemented previously and it is doable to be implemented on-line.

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