FAST CONTINGENCY ANALYSIS AND RANKING FOR POWER SYSTEM SECURITY ASSESSMENT

A SYNOPSIS

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ABSTRACT

Economic and environmental pressures have caused the modern power system to operate more close to its limit of stability. This situation becomes worst when contingencies occur in the stressed power network. Contingencies caused by line, generator and transformer outages are identified as the most common contingencies that could violate the voltage stability limits across the system.

Maintaining power system security in such scenario is one of the challenging tasks for the power system engineers. The security assessment is an essential task as it gives the knowledge about the system state in the event of contingency. Contingency analysis technique is being widely used to predict the effect of outages like failures of equipment, transmission line etc., and to take necessary action to keep the power system secure and reliable. The off line analysis to predict the effect of individual contingency is a tedious task as a power system contains large number of components. Practically, only selected contingencies will lead to severe conditions in power system. The process of identifying these severe contingencies is referred as contingency selection and this can be done by calculating performance indices for each contingencies.

In the present work, contingency analysis and ranking has been done by calculating line stability index named as Fast Voltage Stability Index (FVSI), for single line outage. Maximum loadability search is also done by using FVSI. With the help of Newton-Raphson Load Flow, the FVSI has been calculated in MATLAB environment and contingency ranking is made. Further the contingency analysis suited specially for online environment has been done by using Multilayer Perceptron Network (MLP) and Probabilistic Neural Network (PNN). This provide and effective mean to rank the contingencies for various loading in a power system. The effectiveness of the methods have been tested on IEEE 14-Bus and IEEE 30-Bus test systems.

SYNOPSIS

1 INTRODUCTION

In recent years, several blackouts related to voltage stability problems have occurred in many countries. In order to understand why these failures are happening, it should be taken into account that nowadays power systems have to operate closer to their limits. There is an ever-increasing power demand, which could in a near future expect a higher rise with the establishment of electrical vehicles. At the same time, transmission networks are not enlarged due to economic and environmental considerations and few lines are constructed. In addition, the growing usage of renewable energy tends to make the networks more stressed, since these sources have a higher dynamic and stochastic behaviour. Finally, another factor is the liberalisation of electricity supply industry (deregulation), which has resulted in a significant increase in inter-area or cross-border trades, which are not always well accounted for when planning system security.

Up until now we have been mainly concerned with minimizing the cost of operating a power system. An overriding factor in the operation of a power system is the desire to maintain system security. System security involves practices designed to keep the system operating when components fail. For example, a generating unit may have to be taken off-line because of auxiliary equipment failure. By maintaining proper amounts of spinning reserve, the remaining units on the system can make up the deficit without too low a frequency drop or need to shed any load. Similarly, a transmission line may be damaged by a storm and taken out by automatic relaying.

Systems security can be broken down into three major functions that are carried out in an operations control center:

1. System monitoring.
2. Contingency analysis.
3. Security-constrained optimal power flow.

Contingency analysis, ranking and selection are acceptably considered as crucial activities in power security assessment and normally conducted in line with the voltage stability analysis. Most of contingency analysis algorithms are meant to perform the contingency selection in order to identify and filter out worst contingency cases for further detailed analysis once the preventive and corrective measures have been identified. Complex system mainly caused by the economic and environmental pressures in a continuing interconnection of bulk power systems has caused the system to operate close to its limit of stability. This situation becomes worst when contingencies occur in the stressed power network. Contingencies caused by line, generator and transformer outages are identified as the most common contingencies that could violate the voltage stability condition of the entire system. Previous researches have shown that contingency analysis can be time consuming particularly for a bulk power system. Human factor has been identified as one of main factors that made contingency process a tedious task with the increasing execution time. Approach to reduce computation burden in reducing credible contingency set can be accomplished by performing the automatic contingency analysis and ranking. The algorithm for automatic contingency analysis and ranking is capable to identify the potential harmful contingencies. Contingency analysis is normally conducted at a limit lower than the maximum loadability of a particular load bus in order to obtain correct ranking as described by Musirin *et al.* in reference [13]. The change in load margin between nominal and contingency based on voltage collapse can also be identified via sensitivity analysis obtained from the single nose of a PV curve. On-line contingency analysis requires evaluation and ranking of a large number of contingency cases in order to assess the static security of a power system. Fast methods for contingency ranking techniques using the Jacobian matrix manipulation in the load flow study and involvement of artificial intelligence are alternative methods towards minimising computation burden and the number of contingencies to be simulated. This work presents an algorithm for automatic contingency analysis and ranking technique using a line based voltage stability index. A line-based voltage stability index termed as Fast Voltage Stability Index (FVSI) developed by Musirin *et al.* in ref. [11] is utilized in order to indicate the voltage stability condition on a line. This algorithm is incorporated in the line outage simulation, post-outage voltage stability analysis and ranking technique in one programme, making it fast approach to establish the required task. Highest FVSI value for every line outage simulation can be identified and the ranking in terms of line outage severity could be achieved within few CPU seconds depending on system complexity. In realizing the effectiveness of the proposed algorithm, validation was performed on several IEEE reliability Test Systems and comparative studies were also conducted indicating a remarkable advantage particularly in its computation time. Results obtained from the studies indicated the proposed technique could be implemented on-line.

1.1 Objective

In this dissertation, load flow analysis using Newton-raphson method is done and Fast Voltage Stability Index (FVSI) is calculated for every line in IEEE 14 and IEEE 30 bus system. Also, maximum reactive power loading is calculated at every load bus in the system is calculated to know the maximum loadability margin and weakest bus of the system. Line outage contingency analysis is done to know the system behaviour and to determine the critical line of the system, whose outage can create system security problem and can cause voltage collapse using the line stability index FVSI. After data is generated Artificial Neural Network (ANN) is trained for determining the critical line of the system and once it is trained it exhibits a very fast response when executed.

The main objective of this work is to determine which line contingency is most critical and which bus is weakest in the system at a given load pattern .The methodology used for the present work is:

1. Load flow analysis using Newton-Raphson method has been done.

2. Maximum reactive power loading before voltage collapse at every bus has been calculated and weakest bus of the system has been determined.
3. Contingency analysis for every line outage has been done one by one and critical line outage contingency has been determined.
4. Artificial Neural Network (ANN) has been trained from simulated data and it has been executed for a different load pattern to determine its performance.
5. Results obtained are compared with manual technique used.

2 Contingency Analysis

For Automatic contingency analysis and maximum loadability search, it is necessary to obtain voltage at different buses and line flows to know the system condition. 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 useful to assess voltage stability of power systems by means of voltage stability indices (VSI).

2.1 Fast Voltage Stability Index (FVSI)

A pre-developed line-based voltage stability index, FVSl has been utilized in the contingency analysis as the system condition indicator. It is defined as

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

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 *FVS*I 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.

Developing an algorithm that can analyse and rank the contingencies automatically can minimize the computation burden and error due to human factor. Line outage simulation and voltage stability analysis are the two procedures incorporated together to perform the automatic contingency analysis and ranking by this technique. Prior to the automatic contingency analysis and ranking, determination of maximum loadability has to be first conducted so as to identify the suitable operating loading condition margin. A constraint has been considered in the algorithm by assigning FVSI values to unity for the non-converged load flow and FVSI values exceeding unity.

3 Artificial Neural Network

A neural network can be defined as a model of reasoning based on the human brain. The brain consists of a densely interconnected set of nerve cells, or basic information-processing units, called neurons. Learning is a fundamental and essential characteristic of biological neural networks. The ease and naturalness with which they can learn led to attempts to emulate a biological neural network in a computer.

Artificial Neural Network (ANN) has been used as a tool to learn the system behaviour when reactive power loading at a bus changes and its effect on contingency analysis and ranking. After training from historical data ANN has been used to simulate the result for different load patterns to determine critical lines and it has shown a fast response when executed.

In this work, two network model Feed forward Multilayer Perceptron model and Probabilistic Neural Network has been used.

3.1 Multilayer Perceptron Network

A multilayer perceptron is a feed forward neural network with one or more hidden layers. Typically, the network consists of an input layer of source neurons, at least one middle or hidden layer of computational neurons, and an output layer of computational neurons. The input signals are propagated in a forward direction on a layer-by-layer basis.

3.2 Probabilistic Neural Network

Probabilistic neural networks can be used for classification problems. When an input is presented, the first layer computes distances from the input vector to the training input vectors and produces a vector whose elements indicate how close the input is to a training input. The second layer sums these contributions for each class of inputs to produce as its net output a vector of probabilities. Finally, compete transfer function on the output of the second layer picks the maximum of these probabilities, and produces a 1 for that class and a 0 for the other classes.

4 Results and Discussion

Table 4.1: 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

Table 4.2: 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

Table 4.3: 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	0.3559	8	7	0.6757
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

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

5 Conclusion and Future Scope

5.1 Conclusion

Maximum loadability margin for IEEE 14 and IEEE 30 bus system has been identified. Automatic contingency analysis and ranking algorithm based on voltage stability condition has been presented in this work. It consist program for automatic line removal, post outage contingency analysis and ranking in one single program. 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.

The developed automatic contingency analysis and ranking algorithm has been tested on the IEEE Reliability Test Systems to realize its effectiveness and showed a remarkable improvement in automatic contingency analysis and ranking. The findings from this study can easily recognize the line outage severity without having to go through a long process as implemented previously and it is viable to be implemented on-line.

5.2 Scope for Future Work

1. In the present work load disturbance is of deterministic nature. The work can be extended to dynamic load disturbances.
2. In this work single contingency has been analysed it can be extended from single to multiple contingency analysis.
3. In this work only contingency analysis for line outage has been done it can be extended for generator and transformer outage also

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