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Application of Neural Network for Contingency Ranking Based on Combination of Severity Indices

S. Jadid, S. Jalilzadeh

***Abstract*—** In this paper, an improved technique for contingency ranking using artificial neural network (ANN) is presented. The proposed approach is based on multi-layer perceptrons trained by backpropagation to contingency analysis. Severity indices in dynamic stability assessment are presented. These indices are based on the concept of coherency and three dot products of the system variables. It is well known that some indices work better than others for a particular power system. This paper along with test results using several different systems, demonstrates that combination of indices with ANN provides better ranking than a single index. The presented results are obtained through the use of power system simulation (PSS/E) and MATLAB 6.5 software.

***Keywords*—**composite indices,transient stability, neural network.

I. Introduction

THE increasing load demand in power systems without accompanying investments in generation and transmission has affected the analysis of stability phenomena, requiring more reliable and faster tools. One of the most challenging problems in real-time operation of power systems is the assessment of transient stability. Its importance has increased due to the reduction of operational safety margins. Modern power systems are large and complex systems operated under great economic pressures. With increased pressure to maximize power transfers, electric utilities are gradually being forced to operate their systems closer to their stability limits. The burden on operator is becoming more onerous, due to constant changing of operating conditions.

Consequently, as evidenced by the recent spate of blackouts, power system security has become a major concern. In the past, many blackouts were caused by significant imbalance between loads and generations and by the consequent instability.

The security assessment of a power system requires analysis of the dynamic system behaviour under a prescribed set of events. Conventionally this is done by simulating the system nonlinear equations. This method is accurate and reliable but has two major drawbacks: it is inherently slow because of numerical integration of dynamic equations and it does not provide any information about the degree of stability (or instability) of the system [1]. The large size of the system adds to the complexity. A possible solution to overcome this drawback is the application of the ANN approach.

Authors are with Electrical Engineering department, Iran university of Science & Technology (IUST), Tehran-Iran (e-mail: sa_jalilzadeh@yahoo.com).

Some researchers have tried in the past to determine the stability margin by analyzing the result of the time domain simulation method through the transient energy function method known as hybrid method. Fouad [2] determined an index by evaluating the individual machine energy function along the system trajectory generated by the time domain simulation method. This method requires the computation of corrected kinetic energy. Haque [3] describe the hybrid method to find the stability margin, but only one of the machines in the system is considered. Artificial Neural Networks (ANN) technology has been reported as an important contributor for reaching the goals of transient stability analysis [4-6]. These proposals of neural network application to transient stability evaluation show how these properties can be turned into practical use. In general, these proposals can be said to implement one of the following ideas:

a)to rank or screen the contingencies, and then perform detailed time domain simulations

b)to provide fast stability evaluations.

All these methods find index or stability margin and in this paper a novel severity index to analyze power system stability is presented that is based on combination of five indices by ANN. This paper also shows that combination of indices provide better ranking than a single index. In section II, performance indices and history of what has been done are described. In section III, artificial neural network is described. In section IV, the developed new index is described and finally, in section V, numerical results are presented.

II. Performance Indices

In large complex power system, for successful screening, the indices should be a good measure of system severity in the transient condition. The maximum amplitude of a rotor angle swing in the post-contingency period can be used as a measure of the transient severity of a contingency. Utility operational guidelines usually recommend that large rotor swings should be avoided to maintain security of operation. For this reason the maximum rotor swing amplitude was used as the transient stability index [6].

Previous work on this area of contingency screening has been done by various researchers. Fu and Bose[7] have compared three different screening methods, which are based on the concepts of coherency, transient energy conversion between kinetic energy and potential energy, and three dot products of the system variables. In [7] each index is assigned the same weight to test the overall performance of all indices and composite index can be obtained by tuning the weights for a particular power system.

The method outlined by Chan [8] classifies contingencies into four categories and ranking contingencies with a descending system severity index. The four categories are transiently unstable, oscillatory unstable, stable but poorly, and stable and well damped. Bettiol [9] used an artificial neural network filter for selecting severe cases on the ranking list. This may be achieved by computing the values of the performance index for each line outage and subsequently ranking the contingencies from the most important (largest value of performance index) to the least important (smallest value of the performance index).

The effects of possible contingencies are presented by a severity or performance index (PI).The calculated performance indices are then sorted in such a way to provide an ordered list of contingencies according to their severity.

The coherency concept is stated as follows: for very stable cases, the angle of each machine will move coherently with the center of inertia (COI). For unstable cases, there are some machines whose angles will move from the COI. Obviously, any such index will have to reflect the generator rotor angles with respect to the COI. The following performance indices are defined to measure the coherency of the contingency [10].

$$\mathrm{PI}_1 = \max(\max(\theta_i) - \min(\theta_i))$$

$$\mathrm{PI}_2 = \max(\max(\theta_i - \theta_i^0))$$

$$for \ : i = 1, 2, \ldots\ldots., \quad NG$$

$$and \ : t_{cl} \leq t \leq t_{cl} + T$$

where:

θ : generator rotor angle relative to COI.

NG : total number of generators.

t_{cl} : fault clearance time.

T : length of short period after fault clearing.

θ_i^0 : rotor angle in beginning of the fault.

A dot product was defined for detecting the exit point. The exit point is characterized by the first maximum of transient potential energy with respect to the post-fault network.

$$dot_1 = \sum_{i=1}^{n} f_i \omega_i$$

$$f_i = P_{mi} - P_{ei} - \frac{M_i}{M_t} P_{COI}$$

$$P_{COI} = \sum_{i=1}^{n} (P_{mi} - P_{ei})$$

$$for : i = 1, \ldots, NG$$

where:

M_i : inertia constant of each generator.

M_t : total inertia constant of all generators.

P_{mi} : mechanical power input for each generator.

P_{ei} : electrical power output for each generator.

ω_i : rotor speed with respect to COI

The dot product can give the measure of total accelerating power and the power system response to this accelerating power, thus it could be a good index for ranking dynamic contingencies. The rotor angle and speed are significant measures, thus, the following two dot products are defined:

$$dot_2 = \sum_{i=1}^{NG} f_i \theta_i$$

$$dot_3 = \sum_{i=1}^{NG} \omega_i (\theta_i - \theta_i^{cl})$$

where:

θ_i^{cl} : rotor angle at fault clearing time for generator i.

There are three indices defined from the concept of these three dot products.

$$PI_3 = \max dot_1(t) - \min dot_1(t)$$

$$PI_4 = \max dot_2(t) - \min dot_2(t)$$

$$PI_5 = \max dot_3(t) - \min dot_3(t)$$

$$for : t_{cl} \leq t \leq t_{cl} + T$$

III. Artificial Neural Network (ANN)

The use of artificial neural networks (ANN) in solving power system operation and planning problems includes many areas such as: security assessment, contingency selection, predicting critical clearing times, etc. The interest in ANN is their ability to learn complicated and changing scenarios and thus they are very robust. Our work has been in exploring their use in classifying contingencies and identifying the critical ones. Artificial neural networks have been proposed as an alternative method for the transient stability assessment problem by many authors since Sobajic [4] explored the capability of ANN for Transient Security Analysis(TSA). This method is based on performing off-line training of a pattern classifier using results obtained from a time domain simulator [5,11,12].

In these paper one index or stability margin are presented but in this paper a novel composite index is calculated by ANN.

In order to successfully train the ANN, a good selection of pattern vectors must be carefully conducted. ANN approach to contingency ranking starts with the creation of training samples. The input vectors for training and testing set were normalized and have been obtained using IPLAN programming and PSSE software, which calculate stability indices. These indices are input vectors and maximum rotor angles are output data for the

training. In this paper the selected ANN consists of two-hidden layer perceptrons which have been trained by backpropagation algorithm, and is used to assess transient stability and get composite indices.

IV. Composite Index (CI)

Indices PI_1 to PI_5 may not reliably capture all the severely unsecure cases. Each index can't rank the severity of contingency for different systems under different conditions. From the experience of contingency ranking in static security analysis, combination of indices with ANN is successful in ranking the contingencies. This index assigns different weights to each individual index and adds them together. As shown in next section, this index will provide a better ranking for severely unsecure cases in test systems.

V. Numerical Results

Two systems were used for testing purposes: 9 bus IEEE test system and 39-bus New England system. Data for these systems are constructed based on PSS/E format raw data. The 9-bus system has three generators of GENROE and three exciter of IEEET1 type. The 39-bus New England system has ten generators of GENROU type.

Three phase short circuit fault is applied on the selected bus in all the systems and then removed after 6 cycles (0.12 second). To study the stability of the test systems, the generator's rotor angle, electric power, mechanical power and speed of rotor for these systems is driven from PSS/E simulator and then performance indices PI_1 to PI_5 and combination index CI is calculated by ANN methods.

Maximum rotor swing amplitude is used as a benchmark to compare the results to other performance indices. As shown in results, CI index ranking is closer to benchmark from the largest to smallest value.

The purpose of the combination of indices is to take advantage of the slightly different characteristics of the five indices to find the best index for contingency ranking. Usually PI_1, PI_2 and PI_5 have better behavior and due to this a weighted combination of indices is suggested to take advantage of those indices that work better for a particular power system.

Table -1 shows ranking results in 9 bus IEEE test system. This system has 9 line that 3 line outages, cause instability in the system. In this paper 5 line outages are studied.

As shown in Table -2 ranking using PI_1 to PI_5 is according to only in four, four, two, two and four states respectively but ranking with CI is according to in first five worse states, thus it is better and closer to the benchmark.

VI. Conclusion

This paper demonstrated that various performance indices couldn't reliably capture all the instable cases individually. Each index can't rank the severity of contingency for different system under different conditions, but the combination of indices can give an overall evaluation from different aspects of the system. Results on two test systems showed that combination of indices CI with use of ANN will provide a better ranking for worst cases with respect to weighted factor method and closer to maximum rotor swing amplitude as a benchmark to compare to other performance indices.

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TABLE I
RANKING RESULT WITH 9 BUS IEEE TEST SYSTEM

line tripped *(faulted bus)	PI_1	PI_2	PI_3	PI_4	PI_5	$\max \theta_i$	CI with ANN
2-7*	730.5317	742.1362	20.4647	860.3842	3999.271	877.99	486.4
3-9*	407.0611	413.4649	7.19257	296.6013	1185.111	472.21	312.1
1-4*	89.5223	90.90827	6.40248	154.8796	101.5424	67.94	60.83
5*-7	63.5643	70.30014	2.6165	84.3789	167.1571	59.7176	26.37
6*-9	45.0077	48.53	1.56524	54.255	103.6037	38.62	23.81
…	…	…	…	…	…	…	…
4*-5	64.071	…	…	…	…	…	…
7*-8	…	66.128	…	149.292	…	…	…
4*-6	…	…	4.64	….	…	…	

TABLE II
RANKING RESULT WITH 39 BUS NEW ENGLAND TEST SYSTEM FOR 10 FIRST LARGEST CONTINGENCIES

Liline tripped **(faulted bus)	PI_1	PI_2	PI_3	PI_4	PI_5	$\max \theta_i$	CI with ANN
9*-8	70.34	73.857	41.54	1531.188	278.5	149.372	149.3885
9*-39	70.311	73.8192	41.37	1519.61	277.15	149.354	148.72
1*-39	55.2977	57.744	29.94	807.96	183.92	131.004	131.197
1*-2	55.0259	57.706	29.99	814.66	183.35	130.966	130.734
6*-31	22.39	26.47	12.66	1682.11	131.856	101.6067	93.096
6*-7	16.99	21.176	26.602	1762.84	11.6159	94.0	86.61
8*-7	15.814	19.89	26.3059	1565.134	11.18	92.608	81.97
8*-5	15.79	19.87	26.55	1565.52	12.09	92.489	90.0
6*-11	15.303	19.4839	28.63	1727.8	13.88	92.0	82.35
5*-6	15.033	19.0724	26.506	1645.4	7.27	91.73	90.93
…	…	…	…	…	…	…	…
10*-32	39.93	…	…	…	…	…	…
29*-38	…	57.2	…	…	…	…	…
25*-37	…	…	…	…	176.4	…	…