Electrical Power and Energy Systems 76 (2016) 165–173

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

journal homepage: www.elsevier.com/locate/ijepes

An online power system static security assessment module using multi-layer perceptron and radial basis function network

Pudi Sekhar *, Sanjeeb Mohanty

Dept. of Electrical Engineering, National Institute of Technology, Rourkela, India

ARTICLE INFO

Article history:
Received 3 August 2015
Received in revised form 14 September 2015
Accepted 4 November 2015

Keywords:
Artificial neural network
Power system security
Contingency ranking module
Security assessment

ABSTRACT

Efficient contingency screening and ranking method has gained importance in modern power systems for its secure operation. This paper proposes two artificial neural networks namely multi-layer feed forward neural network (MFNN) and radial basis function network (RBFN) to realize the online power system static security assessment (PSSSA) module. To assess the severity of the system, two indices have been used, namely active power performance index and voltage performance index, which are computed using Newton–Raphson load flow (NRLF) analysis for variable loading conditions under $N-1$ line outage contingencies. The proposed MFNN and RBFN models based PSSSA module, are fed with power system operating states, load conditions and $N-1$ line outage contingencies as input features to train the neural network models, to predict the performance indices for unseen network conditions and rank them in descending order based on performance indices for security assessment. The proposed approaches are tested on standard IEEE 30-bus test system, where the simulation results prove its performance and robustness for power system static security assessment. The comparison of severity obtained by the neural network models and the NRLF analysis in terms of time and accuracy, signifies that the proposed model is quick, accurate and robust for power system static security evaluation for unseen network conditions. Thus, the proposed PSSSA module implemented using MFNN and RBFN models are found to be feasible for online implementation.

Introduction

The power system is a complex network, where the security of the power system has gained importance for reliable operation. The power system security assessment is the analysis performed to determine whether, and to what extent, a power system is reasonably safe from serious interference to its operation [1]. The power system security assessment involves three major tasks, namely security monitoring, contingency analysis and security control. Security monitoring is a mechanism, which provides the system operating conditions to the operational engineers. The contingency analysis plays a vital role in the power system security assessment, the importance of which is discussed in [2,3]. This stage includes contingency screening and ranking. If the power system is found to be insecure, necessary control actions are implemented to bring back the insecure state of the system to secure.

The research in this area has been carried out extensively in the past few years, which includes contingency ranking or screening methods for security assessment. The most ranking methods are based on the evaluation by means of performance indices (PI), which is the measure of the system stress. In this approach, the contingencies are ranked based on the severity obtained from network variables and are directly assessed. The static security assessment inspect the severity under post contingency scenario, which includes solving various load flow methods for base case and $N-1$ line outage conditions. These methods are highly complex and time consuming for online implementation. Also, the system operating conditions vary from time to time, which makes the conventional methods are infeasible for online implementation. Thus, there is a need to develop efficient online tool (which monitor the system security under variable system conditions) for power system security assessment to ensure safe operation of the power system [4]. The deregulation has compelled the utilities to function their systems closer to their security limits, which demands quick and efficient approach for security assessment [5]. Thus, this paper focused on the design of a model that is quick and accurate which can predict the system severity for security evaluation, which is feasible for real time implementation in order to aid the operational engineers.

* Corresponding author.
E-mail addresses: pudisekhar@yahoo.com (P. Sekhar), sanjeeb.mohanty@nitrkl.ac.in (S. Mohanty).

http://dx.doi.org/10.1016/j.ijepes.2015.11.009
0142-0615/

Nomenclature

d_{max}	maximum distance between the chosen centers
$e_1(m)$	error at the *m*th iteration
m	number of iterations
m_1	number of chosen centers
n	exponent of penalty function (=1)
N_B	number of buses in the system
N_L	number of transmission lines in the system
N_h	number of hidden neurons
N_k	number of neurons in the output layer
N_i	number of inputs to the network
Np	number of patterns in the training set
P_l	active power flow in line *l*
P_l^{max}	MW capacity of line *l*
$S_b(j)$	output from the hidden layer
$S_a(i)$	output from the first layer
$\|V_i\|$	voltage magnitude at bus *i*
V_i^{sp}	rated voltage magnitude at bus *i*
ΔV_i^{lim}	upper and lower voltage limits by regulation
W	real non-negative weighting factor (=1),
W_{aj}	weight between the hidden layer and output layer
X_{1p}	actual value
X_{2p}	estimated value after *m*th iteration
X_1	the input pattern
X_2	the co-ordinates of the center
$\|\|X_1 - X_2\|\|$	Euclidean distance between X_1 and X_2
$\delta_k(m)$	error for the *k*th output at the *m*th iteration
$\delta_j(m)$	error for the *j*th output after the *m*th iteration
η_1	the learning rate

Traditionally, the contingency ranking approach is performed based on performance indices (PI) obtained from solving the load flow solutions. However, the accuracy and speed of security evaluation depends on the type of methodology used for ranking approach. Thus in the recent years, the literature revealed the application of artificial neural networks (ANN) to power system static security assessment, indicate that this is a very encouraging research field. The importance and applicability of neural networks for the power system security assessment and control are proposed by the authors in [6–9]. The computation speed and generalization capability of ANN makes it feasible for modern power systems for security monitoring [10]. The combination of ANN and divergence algorithm for feature selection have been used for security assessment in [11]. The authors in [12–14] have investigated a Cascade Neural Network (CNN), in which the filter and ranking module are incorporated with feed forward network, for quick line flow contingency screening and ranking. In [15,16], the authors investigated the application of counter propagation network for active power contingency ranking. A parallel self-organizing hierarchical neural network is investigated in [17,18] for voltage contingency ranking. However, an ideal contingency ranking module should be capable to rank the severity of both the active power and voltage violations for security assessment to prove the robustness of the ANN models. The efficient performance of ANN is observed because of the suitable selection of training features which covers the entire operating states of the power system.

The nature of the power system is dynamic, where the system parameters varies continuously. Thus, the classical offline methods are not reliable for continuous monitoring of the system security. However, a trained ANN have the advantage to respond to unknown system conditions, which enhance the security monitoring and assessment, which makes it feasible for online implementation. The key contribution of this paper is to establish an online power system static security assessment module, which minimizes the offline computational effort and predict the system severity under variable system operating conditions.

For a specific contingency, the contingency ranking varies for active power violations and voltage violations. Thus, it is necessary to incorporate both the violations to accurately monitor the system security. The proposed module make use of active power performance index (PI_P) and voltage performance index (PI_V) for quick and efficient security assessment. The key functions of the module is that: (1) It calculates the system severity (both PI_P and PI_V) for each operating condition. (2) It calculates severity indices under $N-1$ line outage contingency. (3) The model rank the contingencies based on their order of severity. The proposed PSSSA module uses ANN models to compute performance indices for each loading under $N-1$ line outage contingency. The ANN models are trained for various range of operating conditions to obtain performance indices. In this work, the PSSSA module is developed using MFNN and RBFN, investigated on standard IEEE 30-bus test system.

The remainder of the paper is organized as follows: The Section 'Power system security assessment by contingency ranking approach using classical NRLF method' presents the security assessment by classical NRLF method. Section 'The online PSSSA module using MFNN and RBFN models' discuss the design and implementation of PSSSA module using MFNN and RBFN for power system static security assessment. The simulation results in Section 'Simul ation results', demonstrate the robustness and effectiveness of the proposed module for security evaluation. Finally, in Section 'Concl usion' concluding remarks are provided.

Power system security assessment by contingency ranking approach using classical NRLF method

The power system static security can be analyzed by ranking the contingencies based on the contingency severity. This classical method involves the load flow analysis. The contingency analysis involves the simulation of individual $N-1$ line outage contingency for the power system model. In order to make the analysis easier, it consists of three basic steps:

Contingency creation: It comprises of a set of possible contingencies that might occur in a power system. The process consists of creating the contingencies list.

Contingency selection: It is the process of selecting severe contingencies from the list that leads to the bus voltage and the power limit violations. Therefore this process minimizes the contingency list by eliminating least severe contingencies. It uses the index calculation to find out the severity of the contingencies.

Contingency evaluation: It involves the necessary security actions needed to be taken or necessary control action in order to mitigate the effect of the contingency.

Thus one of the major tasks of the power system planning and the operational engineers is to study the effect of the outages in