Applied Soft Computing 29 (2015) 1–11

Contents lists available at ScienceDirect

Applied Soft Computing

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

Simulation of an adaptive artificial neural network for power system security enhancement including control action

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ARTICLE INFO

Article history:
Received 18 June 2012
Received in revised form 1 December 2014
Accepted 5 December 2014
Available online 12 December 2014

Keywords:
Steady-state security assessment
Artificial neural network
Back-propagation
Remedial action
Contingency analysis

ABSTRACT

This paper presents a new method for enhancing power system security, including a remedial action, using an artificial neural network (ANN) technique. The deregulation of electricity markets is still an essential requirement of modern power systems, which require the operation of an independent system driven by economic considerations. Power flow and contingency analyses usually take a few seconds to suggest a control action. Such delay could result in issues that affect system security. This study aims to find a significant control action that alleviates the bus voltage violation of a power system and to develop an automatic data knowledge generation method for the adaptive ANN. The developed method is proved to be a steady-state security assessment tool for supplying possible control actions to mitigate an insecure situation resulting from credible contingency. The proposed algorithm is successfully tested on the IEEE 9-bus and 39-bus test systems. A comparison of the results of the proposed algorithm with those of other conventional methods reveals that an ANN can accurately and instantaneously provide the required amounts of generation re-dispatch and load shedding in megawatts.

1. Introduction

The goal of security analysis, which involves monitoring, assessment, and control, in a power system operation is to determine if the system is currently operating normally within the system constraints. Therefore, including the variables for the safe operation and contingency operation of a system for at least a single component failure, such as the loss of a transmission line or transformer, is common practice. In addition, the use of artificial intelligent systems has become a major aspect in the implementation of new technologies involved in a large interconnected electrical power plan. In a normal operation, cases of thermal line flow and bus voltage limit violation increase. Researchers and engineers focus their efforts on enhancing the reliability and security of power systems. Such systems must be capable of dealing with emergencies, such as line outage and generation failure. In fact, line overloading occurs because of the loss of a transmission line or load increases in the network, which often cause line limit violations and bus voltage instability. In these situations, the operator must intervene with an optimal corrective or preventive control action to restore the secure operation of the system. The effective approaches to alleviating line overloading are generator rescheduling and load shedding.

Under contingency events, the system should operate within the security criteria of the thermal line flow, frequency, phase angle, and bus voltage. The problem formulation of line overload alleviation [1], generation rescheduling, and load shedding provides a proper sequence of control actions to improve system security. The work in [2] was the first to demonstrate the ability of a supervised neural network to help the operator in making a decision. The proposed method considers generator shedding as a control action when a fault occurs to improve power system stability. Several studies investigating artificial neural network (ANN) techniques have been used in many power system applications, such as in static and dynamic security assessment, load flow, contingency analysis, and fault diagnoses [3–10]. The developments in computer programming have heightened the efficiency of the ANN and provided other opportunities for it to be used in power systems control [11].

The adaptive neural network using the delta rule was implemented to estimate the signal parameters of voltage or current waveform contaminated by noise [12]. All weights showed good adaptability, but the learning termination factors, which are important in ending the training process, were not considered. Another drawback of the work developed in Ref. [12] is that the data normalization process was not finalized, in which case the designed

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http://dx.doi.org/10.1016/j.asoc.2014.12.006
1568-4946/

Nomenclature

w_{ki}	set to a random number in the beginning of the training process
b_k	set to 1 to speed up the convergence process
λ	determines the shape of the function = 1
N	number of contingencies

neural network would not work effectively with another system. Yoo and Pimmely [13] applied a self-supervised adaptive neural network algorithm in a power system for short-term load forecasting. They used the temperature and load records of one year for training. The designed neural network was adaptable and accurate with 0.90% error for hour-ahead forecasting and 1.92% error for day-ahead forecasting. However, the data knowledge generation process and data processing were not considered before the training of the neural network. Therefore, the testing results and power system representation could have been affected. In addition, there work did not include a contingency analysis that could help avoid weight overlapping during system disturbance and high errors in predicted value.

A group of researchers [14] designed control learning laws with a projection algorithm and used these laws to guarantee the bound of neural network weight vector. They also introduced a command filter to emulate the mechanical or operating limitations of actuators for Multiple Input Multiple Output (MIMO) nonlinear systems with unknown control coefficient matrices. The proposed method was able to eliminate the analytic computations of the virtual control law derivatives via the command filter in [15,16]. However, the robust adaptive neural network was based on the filter design that considered back stepping control to stabilize the closed-loop adaptive system and reduce the error convergence by updating the designed parameters.

In 2011, Liu et al. [17] proposed an adaptive approach for a class of uncertain MIMO nonlinear systems in a discrete time form. In this approach, the desired controller values are approximated by using a small number of adjustable parameters for the neural network. The developed robust adaptive neural network guarantees the security of the power system with small error convergence by adjusting the neural network weights based on new changes in the power system parameters.

Recent studies focused on the use of an Adaptive Artificial Neural Network (AANN) for time varying systems used in forecasting applications [18,19]. The developed algorithms prove the ability of the ANN to be used specifically in both static and real-time series predictions with high robustness value. ANN implementation is made difficult by increasing the number of inputs/outputs. Such difficulty considered as a main motivation to develop a means to control the whole system with robust data knowledge generation and control action. This study was initiated in 2010 [20] based on simple system with high level of success but it was not efficient with bigger power system, therefore, a new algorithm has been recommended in this paper for any system.

In the present work, a smart system for a control action scheme using AANN is developed. The new system is entirely dependent on system experience and uses historical and contingency analysis data for training. This feature will allow the neural network to solve the nonlinear changes in the system and achieve optimal amounts of generation re-dispatch and load shedding. The results obtained are compared against a steady-state security assessment method using conventional corrective action analysis programs. Simulations are performed using the Power System Simulator for Engineering (PSS^{TM}E) for data knowledge generation. A simulation code is written using the Python language for the AANN learning and testing process as well as for the contingency analysis.

2. Automatic data knowledge generation algorithm

Superior data quality is essential for the neural network approach. Therefore, training data should be correctly generated, and the neural network should possess good data generation capability. In this regard, several points are considered for the proposed enhanced neural network:

1. The automatic procedure guarantees good data quality because a wide variety of system operating points and contingencies are demonstrated for each load level.
2. The accuracy and applicability of the proposed approach is based on the use of feature selection and extraction methods in the data generation process. The selection of AANN model inputs and outputs is based on a statistical feature selection.
3. To verify the ability of the robust AANN to detect a situation and provide an appropriate action, training data are generated from the minimum load up to the maximum load levels with constant increments.
4. Optimization methods are used to estimate the parameters of the AANN. The Root Mean Square Error (RMSE) equation demonstrates several advantages, particularly in terms of improving neural network sensitivity when an error reaches its minimum with a reduced number of iterations.

These factors enhance the performance of the neural network application, making it more robust than the standard back-propagation method.

The automatic data knowledge generation is based on operating point variation, which in turn is based on load profile, production, contingency, and operational practices. Most contingency effects can be reduced by applying a preventive/corrective control action. Conversely, the output or target data (generator re-dispatch and load shedding amounts) are automatically generated for each contingency to be included with a sample of the neural network. Generation rescheduling and load shedding are considered solutions for increasing system reliability and security.

2.1. Contingency analysis

One important part of power system operation is contingency analysis. Contingency analysis allows the designer and operator to examine the system under different operational conditions within the system criteria. Eventually, the design engineers are required to maintain a secure system operation within the system criteria based on the test results. The operator must be able to deal with most contingency events, such as line outage and generation trip. The operator must act quickly before the occurrence of cascading failures, which may cause a system blackout or the separation of the system into islands. In the proposed algorithm, contingency analysis data are used with support from the historical data of the system operation. Hence, the AANN is able to provide the suggested control action under different contingency cases. These parameters are based on a power system model that is used to study outage events and make an automatic decision instead of alerting the operators about overloads or voltage limit violations.

Contingency events correspond to changes in network admittances. Hence, network reconfiguration can be estimated using the sensitivities of voltages, reactive outputs, and thermal flows with respect to admittance changes [21]. As shown in Fig. 1, data are generated for each subsystem separately for a number of n areas (depending on the power system division designed by the utility).