Frequency Stability Assessment of Power System Using Frequency Stability Indices and Artificial Neural Network

Ke Yang\textsuperscript{1, 2, 3, 4, *}, Wen Sun\textsuperscript{1, 2, 3, 4, a}

\textsuperscript{1}Shaanxi Provincial Land Engineering Construction Group Co., Ltd., Xi’an, Shaanxi, China
\textsuperscript{2}Institute of Land Engineering and Technology, Shaanxi Provincial Land Engineering Construction Group Co., Ltd., Xi’an, Shaanxi, China
\textsuperscript{3}Key Laboratory of Degraded and Unused Land Consolidation Engineering, the Ministry of Natural Resources, Xi’an, Shaanxi, China
\textsuperscript{4}Shaanxi Provincial Land Consolidation Engineering Technology Research Center, Xi’an 710075, Shaanxi, China

*Corresponding author e-mail: 398440867@qq.com, aimsunwen@gmail.com

Abstract. Frequency stability assessment (FSA) is an evaluation of a dynamic behavior in power system under severe contingency. One of the significant approach in FSA is using frequency stability indices (FSI) to evaluate the performance of the power system and identify the stability status of the power system. Many methods for frequency stability assessment is Time Domain Simulation, Frequency Stability Index and Individual Generator’s Frequency referred to Slack Generator’s Frequency.

1. Introduction
Today, electricity plays a pivotal role in human life, activities, manufacturing and transportation. The main source of electricity is the power system. Power systems are complex interconnected networks of electrical equipment used to power, transmit, and utilize electricity. The power system is called a power grid system and can be roughly divided into three parts, namely, a power generation system and a power generation system, a transmission system and a power distribution system that transfer energy from a power station to a load center. Provide energy for nearby houses and industries. However, with the increase in power consumption and the emergence of large and complex power systems, due to frequency collapse, voltage collapse, loss of synchronization, and other power system interference, the possibility of power outages increases. Therefore, the power quality and the stability of the power system must always be maintained. The stability of the power system can be broadly defined as the characteristics of the power system, so that it can maintain the operating balance under normal operating conditions and return to an acceptable balance after suffering interference [1].

2. Frequency Stability Assessment
Dynamic stability assessment (DSA) is related to the quantitative and qualitative characterization of the system's ability to maintain a balanced state of operation after severe interference. During the DSA study of this type of transient event, the behavior of the power system was described by a complex and highly nonlinear differential algebraic equation (DAE) [2].
Frequency stability assessment (FSA) is one of the three categories of DSA. In fact, frequency stability is the ability of the power system to maintain a stable frequency after a serious unforeseen event causes a significant imbalance between power generation and load. It depends on the capacity of the power system maintain and restore the balance between power generation and load, and minimize unexpected load losses. Frequency instability can cause continuous frequency swings, which can cause generator sets and loads to trip [3].

Power systems, including networks, machines and equipment, often suffer from various types of failures during operation. There are many possibilities of failure in the power system, including lighting, wind, storms on the line, equipment failures, etc. A fault in a power system can be defined as any abnormal situation involving electrical faults in the system. Equipment, such as generators, transformers, transmission lines, etc. [4]. Failures that occur in the power system can cause overcurrent, undervoltage, phase imbalance, reverse power supply, and high voltage surges. In addition, it will cause interruption of the normal operation of the network, equipment failure, and electrical fire.

3. Time Domain Simulation
Next, the solution of frequency stability evaluation is assisted by time domain simulation. Time-domain simulation is very helpful to analyze the stability of the power system, especially when the power system is running through serious unexpected events. Time domain simulation time may vary from a few seconds to several hours. Simulation is helpful in investigating the impact of a series of power system events and determining the power system's ability to withstand large disturbances in the long term [5].

There are two integration methods for time-domain simulation. They involve forward rules and trapezoidal rules. They are defined as implicit A-stability algorithms and use a complete Jacobian matrix and state variable directions to evaluate algebra at each step [6]. In fact, the essence of analyzing power system dynamics through time-domain simulation is to deal with a series of differential algebraic equations (DAE). When the power system is static, the initial value of the differential equation is usually obtained by calculating the power flow. Time domain simulation includes a large number of differential algebraic equations (DAE) solutions based on the internal elements of the power system and the network (such as generators, transformers, loads, etc.). All these elements can be composed of a set of differential algebraic equations.

4. Frequency Stability Indices Methods
Next, the frequency stability index (FSI) is usually used to evaluate. By applying serious accidents to the power system, the frequency stability of the power system is evaluated. In this project, two types of methods are used in FSI, namely, the frequency of a single generator is called the frequency of a relaxed generator, and the frequency of a single generator is called a COI frequency. These methods are implemented by time-domain simulation of the power system. FSI is used to evaluate the stability of the power system based on the frequency of the generator.

In these two FSI methods, it can be divided into two types of stable state: stable state and unstable state. The frequency of a single generator is called the frequency method of a relaxed generator, and is an index method of frequency stability index method, which is used to identify the stable state of the power system when the power system suffers a serious accident. When the power system meets the same situation as the previous method, it is another method to judge the stability condition of the power system to call the frequency of a single generator as the COI frequency. In fact, the frequency of a single generator (called the COI frequency) is an improved form compared to the frequency of a single generator (called the frequency of a relaxed generator).

5. Individual Generator’s Frequency Referred to Slack Generator’s Frequency
The frequency of a single generator is called the slack generator frequency method, which means that the frequency of each generator should be compared with the frequency of the slack bus. In other words, it should use the frequency of each generator minus the frequency of the slack bus. There are three types of busbars in the power system, namely load busbar, generator busbar and slack busbar. The load bus
defined as PQ bus is a non-generator bus, the generator power is zero, and the active power and reactive power are taken from the load of the system. The generator bus defined as the PV bus is also called the voltage control bus. The PV bus is a generator bus, which can keep the voltage amplitude constant. The most important bus in the system is the Vθ bus defined by the relaxed bus. It is used to balance the active and reactive power in the power system, and can also set the angle reference of all busbars in the power system [7].

In addition, the slack bus is more stable than other buses. This is why the project chose the frequency of the slack bus as a reference. By implementing this indicator of the project, the frequency of each generator can be collected, and it is usually used in power systems (such as the IEEE 14 bus system) through time domain simulation. In addition, it improves the efficiency of FSA analysis in many power systems. Obviously shows the steady state of the power system.

6. Artificial Neural Network
An artificial neural network is a mathematical creation that is inspired by observations of biological system research, although it is based on loose actual biology. In fact it is a branch of artificial intelligence [8]. An artificial neural network can be described as a mapping from input space to output space. It has a large number of mathematical functions and can be simulated like a real human brain. The purpose of the artificial neural network is to map the input to the desired output through the neural network system.

7. Multilayer Perceptron Neural Network
Multilayer Perceptron Neural Network (MLPNN) is currently the most widely used feedforward artificial neural network (ANN). This neural network method is a necessary technique used in this project to evaluate the steady state of the power system frequency as a classifier. A multi-layer perceptron neural network can be trained to approximate any smooth, measurable function. And, it can also model complex nonlinear functions and can be trained to accurately summarize when encounter new and unknown data [9]. The multi-layer perceptron neural network structure consists of three subsequent layers, namely the input layer, hidden layer and output layer. Each layer contains multiple neurons, and each neuron in each layer is connected to the next neuron in the adjacent layer with different weights [10]. In fact, the input layer receives and detects the data, passes and analyzes the data through the hidden layer, and then reaches the output layer. The output layer finally sends the output information of the multilayer neural network.

8. Conclusion
The focus of frequency stability assessment is to assess the stability of the power system and determine the stability status of the power system during severe emergencies. In addition, the proposed method of FSI, the frequency of a single generator is called the frequency of the slack generator and the frequency of the single generator is called the frequency of the COI, has been successfully used in frequency stability assessment to identify power during three-phase The steady state of the system.

Reference
[1] Bourguet, R.E., & Antsaklis, P. J. (1994). Artificial Neural Networks In Electric Power Industry, Technical Report of the ISIS (Interdisciplinary Studies of Intelligent Systems) Group, No. ISIS-94-007, Univ of Notre Dame, p1-5.
[2] Kyriakidis, T., Lanz, G., Sallin, D., Lilis, G., Fabre, L., Cherkaooui, R., & Kayal, M. (2013). A Mixed-Platform Framework for Dynamic Stability Assessment. Power and Energy Society General Meeting (PES), IEEE, p15.
[3] Hill, D. (2004). Definition and Classification of Power System Stability. IEEE Trans.Power Syst. IEEE Transactions on Power Systems, 19(4), p1387-1401.
[4] Santamaria, J., & Turan, G. (2011). Analysis of power systems under fault conditions (Unpublished master's thesis). California State University, Sacramento, p1-8.
[5] Fu, C. (2011). High-speed extended-term time-domain simulation for online cascading analysis
of power system (Unpublished master's thesis), p41-48.

[6] Milano, F. (2005). An open source power system analysis toolbox. IEEE Transactions on Power Systems, 20(3), p1199–1206.

[7] Dimitrovski, A., & Tomsovic, K. (2005). Slack bus treatment in load flow solutions with uncertain nodal powers. International Journal of Electrical Power and Energy Systems, 27(9-10), p614–619.

[8] Kevin L, Priddy & Paul E. Keller. (2007). Artificial neural network – an introduction, Prentice-Hall of India Private Limited, M-97, p1-3.

[9] Madyastha, R. K., Member, S., Aazhang, B., & Member, S. (1994). An Algorithm for Training Multilayer Perceptrons for Data Classification and Function Interpolation,IEEE Transactions on Circuits and System, p886-875.

[10] Valero, S., Aparicio, J., Senabre, C., Ortiz, M., Sancho, J., & Gabaldon, a. (2010). Comparative analysis of self organizing maps vs. multilayer perceptron neural networks for short-term load forecasting. 2010 Modern Electric Power Systems, (1), p1–5.