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Soft computing technique for developing turbine cycle model of Chinshan Nuclear Power Plant Unit 2

Yea-Kuang Chan *, Yu-Ching Tsai

Nuclear Engineering Division, Institute of Nuclear Energy Research, No. 1000, Wenhua Rd., Jiaan Village, Longtan District, Taoyuan City 32546, Taiwan, ROC

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ABSTRACT

The objective of this study is to develop a turbine cycle model using the adaptive neural-fuzzy inference system (ANFIS) to estimate the turbine-generator output for the Chinshan Nuclear Power Plant (NPP) owned by Taiwan Power Company. The plant operating data was verified using a linear regression model with a corresponding 95% confidence interval for the operating data. In this study, the key parameters were selected as inputs for the neuro-fuzzy based turbine cycle model. After training and validating with key parameters, including main steam to turbine pressure, condenser backpressure, feedwater flow rate, and final feedwater temperature, the proposed model was used to estimate the turbine-generator output. The effectiveness of the proposed ANFIS based turbine cycle model was demonstrated by using plant operating data obtained from the Chinshan NPP Unit 2. The results show that this neuro-fuzzy based turbine cycle model can be used to accurately estimate the turbine-generator output. In addition, a linear multiregression based turbine cycle model was also developed by using the same parameters in order to compare the performance of the ANFIS based turbine cycle model. The results show that the proposed neuro-fuzzy based turbine cycle model is capable of accurately estimating turbine-generator output and providing more reliable results than the multiregression based turbine cycle model, with regard to estimation accuracy and clearly defined trends. The results of this study also provide an alternative approach to evaluating the thermal performance of nuclear power plants.

1. Introduction

The power generation business is becoming increasingly competitive and the need to reduce and manage operating costs has become considerably more important. Improvements in thermal performance can help power plant operators gain a competitive advantage by lowering operation costs and increasing plant output. In this regard, the Electric Power Research Institute (EPRI) has already issued guidelines for utilities to set up performance monitoring programs (EPRI 1992, 1997).

Nuclear power plants consist of very complex sets of systems and interrelated thermodynamic processes. Creating accurate simulations to optimize performance is correspondingly difficult. Up until now, the fundamental principles used to simulate the turbine cycle are steady-state mass and energy balance equations, which have been well studied worldwide and several solutions have been developed to evaluate plant performance. PEPSE® is a commercial software developed by Scientech Inc., and it is widely used to develop turbine cycle models for power plants under normal operation conditions and yields performance analyses for major components (Minner et al., 2001). System modeling and performance evaluation must be processed step by step with PEPSE to construct a turbine cycle model based on a thermal kit provided by the turbine vendor. Chang et al. (2004) developed an on-line thermal efficiency monitoring and analysis system to calculate generator output, heat rate, and component operating conditions for the Kuosheng Nuclear Power Plant (NPP) in Taiwan. Heo et al. (2005) developed a need-oriented turbine cycle simulation toolbox, and Kim and Choi (2005) developed a performance upgrade system to aid on-line turbine cycle performance analysis for nuclear power plants in Korea. In addition, Nakao et al. (2009) developed a general purpose software application to analyze the static thermal characteristics of the power generation system.

These approaches all have the same drawbacks; they are dependent on system models that may deviate from ideal conditions and

Abbreviations: P_t, core thermal power (MWt); W_{fw}, feedwater flow rate (kg/s); h_s, enthalpy of main steam (J/kg); h_{fw}, enthalpy of final feedwater (J/kg); P_{loss}, system losses (MWt); y_i, measured turbine-generator output (MWe); y_i^*, estimated turbine-generator output (MWe); n, data number.

* Corresponding author. Tel.: +886 3 4711400x6093; fax: +886 3 4711404.
E-mail address: ykchan@iner.org.tw (Y.-K. Chan).

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usually involve empirical relationships, approximations of the actual process, and linearization of nonlinear phenomena.

A practical alternative to overcome these problems is soft computing, which can be used to solve computationally complex and mathematically intractable problems. The main components of soft computing, fuzzy logic and neural networks, have been shown to be capable of solving complex nonlinear system identification problems (Ubeyli, 2009). These methods are the basis of the artificial intelligence concept, which has been widely applied in most fields involving computational studies. The main features of these two methods are the abilities to self-learn and self-predict particular desired outputs.

The adaptive neuro-fuzzy inference system (ANFIS) combines these two methods and uses the advantages of both methods (Jang, 1993; Jang et al., 1997). Since Jang (1993) proposed ANFIS, it has been widely adopted in many real world applications and has achieved high accuracy rates (Chen and Lai, 2010; Hasiloglu et al., 2004; Awadallah et al., 2005; Guimaraes and Lapa, 2007; Mellit and Kalogirou, 2011). The ANFIS architecture can be used to construct an input–output mapping based on human knowledge and stipulated input–output data pairs. Guo and Uhrig (1992) proposed a 3-layer hybrid neural network approach to study heat rate and thermal performance in nuclear power plants. This hybrid neural network, which combines self-organization and back-propagation neural networks, analyzed plant data and extracted some useful information to help the operation of the plant more efficiently.

In this study, ANFIS is used to develop a turbine cycle model for Unit 2 of the Chinshan NPP to estimate turbine-generator output with key parameters. This ANFIS based turbine cycle model is used to estimate turbine-generator output without any prior system knowledge pertaining to the exact structure of the mathematical model.

To validate the steam turbine cycle simulation algorithm that is used, the authors have also developed a turbine cycle model using a linear multiregression approach. For this study, measurement data for the model was obtained from Unit 2 of the Chinshan NPP. As this data needs to be validated and verified, a linear regression model is adopted to detect sensor failure or degradation. The data collected and validated as the baseline performance data set is the plant's operating data at above 95% load during the past five fuel cycles. Then, signal errors of new operating data were detected by comparing with the baseline data set and their allowable range of variations. The residual parts of this paper are organized as follows. Section 2 briefly describes the Chinshan NPP. Section 3 states the system used to process the plant operating data. Section 4 details the development of the ANFIS based turbine cycle model for the Chinshan NPP. Section 5 presents the results to validate the effectiveness of the proposed ANFIS based turbine cycle model. Finally, Section 6 presents the concluding remarks.

2. The Chinshan Nuclear Power Plant

The Chinshan Nuclear Power Plant, owned by Taiwan Power Company, is the first nuclear power plant constructed in Taiwan. It has two identical units of GE-designed BWR/4 reactors with Mark I containment. Unit 1 and Unit 2 each had original licensed thermal power (OLTP) of 1775 MWt, and began commercial operation in December 1978 and July 1979, respectively. Through the implementation of the Measurement Uncertainty Recapture Power Uprate (MUR PU) program, the core thermal power of each unit has been uprated to 1804 MWt (101.66% OLTP) in February 2009 and July 2008, respectively. MUR PU is achieved by using state-of-the-art feedwater flow measurement devices, i.e., ultrasonic flow meters (UFMs), which reduce the degree of uncertainty associated with feedwater flow measurement and in turn, provide a more accurate calculation of core thermal power. The increases in generator output for Chinshan Unit 1 and Unit 2 due to the MUR PU are approximate 5.89 MWe and 5.45 MWe, respectively. Moreover, the Chinshan Stretch Power Uprate (SPU) was successful conducted to further increase the core thermal power of both units to 1840 MWt (103.7% OLTP) on November 23, 2012 and November 29, 2012, respectively. The increases in generator output for Chinshan Unit 1 and Unit 2 due to the SPU are approximately 12.01 MWe and 12.44 MWe, respectively.

Fig. 1 shows the simplified schematics of the overall BWR nuclear power plant. The turbine-generator is the primary component that converts the thermal energy produced by the reactor and primary system into electrical power. The main turbine is a tandem-compound unit, consisting of one double-flow high pressure turbine and two double-flow low pressure turbines, running at 1800 rpm with 46 inch last stage blades. The generator is a hydrogen inner cooled, 3 phase, 19,000 V, and 1800 rpm unit rated at 706,800 kVA at 0.9 power factor (Taiwan Power Company, 2013).

3. Operating data processing system

The plant's actual operating data for Unit 2 was obtained from the plant's emergency response facility (ERF) computer from April 2005 to April 2014. Daily routine data was usually collected by the

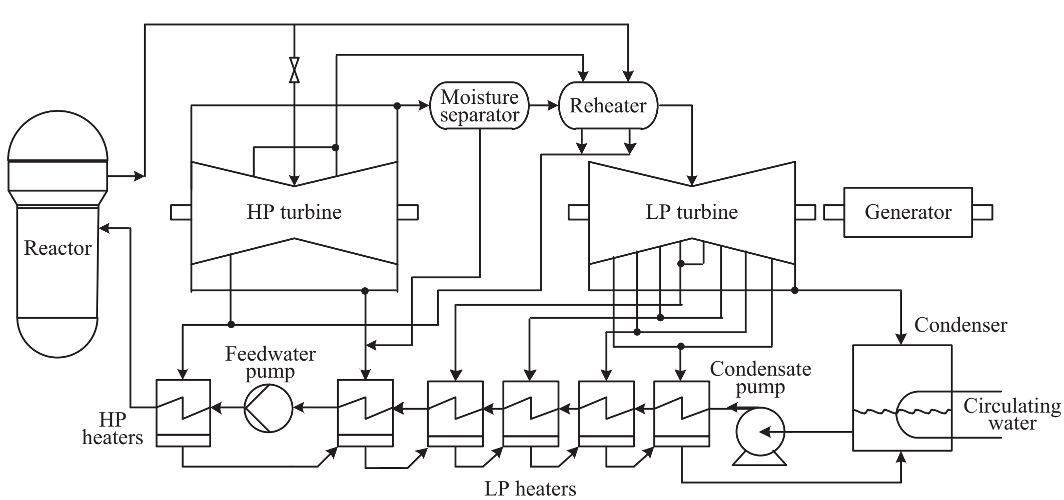

Fig. 1. Simplified schematics of the overall BWR nuclear power plant.