Applied Thermal Engineering xxx (2013) 1–11

Contents lists available at ScienceDirect

Applied Thermal Engineering

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

Thermodynamic modeling based optimization for thermal systems in heat recovery steam generator during cold start-up operation

Peyman Sindareh-Esfahani [a], Ali Ghaffari [a], Pouria Ahmadi [b,*]

[a] Department of Mechanical Engineering, K.N. Toosi University of Technology, Pardis St., Vanak Sq., Tehran, Iran
[b] Faculty of Engineering and Applied Science, University of Ontario Institute of Technology (UOIT), 2000 Simcoe St. North, Oshawa, ON L1H 7K4, Canada

HIGHLIGHTS

- A comprehensive model for thermal systems in HRSGs, cold start-up is presented.
- Two parameter identification algorithms are applied to the model.
- A designed parameter identification algorithm based on GA is presented.
- The aspects of the model and proposed parameter identification algorithm are studied.
- Application of experimental data in order to modeling and validation experiments.

ARTICLE INFO

Article history:
Received 1 August 2013
Accepted 14 November 2013
Available online xxx

Keywords:
Modeling
Adaptive parameter identification
Genetic algorithm
Heat recovery steam generator
Cold start-up

ABSTRACT

In this research paper, a comprehensive thermodynamic model of a thermal system in a dual pressure heat recovery steam generator during cold start-up operation is presented. The model consists of unknown parameters identified by two parameter identification techniques. The first algorithm is an online adaptive parameter identification algorithm which is based on gradient algorithm with integral cost function and forgetting factor. Second algorithm is a designed parameter identification algorithm based on the genetic algorithm method. Results are compared with a broad set of actual data taken from one of the Iranian power plants during cold start-up. Simulation results represent the effectiveness and reliability of the developed model and each of two parameter identification techniques. A comprehensive study is carried out in order to compare two applied techniques. The first technique leads to time-varying parameters and the second reaches the constant parameters with a piecewise model. In order to achieve a simulated model for heat recovery steam generator cold start-up, the costs of the modeling and identification process, and the concepts of the optimization lead to the designed algorithm based on genetic algorithm.

1. Introduction

Over the past few decades, the number of combined cycle power plants has increased due to their higher thermal efficiency than individual steam or gas turbine cycles. A heat recovery steam generator is a kind of heat exchanger used in CCPPs and is a connector between gas turbine and steam turbine cycle.

An HRSG produces steam by using the exhaust gases from gas turbine. The produced steam feeds to the steam turbine to generate electricity. The combination of gas turbine, steam turbine, and HRSG makes the possibility of reaching more efficiency and less emissions [1]. One of the most critical operations of HRSG is the start-up stage; because in this stage, there are some concurrent fulfillments of conflicting objectives such as maximizing the produced energy and minimizing the pollutant emissions [2–4]. Some studies concentrate on the problem of CCPP start-up optimization to reduce the start-up time and pollutant emissions [5–8]. Furthermore, increasing the produced energy considering the limitation of temperature and pressure gradients is also taken into account in these studies. In order to control the key parameters of HRSG such as temperature and pressure during cold start-up and optimize this stage based on the defined objective functions and constraints, it is necessary to have a comprehensive model of the HRSG cold start-up [9].

Previous studies focused on dynamic modeling in steady state and transient conditions can be divided into three categories. The

* Corresponding author. Tel.: +1 289 6009505.
E-mail addresses: Peyman.Sindareh@gmail.com (P. Sindareh-Esfahani), Ghaffari@kntu.ac.ir (A. Ghaffari), Pouria.Ahmadi@uoit.ca, pouryaahmadi81@gmail.com (P. Ahmadi).

1359-4311/$ – see front matter Crown Copyright © 2013 Published by Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.applthermaleng.2013.11.031

Please cite this article in press as: P. Sindareh-Esfahani, et al., Thermodynamic modeling based optimization for thermal systems in heat recovery steam generator during cold start-up operation, Applied Thermal Engineering (2013), http://dx.doi.org/10.1016/j.applthermaleng.2013.11.031

Nomenclature

C	specific heat [kJ/kg K]
E	energy [J] or error
h	specific enthalpy [kJ/kg]
K	parameters
m	mass [kg]
$\dot{m}$	mass flow rate [kg/s]
P	pressure [bar]
Po	position
Q	heat transferred [J]
T	temperature [°C]
t	time [s]
u	internal energy [kJ/kg]
V	volume [m^3]
v	specific volume [m^3/kg]
W	gas unit actual power

Greek symbols

α	heat transferred coefficient
β	forgetting factor coefficient
ε	estimation error
φ	states parameter
θ	parameters of the SPM
ρ	specific density [kg/m^3]
τ	time constant [s]

Subscripts

cv	control volume
gas	exhaust gas
in	input
out	output
p	constant pressure
M	metal
v	constant volume
w	water

Abbreviations

CCPP	combined cycle power plant
DD	diverter damper
EA	evolutionary algorithm
GA	genetic algorithm
HP	high pressure
HRSG	heat recovery steam generator
LP	low pressure
sh	superheater
SPM	static parameter model

first includes the analytical plant model that can be developed based on the fundamental laws of physics such as mass conservation, momentum, and energy semi-empirical laws for heat transfer and thermodynamic state relations [10,11]. In transient conditions, these models often can predict the behavior of the system well. The models belong to this category are called white box ones. In these models, it is necessary to define the parameters with respect to boundaries, inputs and outputs. The second category consists of black box models are trained to estimate the behavior of the system using neural and fuzzy networks [12]. The gathered information from experiments can be used to develop test-data-based models by using system identification techniques. Generally, these models have the capability of prediction based on the input and output data of the system, but do not provide accurate results if confronted with inaccurate or impair data. The third type of models is called grey box models. These models are extracted based on dynamic and thermodynamic equations but with unknown parameters that should be identified during training process [13–17]. Despite having more accuracy and validity than black box models, these models are trained based on input and output data, too. Similar to black box models, the gray boxes need accurate data to train and test the model and determine the parameters.

Using either three aforementioned models, numerous dynamic models of the HRSG system have been presented [18,19]. In the early works, extreme efforts have been carried out for dynamic modeling of a boiler and its subparts based on data logs, parameter estimation [20,21], system identification [22], and simplification of nonlinear models [23]. Ghaffari et al. [24] developed an effective non-linear model of the second left hand de-superheater operating in the power plant using adaptive neuro-fuzzy inference system. In order to improve the performance of the system, they developed a low-order control scheme based on PI controller design method and genetic algorithms. Astrom and Bell [25] presented a nonlinear dynamic model for natural circulation drum-boilers. The model described the complicated dynamics of the drum, downcomer, and riser components. Many researches are done based on this fourth-order model [26–28]. Ahmadi and Dincer [29] performed the thermodynamic analysis and thermoeconomic optimization of a dual pressure combined cycle power plant with a supplementary firing unit. They introduced a gray-box model and then by defining an objective function and applying an evolutionary algorithm type optimization method, the optimal design of operating parameters of the plant is performed. Chaibakhsh et al. [30] present a comprehensive model for once-through type boiler based on physical rules, thermodynamics principles and energy mass balance. They executed an optimization approach based on EA to estimate the model parameters and fit the models response on the real system dynamics. Recently, some noticeable researchers have carried out the modeling and optimization in power plant and HRSG systems. The concept of these works is concentrate on the new strategies in modeling and optimization methods in order to improve the system efficiency and performance in various stages such as change load, shutdown and start-up [31,32].

In cold start-up operation, since it occurs scarcely, the lack of adequate real data makes it difficult to get an accurate model for the HRSG start-up. However, some efforts devoted to model this transient condition. Some of the models used in control approaches are obtained based on fundamental principles in physics like principles of mass and energy conservation. The parameters of such models should be determined [33]. In the cases which gray box model is utilized, a parameter identification algorithm should be applied to obtain system parameter based on the experimental data of the real performance of the plant [30]. Furthermore, such model needs validation and test in specific operating conditions [34–36].

Besides the importance of modeling subjects of power generation systems, the optimization of these systems is one of the most prominent issues in the energy-engineering field. Because of the subtractive fossil fuel recourses and the high prices of energy, the significant of the optimum application of energy and the energy consumption management methods are increased [37,38]. Kaviri et al. [39] conducted the thermodynamic modeling of an HRSG with supplementary firing. In this work, thermodynamic optimization was based on the minimization of exergy destruction rate, while the thermoeconomic optimization is based on the minimization of

Please cite this article in press as: P. Sindareh-Esfahani, et al., Thermodynamic modeling based optimization for thermal systems in heat recovery steam generator during cold start-up operation, Applied Thermal Engineering (2013), http://dx.doi.org/10.1016/j.applthermaleng.2013.11.031