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Dynamic modelling, validation and analysis of coal-fired subcritical power plant

Eni Oko, Meihong Wang *

Process and Energy Systems Engineering Group, School of Engineering, University of Hull, Hull HU6 7RX, United Kingdom

HIGHLIGHTS

- Dynamic modelling of coal-fired subcritical power plant based on first principles.
- *Shrink and swell* characteristics considered in modelling the drum dynamics.
- Steady state model validation of coal-fired subcritical power plant at different operating loads.
- Process analysis for load changes through ramping better than step change.

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ABSTRACT

Coal-fired power plants are the main source of global electricity. As environmental regulations tighten, there is need to improve the design, operation and control of existing or new built coal-fired power plants. Modelling and simulation is identified as an economic, safe and reliable approach to reach this objective. In this study, a detailed dynamic model of a 500 MWe coal-fired subcritical power plant was developed using gPROMS based on first principles. Model validations were performed against actual plant measurements and the relative error was less than 5%. The model is able to predict plant performance reasonably from 70% load level to full load. Our analysis showed that implementing load changes through ramping introduces less process disturbances than step change. The model can be useful for providing operator training and for process troubleshooting among others.

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1. Introduction

1.1. Background

In 2011, coal-fired power generation contributed about 41% to world electricity generation [1]. This makes coal the largest single source of electricity. Future projections suggest that coal will remain a significant component of global energy mix regardless of increasing stringent environmental regulations. There is need however for more efficient design and operation of the power plant. This can be achieved by bringing in more process knowledge in the design, operation and control of the plant. Modelling and simulation is an economic, reliable and convenient approach for gaining more process knowledge and insight. The approach has been widely used for investigating the process behaviour of coal-fired subcritical power plants in the literature [2–12].

1.2. Process description

In a coal-fired power plant, heat energy from coal combustion is used to generate steam. The steam enters a steam turbine at high pressure and consequently generates torque which is converted to electricity in the generator (Fig. 1). Low pressure steam leaving the turbine is condensed and pumped back to the boiler. The entirely process basically follows a Rankine thermodynamic cycle though in reality there are other processes such as air pre-heating using combustion gases, feedwater heating using steam extracted from the turbine stages, and reheating steam between the turbine stages.

1.3. Motivations

As noted in the previous section, modelling and simulation of coal-fired power plant is necessary for studying the process behaviour. This can become useful for more efficient and reliable operation of the plant. Models of coal-fired power plants are widely reported in literature [2–12].

* Corresponding author. Tel.: +44 1482 466688.
E-mail address: Meihong.Wang@hull.ac.uk (M. Wang).

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Nomenclature

A	cross sectional area (m^2)
$C_{p,ash}$	specific heat capacity of ash (J/kg K)
$C_{p,coal}$	specific heat capacity of coal (Btu/lb °F)
g	acceleration due to gravity (m/s^2)
h	specific enthalpy (J/kg)
K	empirical constants
k	attenuation coefficient
L	water level (m)
$\dot{m}$	mass flowrate (kg/s)
N	pump speed (rev/s)
NCV	net calorific value of coal (J/kg)
P	pressure (Pa)
Q	heat flow (W)
T	temperature (°C)
$Torq$	torque (J)
U	admittance (W/K)
V	volume (m^3)
Z	deaerator altitude (m)
Greek letters	
β	empirical factor
ΔI	deviation from drum level at design point (m)
ρ	density (kg/m^3)
σ	Stefan–Boltzmann constant ($W/m^2 K^4$)
v	specific volume (m^3/kg)
γ	isentropic index
Subscripts	
D	drum
g,ad	adiabatic flame
g,avg	gas (average)
bfp	boiler feed pump
F	furnace
$FEGT$	furnace exit gas temperature
g	gas
in	inlet
R	radiant
s,avg	steam (average)
sD	steam below water surface in drum
SE	Stodola ellipse
trb	BFP turbine
out	outlet
vf	valve coefficient
w	wall
wD	water in drum

However, most of these models consider only the boiler and turbines [2,3,5,12]. Without considering the feedwater heating sections, actual dynamic behaviour of the plant may not be captured accurately. This is because the power cycle is effectively treated as open loops (instead of a closed loop) without the feedwater heating trains. In Liu et al. [7], and Lu and Hogg [6] etc where the feedwater train was considered, no form of validation was provided. As such, there is little basis to establish the prediction accuracy of the models. Colonna and VanPutten [9] presented a validated model with the boiler, turbine and feedwater system components. However, the authors assumed that the riser was electrically heated. This leaves out the furnace which is a key component.

In other studies, Oke [10], Sanpasertparnich et al. [13], and Lawal et al. [14], development of models of subcritical coal-fired power plants was also reported. Again, the model reported by Sanpasertparnich et al. [13] is a steady state model whereas that of Lawal et al. [14] and Oke [10] does not include some key dynamic characteristics such as the drum level. Jinxing and Jiong [11] used fuzzy-based approach for modelling a dynamic model of a subcritical coal-fired power plant. Methods such as this are greatly hindered by the quality of data used. Also, it is difficult to generalise

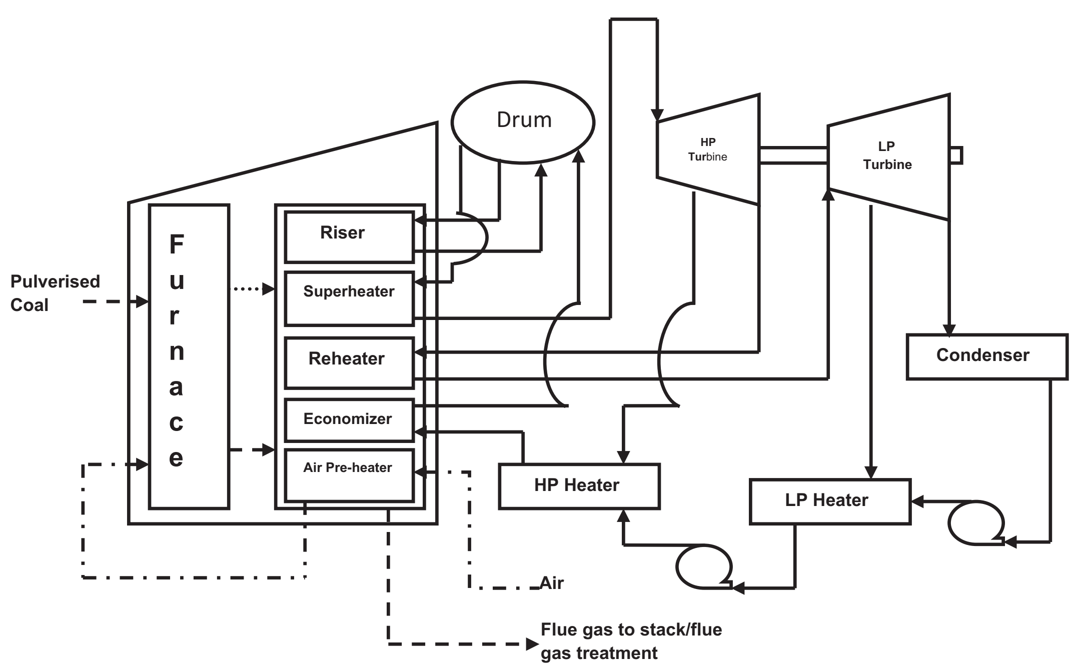

Fig. 1. Schema of coal-fired subcritical power plant.

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