Simulation Modelling Practice and Theory 57 (2015) 58–70

Contents lists available at ScienceDirect

Simulation Modelling Practice and Theory

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

Artificial neural networking model for the prediction of high efficiency boiler steam generation and distribution

Dušan Strušnik *, Marjan Golob, Jurij Avsec

Energetika Ljubljana d.o.o. TE-TOL Unit, Toplarniška ulica 19, SI-1000 Ljubljana, Slovenia

ARTICLE INFO

Article history:
Received 2 August 2014
Received in revised form 16 March 2015
Accepted 4 June 2015
Available online 19 June 2015

Keywords:
Prediction of production
Boiler efficiency
Real plant data
Fuzzy logic controller
Matlab
Industrial steam

ABSTRACT

Development of artificial neural network (ANN) models using real plant data for the prediction of fresh steam properties from a brown coal-fired boiler of a Slovenian power plant. The power plant generates electrical and thermal energy used for the city-wide district heating. The energy is produced in three blocks. Each block consists of a coal-fired boiler and an extraction condensing steam turbine. The electricity production is planned, while the generation of heat for heating purposes depends on the ambient temperature. A model will be presented which, using an ANN, predicts the power production of the power plant and distributes the production between the boilers so that the latter operate at their highest efficiency. The real data on the amount of the generated steam in the existing system boilers will be compared to the results of the model and the findings will be indicated regarding the coal consumption savings and their impact on the environment. However, the final set of input parameters was optimised with a compromise between smaller number of parameters and higher level of accuracy through sensitivity analysis. Data for training were carefully selected from the available real plant data.

1. Introduction

Accurate modelling and simulation of components of power plants are very important for training, strategic planning and maintenance, techno-economic decisions as well as continuous monitoring of the operation of the plant. With increasing concern for environment and market that is more competitive after the deregulation of electricity, the need for better and more user-friendly simulation and monitoring tools is even more stringent [1]. In existing plants, large number of operational data is captured continuously by the on-line plant's monitoring system for its proper operation. These are usually stored as database only. Using these data, (ANN) models can be created for the simulation of the plant operation [1]. ANN modelling of various energy systems has been studied by numerous researchers [2–7].

The Matlab – Simulink software tool will be used to develop a model to predict, by means of the ambient temperature input data and an ANN not being pre-trained, the necessary power production of the power plant in Slovenia. The power to be provided by the plant will be distributed between the boilers through primary and secondary regulation, comprising a fuzzy logic controller (FLC) sub-model, so that the boilers will operate at their highest efficiency. This will result in a lower price of the generated steam and a decrease in the greenhouse gas emissions. The greenhouse gas emissions are closely connected to the new European environmental directive based on a greenhouse gas emission reduction, entering into force in

* Corresponding author. Tel.: +386 031 728652; fax: +386 08 3806 104.
E-mail address: dusan.strusnik@gmail.com (D. Strušnik).

http://dx.doi.org/10.1016/j.simpat.2015.06.003
1569-190X/

Nomenclature

Abbreviations
ANN artificial neural networking
FLC fuzzy logic controller
SCADA supervisory control and data acquisition

Parameters
dh enthalpy differential, kJ/kg
$\dot{m}$ mass flow rate, kg/s
$\dot{m}_{b1,2}$ mass flow rate, boilers 1 or 2, kg/s
$\dot{m}_{b3}$ mass flow rate, boiler 3, kg/s
$\dot{m}_{total}$ total mass flow rate, kg/s
$\dot{W}_{gross}$ power plant gross power output, kW
$\eta_{b1,2}$ efficiency, boilers 1 or 2, %
η_{b3} efficiency, boiler 3, %

Subscript and superscript
B-1, 2 boilers 1 or 2
B-3 boiler 3
CO_2 carbon dioxide
er error
j iteration
k_{172} steam distribution factor, boiler 1 or 2
k_3 steam distribution factor, boiler 3
MAPE mean absolute percentage error
MSE mean square error
NO_x nitrogen oxide
o output value
p number of learning data sets
R correlation coefficient
RMS root mean square
t target value
x model output

2016 [8]. After 2016, all fossil fuel-fired power plants over 500 MWe should have also a DE nitrogen oxide system. Selective Catalytic Reduction with ammonia injection. In all cases it will be important that the nitrogen oxide concentration after the combustion process is as low as possible because of ammonia consumption in the DE nitrogen oxide systems [9,10] and also degradation of amine absorbents in the future post combustion carbon dioxin capture technologies [11]. Process optimisation for minimal stack emissions and efficiency improvements in coal fired units plays an important role in minimising operational and maintenance costs [12]. Power plant boilers are equipped with Supervisory Control and Data Acquisition [13] (SCADA) systems which supply the information about the plant's operation [14].

Many other authors have also presented the ways of reducing greenhouse gas emissions using the ANNs [15–18]. In our case, the greenhouse gas emissions will be reduced so as to ensure that the boilers will consume less coal to produce the same amount of steam since they will operate at higher total efficiency. In the analysis, the real data of the 2013/2014 heating season process will be compared to the data provided by the model. The average annual efficiency of the real process and the model will be calculated and the results indicated regarding the savings of coal, money and the greenhouse gas emission reduction.

2. Production process description

The district heating plant in Slovenia generates electrical and thermal energy as well as industrial steam. The power generation is known in advance and planned 7 days ahead. The generation of heat for the city-wide district heating purposes largely depends on the ambient temperature variations and can easily be predicted using the past analysed data. The amount of steam used for industrial purposes is rather low and has a constant flow rate. The boilers of block 1 and 2 are of the same design, manufactured by Ganz and they generate from 26 kg/s to 50 kg/s of steam of approximately 520 °C and 92 bar. The block 3 boiler, manufactured by Babcock, generates from 35 kg/s to 72 kg/s of steam of approximately 520 °C and 92 bar. Three generators are used for electricity generation. The maximum power output of block 1 generator is 42 MW_e, 32 MW_e of generator 2 and 50 MW_e of generator 3. The district heat is generated at two thermal substations. Blocks 1