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Artificial neural networking and fuzzy logic exergy controlling model of combined heat and power system in thermal power plant

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ABSTRACT

This paper presents entropy generation minimisation model of combined heat and power system. The turbine control valves and heater throttle valves were analysed. The high-pressure control valves regulate the mass flow rate of steam into the turbine, whereas the intermediate-pressure and low-pressure control valves the steam pressure of the turbine extracts 3 and 5. The steam of the turbine extracts 3 and 5 is used for the city-wide heating system purposes by means of the peak and basic heaters. The quantity of the extracted steam used for the city-wide heating system is additionally controlled by the throttles regulating the extracted steam into the basic or peak heater. This results in a double throttling of the extracted steam of the turbine, double generated entropy and a double loss of work. If adequate pressure of the extracted steam of the turbines is maintained by means of the turbine control valves the two heaters for the heating system could operate with the throttles open. As a result, the generated entropy of the throttles of the steam admitted to the heater could be avoided and the amount of generated entropy of the turbine control valves reduced.

1. Introduction

The amount of the generated entropy of a circular process is an indicator of the process irreversibility and a loss of work. The minimum generated entropy concept is based on the maximum exergy efficiency of a system. A steam turbine entropy generation varies in proportion to the turbine efficiency. This means that the turbine efficiency decreases with entropy generation or system irreversibility [1]. Energy and exergy analysis are well-established methods, used to investigate thermal systems [2] and [3]. Some authors [4–8] present the exergy concept in detail. The low exergy concept was brought to the built environment to pursue the quality match between the energy demand and the energy supply [9]. The analysis and design of engineering systems based on only the first law is not adequate [10]. In the exergy method, known as the second law analysis, the exergy loss caused by irreversibility, which is an important thermodynamic property in thermal process, can be calculated [11]. A computer model was designed to minimise entropy generation of the turbine steam CV (control valve). The Simulink software tools, the ANN (artificial neural network) FLC (fuzzy logic controller) and curve fitting were used to design the computer model. The Simulink serves as a building block of the model, integrating the sub-models. The ANN is aimed at identifying and modelling the complex nonlinear relationships between the input and the output target of a system [12]. ANN modelling of various energy systems has been recently studied by numerous researchers [13–16]. The FLC is used for soft computing and artificial intelligence methodologies, such as fuzzy logic control, for high level supervisory control [17].

The ANN approach is an evolutionary and fast calculation methodology that does not require complex mathematical equations to explain a non-linear and multidimensional system [18] and [19]. In our case, the actual operating data of the combined heat and power system obtained from the SCADA (Supervisory Control and Data Acquisition) [20] system which supply the information about the plant's operation. SCADA was used for the ANN development. In our model, 3 ANNs were used, computing the position of a CV and the quality of the turbine extracted steam.

The FLC can play an important role because the knowledge-based design rules can easily be implemented in systems with unknown structure, and it is going to be a conventional control method since the control design strategy is simple and practical and is based on linguistic information [21]. The FLC design is rather easy and based on a criteria correlation of input output signals. The

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Nomenclature

Abbreviations

ANN	artificial neural networking
CV	control valves
FLC	fuzzy logic controller
HPCV	high pressure control valves
IPCV	intermediate pressure control valves
LPCV	low pressure control valves
MAE	mean absolute error
MAPE	mean absolute percentage error
MSE	mean square error
RMSE	root mean square error

Parameters

E	energy, kWh
$\dot{E}_x$	exergy, kW
g	gravitational acceleration, m/s^2
h	enthalpy, kJ/kg
$\dot{m}$	mass flow, kg/s,
$\dot{Q}$	heat transfer, kW
t	time, s, min
T	temperature, K
S	entropy, kJ/kgK
V	velocity, m/s
$\dot{W}$	power, kW
z	high potential, m
ε	specific exergy, kJ/kg
η	efficiency

Subscripts and superscripts

j, k, i	iterations
M	accumulation
o	output value
p	number of learning data sets
R	correlation coefficient
t	target value

criteria correlation of signals is defined through simple command functions, i.e. if, and, then, or and not. The FLC is used for nonlinear system control. Also, the some earlier researchers used FCL for nonlinear system control [22–25]. Two FLCs were used in our model, namely to control the steam turbine power and the position of the LPCV (low pressure control valve).

2. System description

A turbine in combined heat and power system may operate in two ways, namely using a counterpressure or a condensation method. In a counterpressure method of operation, the electricity and heat energy productions coincide. This means that there is no condensation of the turbine exhaust steam as the entire steam outlet from the turbine system is carried out via the turbine extracts. In a condensation method of operation, however, the steam not being outlet from the system via the turbine extracts, expands to the turbine exhaust and enters the condenser. Fig. 1 illustrates the methods of operation and the results of the measurements of the analysed turbine steam:

- counterpressure operation method: points 1, 10, 9, 8 and 8*, where the exhaust turbine steam is minimum with the outlet of almost the whole amount of steam from the turbine taking place at the extracts;
- condensation operation method: points 2 and 6, where the outlet of only the steam for regenerative heating of the turbine condensate takes place at the extracts, no heat for the heating system is produced, the remaining steam enters the condenser;
- condensation operation method: points 7 and 12, with various quantities of extracted steam and turbine exhaust steam [26].

The electrical and thermal energy volume control is carried out using the CVs by controlling the steam mass flow rate through throttling. The HPCV (high pressure control valves) control the amount of steam admitted to the turbine in respect of the required electrical energy production. The HPCVs start to open and increase

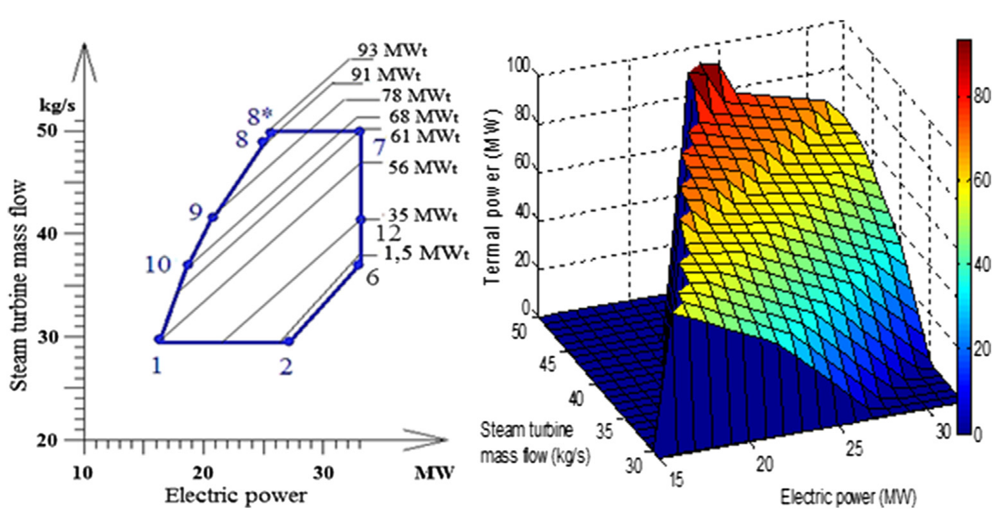

Fig. 1. Turbine real process production diagram [26].