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Research Paper

Optimization of district heating system aided by geothermal heat pump: A novel multistage with multilevel *ANN* modelling

Halit Arat, Oguz Arslan

Mechanical Engineering Department, Engineering Faculty, Dumlupinar University, 43270 Kutahya, Turkey

HIGHLIGHTS

- Geothermal Heat Pump System (*GHPDHS*) working under high temperature conditions was investigated.
- A novel multistage with multilevel *ANN* model was developed.
- *GHPDHS* was optimized by the performed *ANN* model.

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ABSTRACT

The aim of this study is to obtain the optimum design of geothermal heat pump aided district heating system (*GHPDHS*) by using a novel *ANN* model that composed of multistage with multilevel. For this purpose, the acquiring of the best design were performed by utilizing the back-propagation learning algorithm with three different variants which were Levenberg-Marquardt (*LM*), Pola-Ribiere Conjugate Gradient (*CGP*), and Scaled Conjugate Gradient (*SCG*). In this aim, the proposed *ANN* model was mainly formed from two stages. The first one has a single level whereas the second one composed of three levels in this new *ANN* model. According to results, the maximum rate of the error occurred in the Pump 2 as % 3.0092 and the minimum of that was obtained from COP_{sys} with % 0.0018. The best R^2 value of the third level of the second stage network structure was calculated as 1 for *LM*-20. As a consequent, this study showed that the multistage with multi-level *ANN* model could be easily applied to other energy systems in order to save more time and simplicity.

1. Introduction

The consumption of energy increases with the increase of world population and the countries have started to use renewable energy in more areas efficiently. Among renewable energy resources, geothermal energy is more advantageous than others in terms of great, clean and continuous availability. Geothermal energy is used for heating of residences and this is a solution of environmental problems at the global scale in spite of its local source. Geothermal resources are utilized for many purposes such as power generation, greenhouse heating, district heating and balneological in worldwide [1–4].

The first artificial neural network models that composed of a number of ordinary neuron processing elements and weighted linkages between elements have been started since the 1940s. A neural network has a parallel-distributed structure with a number of nodes and linkages that are combined to a weight. If experimental studies include a large number of variables, they could spend a lot of money and time. Optimum thermal system design needs defining a number of unknown variables; so, *ANN* can manage this case quickly and accurately. *ANN* manages the solution of the complicated problems instead of complex formulations easily [5–7]. *ANN*s have been successfully used in different areas for last decades [8–25]. *ANN* application studies on energy generation systems that were using the Kalina cycle [26] and the supercritical *ORC-Binary* in geothermal power plant [27,28] have been performed in literature. Also, there were *ANN* models of refrigeration systems that provided well-matched to experimental data and *ANN* data [29,30]. There were a lot of studies on *ANN* models and analysis of heat pumps. Some of them were about absorption heat pump [31,32], some were about ground source heat pump [33–43] and some of them were about the hybrid heat pump [44–51].

On the other hand, there were limited studies on the energetic and exergetic analysis of geothermal district heating systems by using *ANN* in the literature. Keçebaş et al. [52], predicted the exergy efficiency of Afyon geothermal district heating system by using *ANN* model. They found that the ANN model showed the

E-mail addresses: halit.arat@dpu.edu.tr (H. Arat), oguz.arslan@dpu.edu.tr (O. Arslan)

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Nomenclature

ANN	artificial neural network
b	bias
C	cost (US$)
CGP	Pola-Ribiera Conjugate Gradient
COP	coefficient of performance
cov	the coefficient of variation
$\dot{E}$	energy rate (kW)
$\dot{E}x$	exergy rate (kW)
GHPDHS	geothermal heat pump aided district heating system
h	enthalpy (kJ/kg)
LCC	life cycle cost
LM	Levenberg-Marquardt
$\dot{m}$	mass flow rate (kg/s)
MPE	the mean percentage error
n_r	number of heated residence
NPV	net present value (US$)
P	pressure (kPa)
R^2	the percentage of absolute change
RMSE	the error of the square root
s	entropy (kJ/kg K)
SCG	Scaled Conjugate Gradient
$\dot{Q}$	heat rate (kW)
T	temperature (°C)
X_n	inputs
$\dot{W}$	work rate (kW)
W_n	weights
y	outputs
y_{actual}	the actual value
$\bar{y}_{actual}$	the average actual value
y_{output}	the output value
$\bar{y}_{output}$	the average output value
ΔT	temperature difference (°C)

Greek letters

ε	exergy efficiency (%)
ψ	physical exergy (kJ/kg)
Σ	total function

Subscriptions

comp	compressor
con	condenser
evap	evaporator
in	inlet
inst	installation
n	the number of value
op	operating
out	outlet
o&m	operating&maintenance
sal	salvage
sys	system
t,equip	total equipment

good statistical values with R^2 in the range of 0.9924–0.9942 when RMSs in the range of 0.0571–0.0810. Keçebaş et al. [53], used the ANN model for predicting some parameters such as the energy input, losses, output, and efficiency of Afyon geothermal district heating system. Also, they evaluated that system in point of economical. R^2 value was calculated as 0.9983 with minimum *RMS* and *MAPE* values.

In this study, geothermal heat pump aided district heating system (*GHPDHS*) taking into account of Simav geothermal sources was optimized by using a novel *ANN* model that composed of multistage with multilevel. In the present study, the obtaining of the best design were performed by utilizing the back-propagation learning algorithm with three different variants which were Levenberg-Marquardt (*LM*), Pola-Ribiere Conjugate Gradient (*CGP*), and Scaled Conjugate Gradient (*SCG*). In this aim, the proposed *ANN* model was mainly formed from two stages. The first one has a single level whereas the second one composed of three levels in this new *ANN* model. By this way, the more complicated calculation procedures were simplified and proven for the optimization process of *GHPDHS* with high temperature.

2. Design of GHPDHS

In this study, the resources of Simav geothermal field was taken into account for the design of *GHPDHS*. This field, which is located in the southern part of the Simav graben system (39° latitude, 28°.4′ longitude) at Kutahya province in western Anatolia, is one of the 15 largest geothermal fields in Turkey. There are 10 active wells which one of that is used for the purpose of re-injection (see Fig. 1). The depths of these wells ranges between 169 m and 725 m while the ranging of flow rates and temperatures of that are respectively 35–72 kg/s and 84–162 °C [4,54]. Geothermal fluid with high temperature, used in the geothermal heat pump aided district heating system, was taken into consideration as a mixture of wells. In this case, the pressure and temperature of this mixture are respectively 300 kPa and 133.5 °C with a mass flow rate of 462 kg/s [55].

The schematic of proposed geothermal heat pump aided district system (*GHPDHS*) that takes Simav geothermal resources into account is sketched in Fig. 2. *GHPDHS* system is composed of four subcircuits. The Circuit I is geothermal flow circuit which transfers the heat from the geothermal fluid to evaporator, Circuit II is heat pump circuit in which use different refrigerant fluids, Circuit III is district heating cycle and Circuit IV is residential heating cycle which utilizes three different acceptable radiator inlet - outlet temperature such as 50–39 °C, 55–44 °C and 60–49 °C for an effective heat transfer [4,56,57].

Twelve different refrigerant fluids with different *T-s* trends were taken into account in Circuit II. According to this, the saturation curves belonging to refrigerant fluids were classified into two types called as bell type and over-hanged type. The thermodynamic properties of these refrigerant fluids are listed in Table 1.

3. Energy and exergy analysis

In the analysis, kinetic and potential energy terms were neglected. Besides this, an adiabatic efficiency of 80% for the compressor was taken into consideration. Under these assumptions, the mass balance equation is expressed in the rate form as:

$$\sum \dot{m}_{in} = \sum \dot{m}_{out} \tag{1}$$

where $\dot{m}$ is the mass flow rate and the subscript in stands for inlet and out for outlet. The general energy balance can be expressed as the total energy inputs equal to total energy outputs given by the following equation:

$$\sum \dot{E}_{in} = \sum \dot{E}_{out} \tag{2}$$