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Modelling of small scale central heating installation using artificial neural networks aiming at low electric energy consumption

G.C. Bakos*, A. Sismanis

Democritus University of Thrace, Department of Electrical and Computer Engineering, Laboratory of Energy Economics, 67 100 Xanthi, Greece

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ABSTRACT

Artificial neural networks (ANNs) used to control the operation of energy systems is an important field of research. This paper deals with the use of ANNs as a technique of modelling real non-linear energy systems such as the flow and pressure processes related to pump and valve input voltages of a small scale central heating system aiming at low electric energy consumption. The system is located in the Energy Economics Laboratory of Democritus University of Thrace in Greece and its operational parameters were accurately captured using a backpropagation neural network. The approach described in this paper has the advantages of computational speed, low cost for feasibility and ease of design by operators.

1. Introduction

In 1995, the Greek Ministry of Environment, Urban Planning and Public Works prepared an Action Plan, entitled “Energy 2001”, aiming at promoting the application of energy-efficiency technologies, in the building sector. The Action Plan was prepared in order to define specific measures for the reduction of greenhouse gas emissions in buildings, in accordance with the “National Action Plan for the Abatement of CO_2 and Other Greenhouse Gases”. Following official adoption of the Action Plan by the Greek Government, “Energy 2001” was further reinforced by the enactment of Ministerial Decree (MD) 21475/98, which incorporated the provisions of Council Directive 93/76/EC (SAVE Directive) for the stabilisation of CO_2 emissions and the efficient use of energy in buildings [1]. Space air-conditioning dominates the energy consumption in residential and public building sector [2–4]. In Greece, the largest percentage of buildings (old and new) is using the classic oil-based central heating installation with water as heat transfer agent. The effective operation control of these central heating installations, based on the monitoring of different operational and performance parameters, leads to substantial energy saving reducing simultaneously the environmental pollution and the need for further capital investment in power plants construction.

The use of ANNs in energy systems can be viewed as a natural step in the evolution of control methodology. This is mainly due to the fact that ANNs have good approximation capabilities and offer additional advantages such as short development and fast processing times [5]. A detailed description of various applications of ANNs in energy systems is provided by Kalogirou [6]. In particular, ANN applications to building sector have attracted considerable attention from the scientific community [7–9].

Many different types of neural networks are available. Feedforward Multilayer (MLP) networks, where the inputs are fed forward through the layers to the output, have been applied in system identification problems. Normal use of an MLP network involves training the network on a set of data obtained from the installation to be controlled. The learning rule for feedforward MLP networks is called the ‘Generalised Delta rule’ or the ‘Backpropagation rule’. The backpropagation training algorithm is an iterative gradient algorithm that attempts to minimise the mean square error between the actual network output and the desired one, so that the network input–output relationship best approximates the energy system data.

The model structure needs to have sufficient representation ability to enable underlying system characteristics to be approximated with an acceptable accuracy and in many cases the model needs to retain simplicity. Also the input signal to the energy system used for the generation of data must be carefully chosen so that it excites all the dynamics of the process to be modelled and generate cause and effect data which are maximally informative. Validation tests are necessary to be carried out in order to check the performance and accuracy of the developed NN model.

2. Description of the small scale central heating installation

In this paper, the small scale central heating installation to be modelled is operating in the premises of the Laboratory of Energy Economics of Democritus University of Thrace in Xanthi – Northern

* Corresponding author. Tel.: +30 25410 79725; fax: +30 25410 79734.
E-mail address: bakos@ee.duth.gr (G.C. Bakos).

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Photo 1. Small scale central heating installation.

Greece. The block diagram of the experimental setup installation and its physical representation are shown in Fig. 1 and in Photo 1, respectively.

The laboratory central heating system can operate as closed circuit water system. The total capacity of the system is approximately 22 l. There are 6 m of 22 mm piping and a small amount of 15 mm having a total capacity of 3 l. The pump is capable of delivering up to 45 l/min; however the system will impose restrictions on this. Water is delivered from the pump via the heater to the radiator. Forced convection through the radiator results in heat loss. Initial temperature measured by the probe will be the room temperature. When heating is started this temperature will rise and equilibrium will eventually be reached between the radiator and room temperature through heat loss, and the system temperature. This operating point can be controlled by:

Photo 2. View of radiator–ventilator system.

1. Controlling the flow and pressure using the control valve.
2. Controlling the flow and pressure using the pump.
3. Controlling the temperature using the heater.

The heating system is used to heat a room, situated inside the laboratory premises, constructed from compound polystyrene slates with dimensions 3.00 m × 3.00 m × 3.00 m. The radiator–ventilator system used inside the room is shown in Photo 2. The presentation of the experimental results on a PC Intel Pentium and the time interval of measurement storage can be controlled through the developed LABVIEW software. The developed data acquisition system (Photo 3) was based on two AdvanTech cards (an A/D input card PCI-1714 which can accept up to 32 analogue inputs and a D/A output card with 8 output channels). Calibration of the measurement equipment was necessary in order to capture the relationships between the two variables (flow and pressure) and the outputs of the meter circuits.

3. System representation approach

The model structure needs to have sufficient representation ability to enable the underlying system characteristics to be approximated with an acceptable accuracy and in many cases the model also needs to retain simplicity.

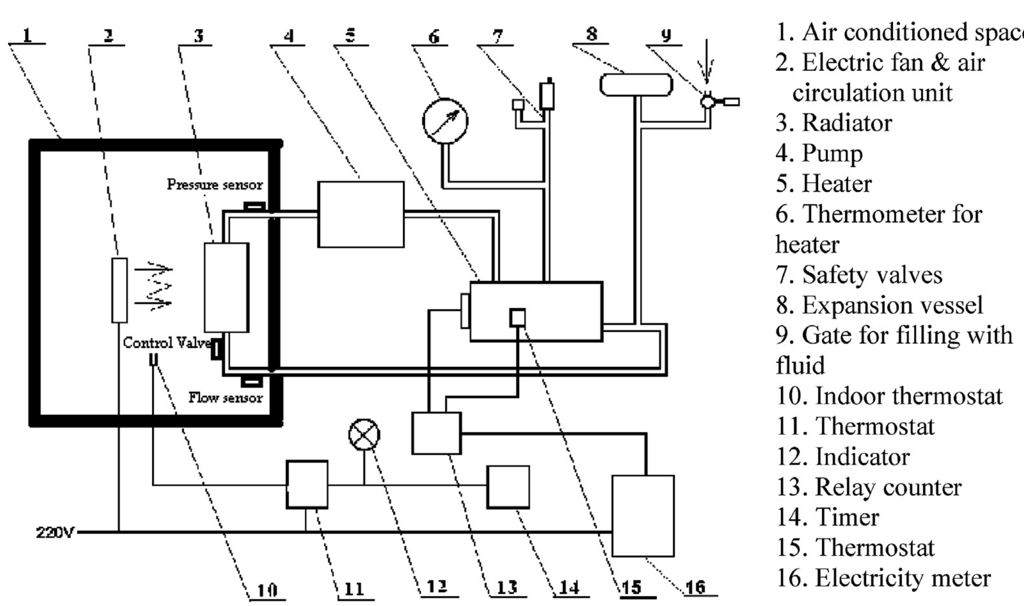

Fig. 1. Block diagram of the small scale central heating system.