DISTRICT HEATING SUBSTATIONS WATER TEMPERATURE CONTROL BASED ON SOFT COMPUTING TECHNOLOGY

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Abstract **– The concept of a durable development in the field of thermal energy supply of the localities implies the use of efficient technical solutions that are capable to ensure the fulfillment of their social needs in conditions of economic efficiency and energetic efficiency. Having as research base the centralized district heating of the Iasi city the research team proposes to resolve the control problem of its district heating substations using soft computing methods. The main goal is in connection with the performance improvement of CET Iasi for the production and centralized distribution of the thermal agent to the consumers, through the fuel consumption reduction, the power efficiency increase and guaranteeing the supply with efficient thermal energy services by means of measures relating to the offer and demand and the reduction of the thermal power production cost. The paper presents the water temperature control of a district heating substation using soft computing methods.**

Keywords: *Soft computing, Fuzzy logic, District heating, Plate heat exchanger, Temperature control.*

1. INTRODUCTION

The basic idea behind district heating is to use cheap local heat production plants to produce hot water (in some countries steam is used instead of water). The water is then distributed by using pumps at approximately 1-3 m/s through pipes to the customers where it may be used for heating both tap water and the radiator water. The cooled water then returns to the production plant forming a closed system (Figure 1).

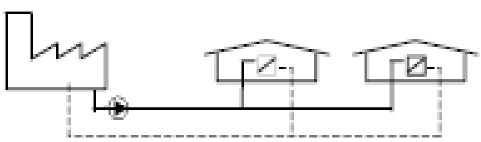

Figure 1: A simple district heating network containing one heat producer and two consumers.

At the customer side, there is a substation (Figure 2). It is normally composed of two or more heat exchangers and a control unit, which receives hot water from the district heating network. The substation heats both cold tap water and the water in the radiator circuit by exchanging the required heat indirectly from the primary flow of the distribution network. The hot network water is returned to the network at a somewhat lower temperature. Both the temperature of the returning water and the flow rate in the network are dependent on the consumption of substations. When the water, returned by substations, arrives at the heat production plant it is heated and again pumped into the distribution network. Several different energy sources may be used for heating, e.g., waste energy, byproduct from industrial processes, geothermal reservoirs, otherwise combustion of fuels as oil, natural gas etc. is used. If the demand from the customers is high, several heat producing units must be used. A district heating system in a large city can be very complex, containing hundreds of substations and hundreds of kilometers of distribution pipes. In addition, they are dynamic as new substations may be added or old substations may be replaced by new ones with different characteristics.

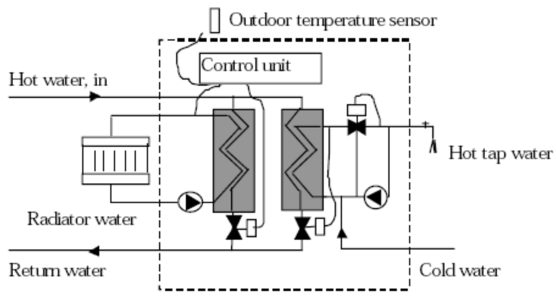

Figure 2: A substation consisting of heat exchangers (the shaded boxes), control valves, pumps and a control unit. The radiator system (household heating) is controlled by the control unit, using information about actual outdoor temperature.

Most district heating control systems of today are strictly reactive, i.e., they only consider the current state and do not predict what is likely to happen in the future. As the distribution time from the heat production plant to the customers is large, the decision on how much heat to produce becomes complicated.

Ideally, the control engineer knows the amount to produce several hours ahead of consumption.
Load prediction is difficult since many factors are unknown or uncertain which force the operators to make coarse estimations of future consumption based mainly on experience and simple rules-of thumb. As a consequence, and in order to be sure to satisfy the consumers, district heating systems are typically run with large margins producing more heat than necessary. Furthermore, operators are usually busy with keeping the heating plants running and the time available for making production decisions is therefore limited [1]. Consumption in a district heating network is mainly composed of two parts:
- The heating of buildings, which mainly is a linear function of the outdoor temperature.
- The consumption of tap water, which mainly is dependent on consumption patterns, e.g., social factors.
In order to efficient work of a district heating substation the water temperature delivered to the consumers must be continuously controlled to the proper value [2]. The water temperature control delivered to the consumers will contribute to the performance improvement of the production and centralized distribution of the thermal agent to the consumers. The paper proposes to achieve this objective by using computational intelligence methods (soft computing). The main parts of the computational intelligence are: fuzzy logic, artificial neural networks, genetic algorithms, evolutionary programming, the chaos theory and the probabilistic reasoning [3]. It is accepted that the computational intelligence is based on fuzzy logic, neural networks and genetic algorithms and any kind of hybrid combinations among them.

2. PROCESS TEMPERATURE CONTROL BASED ON FUZZY LOGIC THEORY

The theory of fuzzy sets was introduced by Zadeh in 1965. In the case of a fuzzy set, an element is characterized by a membership function that can take any value within the interval [0, 1]. Further, Zadeh introduced the concepts of linguistic variables and the fuzzy inference rules that allowed for an interpretation through the fuzzy logic of simple and composed fuzzy statements of "if – then" type and the possibility to move to industrial control application using fuzzy logic. The advantage of the system control approach based on fuzzy controllers consists in the possibility of expressing the input – output dynamic of the system by linguistic rules of "if-then" type. In this way, the practical experience of the human operator can be implemented not by simple mathematical equations, but in a linguistic form that can be interpreted through fuzzy logic techniques. After Mamdani achieved in 1975 the first control system based on fuzzy logic for a steam turbine, at the end of the 80's the first electric house devices produced in Japan that were based on fuzzy logic appeared on the market. Fuzzy logic is now applied in a wide range of domains such as industry, medicine, economy etc.
A fuzzy logic controller can be designed taking into account the operators expertise and the knowledge in control. Currently, to control a SISO plant, an operator after observing the *error e* (the difference between set point and the process output) and the *rate of change of the error* $\dot{e}$, he can take a decision to change the *process control u* [4]. In fuzzy terms these actions can be formulated as "if - then" rules:

if *error* is A and error *change* is B then *control* is C (1)

To implement a fuzzy logic controller for a real time application, the fuzzy algorithm computation time is an important criterion. Usually, look-up decision tables are used in order to decrease the time computation, especially in the fuzzy inference reasoning and output defuzzification [5]. All computations are carried out beforehand (off-line) and the resulting look-up tables are stocked in memory. In real time control only quantizations are performed and the corresponding values from look-up tables are obtained. When output quantization is linear, the values contained in the look-up tables are multiplied by different constants and then applied to the process as control variables [6].
To improve the control performances a fuzzy logic controller must to manipulate two look-up tables for each control variable, one for a coarse control and the other for a fine control [7]. A fuzzy logic controller for temperature control can be realized following the approach described above.
The fuzzy controller is implemented as follows:

$$U_k = (E_k \times \dot{E}_k) \circ R_F \qquad (2)$$

where U_k is the fuzzy controller output, E_k is the fuzzified process output error, $\dot{E}_k$ is the fuzzified process output derivative error, R_F is the input-output fuzzy relation of the controller, $\times$ is the Cartesian product and $\circ$ is the compositional rule of inference based on Mamdani reasoning [4].
If E_k and $\dot{E}_k$ are obtained as fuzzy singletons, respectively as e_k and $\dot{e}_k$, and R_F is in the form of a look-up table **U**, the deffuzified controller output is computed as

$$u_k = u(e_k, \dot{e}_k) \qquad (3)$$

where $u(e_k, \dot{e}_k)$ is the element of **U** at the position $(e_k, \dot{e}_k)$. The output defuzzification is based on the center of area method.

Because e_k and $\dot{e}_k$ are quantized into a finite number of values, the look-up decision table **U** has a finite numbers of control values. Two look-up decision tables are introduced, one for a coarse control ($\mathbf{U_c}$) and the other for a fine control ($\mathbf{U_f}$). These look-up tables differ from each other for a control variable by the step of quantization. The configuration of the fuzzy logic controller is given in figure 3. The operator will adjust the fuzzy controller parameters to obtain the best process performance.

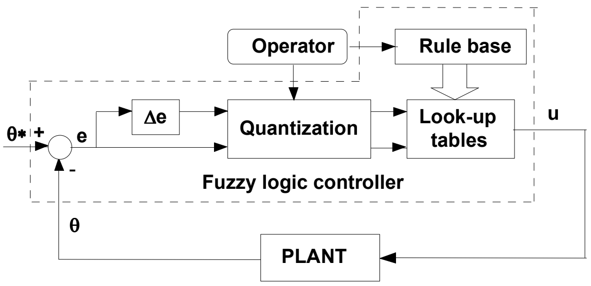

Figure 3: Temperature control using fuzzy logic controller.

The operator can modify the scaling factors for each variable e_k and $\dot{e}_k$ and the fuzzy rule base by trials and errors. He will try to obtain the best transient and steady state system performance introducing in fuzzy control rules the same strategy as like he would been applied if he would been control himself the process.

3. SOFT COMPUTING TEMPERATURE CONTROL OF PLATE HEAT EXCHENGERS

Heat exchangers are equipments which transfer the heat from a fluid to another for thermal processes in whitch two fluids have different temperatures [8]. Plate heat exchangers consist of a number of very thin corrugated stainless steel heat transfer plates clamped together in a frame. Every second channel is open to the same fluid. Between each pair of plates there is a rubber gasket, which prevents the fluids from mixing and from leaking to the surroundings. Heat is thus transferred from the warm fluid to the colder fluid via the thin stainless steel plate. The corrugations support the plates against differential pressure and create a turbulent flow in the channels. In turn, the turbulent flow provides high heat transfer efficiency, making the plate heat exchanger very compact compared with the traditional shell-and-tube heat exchanger. In most cases the plate type heat exchanger is the most efficient heat exchanger. Generally it offers the best solution to heating and cooling applications since it can better handle the widest pressure and temperature limits.
Figure 4 presents the Alfa Laval type plate heat exchanger used in district heat substations of Iasi city for heating both tap water and the radiator water for the domestic consumers.

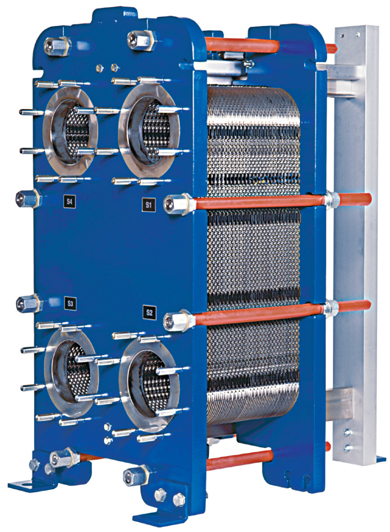

Figure 4: Alfa Laval type plate heat exchanger.

The water temperature control system of the plate heat exchanger can be achieved using models of this equipment based on soft computing with neuro-fuzzy hybrid techniques [9], [10]. The water temperature control system of the plate heat exchanger is implemented in Fuzzy Logic Toolbox from MatLab software [11]. The control strategy is the same used to control the pit gas flow of the CPG 420 steam boiler [12], to control the water level of the CPG 420 steam boiler drum [13], or to control the steam flow rate of the CPG 420 steam boiler [14].
Figure 5 presents the water temperature control system response of the plate heat exchanger using a PD type fuzzy logic controller.

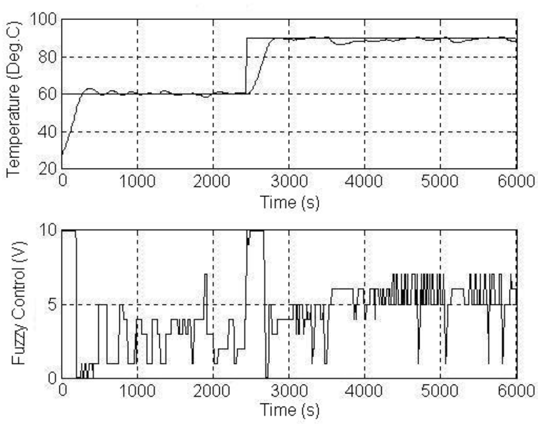

Figure 5: Temperature control using PD type fuzzy logic controller.

The PD type fuzzy logic controller uses only 11 values of the control signal both for the coarse control and for the fine control. The control performance is not so good because of the temperature oscillations.

Figure 6 presents the water temperature control system response of the plate heat exchanger using a PI type fuzzy logic controller.

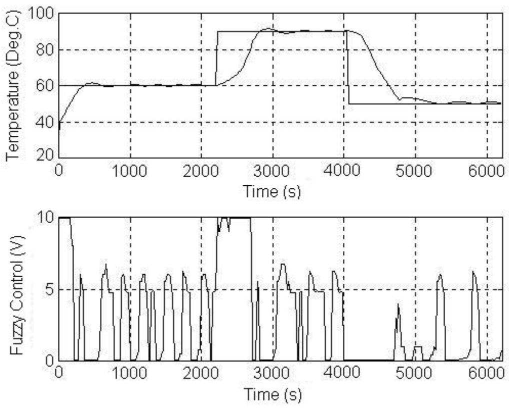

Figure 5 Temperature control using PI type fuzzy logic controller

The control performance is better both for the increase and the decrease of the set point.

4. CONCLUSIONS

Soft computing techniques are used to control the water temperature of the Alfa Laval type plate heat exchanger. Fuzzy logic control is implemented and the good performance of the fuzzy control proves that this can be an alternative to the classic control.

Acknowledgments

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