Simulation Model of Heat Distribution and Consumption in Practical Use

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Abstract: - This paper describes the designed and implemented computer model of the distribution system of heat consumption in the urban agglomeration (SHDC - System of Heat Distribution and Consumption) in practical experiments. This model is designed as a simulation model linked to prediction mechanism. The simulation is one of the (few) methods, which can be effectively used for the analysis of large and complex dynamic systems properties, which the distribution system and heat consumption in the municipal heating networks is without doubt. The model is implemented in the form of computer applications and provides interfaces to adapt it into a real heating system. To provide necessary functionality, the model takes basic information from the system to be modeled, such as the lengths and diameters of the real pipe system along with operational data. The model and all its subsequent links are designed for heat supply prediction, which can be used in system regulation. Depending on the structure of the particular real system, the temperature of heating water is usually required to predict.

Key-Words: - Distribution, heat, model, prediction, simulation, temperature.

1 Introduction

Problems of distribution and consumption of heat energy in the urban agglomeration are very actual, especially in the context of finite worldwide energy resources and the constant increase in energy prices. There is also important ecological aspect, because obtaining and using of energy generally has mostly negative environment impact. Therefore, it is necessary to seek all paths leading to energy, including heat energy, savings [7].

Heat energy must be transported to the place of consumption in time when it is required and in the expected quantity and quality. Quality of supplied heat energy is expressed in the temperature of heat transferring media. The correct delivery time, quantity and quality of heat energy must go hand in hand with minimal distribution costs [1].

System of production, distribution and consumption of heat is very large and complex. Analysis of the features that need to be known for its efficient management is very difficult and there is not much practice, how such an analysis should be carried out with sufficient accuracy. Applicable procedures are almost exclusively based on modeling.

This paper describes the designed and implemented computer model of the distribution system of heat consumption in the urban agglomeration (SHDC - System of Heat Distribution and Consumption) and its subsequent use in experiments on the real heating system.

For our model, the chosen city system was simplified and model was trained on real measured data [2]. The main aim of this experiment were to verify model itself, its ability to adapt to real process and also to proof associated potential for prediction.

Beside the model description, this paper shows results of two days experiment on heating system of midsize city with more than hundred heat exchangers. Even the experiment confirmed many theoretical presumptions, it also showed several new task to deal with for the further improvements.

2 Model description

The distribution network can be presented as a set of sources of heat energy (supply heating stations) and heat consumers, which are cross connected trough piping. The pipes are divided for model in sections, which are linked in nodes. Section starts and ends in the node and can be divided in several pipe lines. Pipe line is a part of piping, which has constant characteristic from the point of view flow and heat transfer.

Pipeline losses can be determined by the relationship

$$ {}^{j}Q_{i\ loss} = k_p * ({}^{j}T_i - {}^{j}T_{p\ ext}) * \Delta t \qquad (1) $$

where:
- k_p is the heat transfer coefficient in the current pipe line *p*,
- ${}^{j}T_i$ is water temperature for the DFQ_i
- ${}^{j}T_{p\ ext}$ is the outside temperature for the pipe line *p*, both in simulation step *j*.

Coefficient k_p is based on pipe structure - pipe material, style and material of insulation, pipe seating, etc.

For example, for the heat consumption at consumer *r* at time interval Δt_j the following equation can be used:

$$ {}^{j}Q_{i\ cons} = s_r({}^{j}T_i, {}^{j}T_{r\ ext}, \ldots) * \Delta t \qquad (2) $$

where:
- $s_r(...)$ is the function describing heat consumption for the consumer *r*.

Determination of this function is obviously very difficult, but for the final solution of this task, especially in terms of its accuracy for those particular parts "consumers", it is very important. There may be applied many different important factors such as:
- type of the day: workday , weekend, holiday etc.,
- part of the day: morning, afternoon, evening, night,
- type of the consumers in the particular part of the network: flats, schools, industrial companies etc.,
- other weather conditions: sun intensity, wind, air humidity.

To determine the functional dependences of heat consumption on these factors it is also possible to successfully use the proposed simulation model.

Detailed information about particular parts, such as the flow modeling and heat transfer modeling can be found in [7].

3 Model use and applicability

It is expected that the proposed simulation model will be used in the control system SHDC for the following purposes:

1. Identification of model parameters for the selected time period
2. Prediction of appropriate timing of the supplied amount of heat energy for the next period.

3.1 Identification of model parameters for the selected time period

As mentioned, essential for the modeling approach to SHDC is to determine the function $s_r(...)$ used in equations (2). This means that it is necessary to choose the appropriate form of parametric functions and find values of the parameters for the given conditions.

The procedure will be described in detail on simple example where the function $s_r(...)$ shall only affect consumption fluctuations during the day. We will therefore assume that the function $s_r(...)$ will have the form

$$ s_r(\ldots) = \lambda_r * ({}^{i}T_j - T_{ext}) * k_h \qquad (3) $$

where:
- λ_r is the coefficient of heat transfer in segment *r* (here we suppose that the segments are pipe sections as well as consumer units, depending on the value of the coefficient λ),
- ${}^{i}T_j$ is the current temperature DFQ_i for the particular simulation step *j*,
- T_{ext} is the current outside temperature and
- k_h is coefficient which corrects heat consumption oscillations during a day.

To determine searched values k_h (points of timeline) is possible to use several methods based on principles allowing us to find a function(s) which should have the best course approximating analyzed variables. One option is for example to use genetic algorithms. In the presented solution was the method PSO (Particle Swarm Optimization) used - see [4]. This method has been lately compared with other methods, such as SOMA, neural networks [6], and Levenberg-Marquard algorithms for nonlinear methods of least squares. It was found that the results achieved in terms of accuracy and speed of convergence is similar. PSO is therefore comparable for the determination of the correction factors and we use it.

3.2 Prediction of appropriate timing of the supplied amount of heat energy for the next period

The individual steps of the proposed procedure are as follows:
- Prediction of conditions for a selected future time interval of the SHDC control.
- Seeking the time interval with similar conditions.
- Identification of model parameters for time period with similar conditions.

- Identification of model parameters for previous time period.
- Calculation of control actions for the selected time interval

Implementation of these particular steps is described in [7] as well as test results. Remaining part of this paper introduce above mentioned steps in practical experiment as already advised.

4 The experiment

This chapter shows two days experiment performed on heating system of midsize city with more than hundred heat exchangers. The experiment was conducted from March 8th to March 10th. Its main purpose were to predict sequence of heating water temperatures *(Tv)* to control quality of heat supply [1].

The first step of experiment was to prepare simplified pipe model. Because there were not enough information about heat consumption spreading, the city for model purpose were divided into twelve heat consuming spots which represents group of heat exchangers with similar distance from the heating plant. Also all spots have the same power requirements.

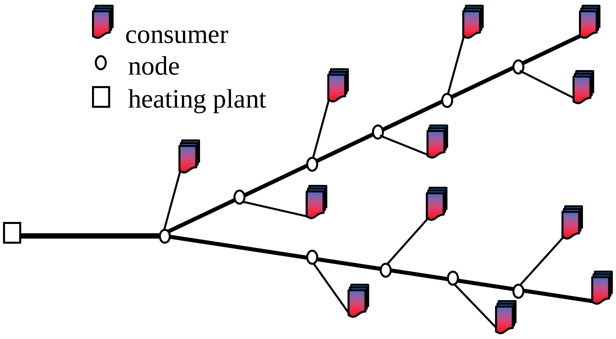

Fig. 1 Simplified diagram of the network model

Next step was to set up model for identification. According to unknown condition of day in future a day with similar outside temperature from the past were chosen to train the model [2]. This step provide resources for identification and expected heat consumption were calculated.

Based on the heat requirements the prediction mechanisms took the place. The sequence of *Tv* were predicted, see Fig. 2. These *Tv* were than imposed into the heating plant system and real control took the place.

The next day were model updated and all steps were repeated for subsequent time period.

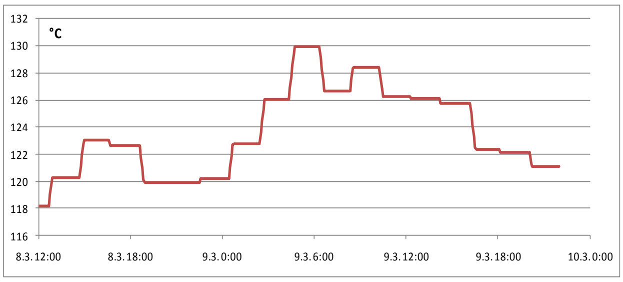

Fig. 2 Proposed values of *Tv* for fist day (water in the supply line)

4.1 Evaluation of experiment

The proposed values were found acceptable by the heating plant and followed for both days. After The measured results and its comparison with model prediction are showed in the following pictures.

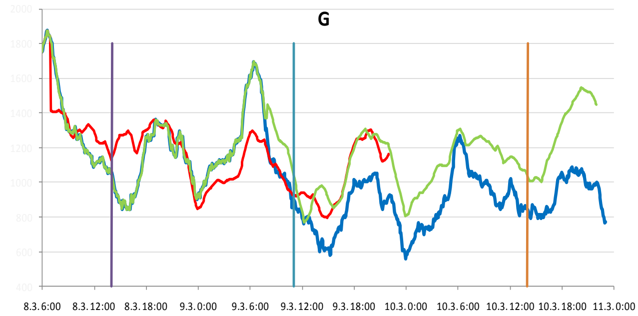

Fig. 3 Flow (transfer fluid)

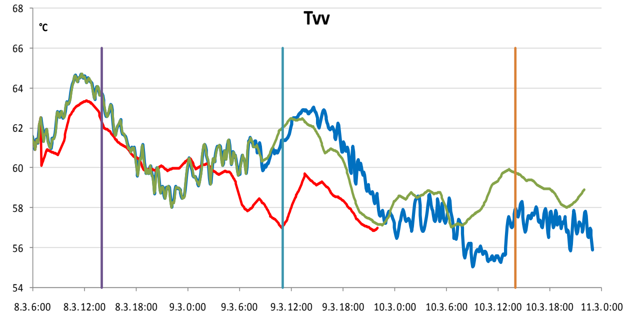

Fig. 4 Returned water temperature (water in the return line)

Graph legend:
____ first day prediction
____ second day prediction
____ measured course

5 Conclusion

The results obtained during the model verification, tested on real measured data show that the proposed simulation model is a well suited tool for analyzing the properties and behavior of SHDC.

Introduced simulation model has been subjected to real heating plant system. The results obtained in this case show that modal perform well in real situation as well, however several insufficient remain. As can be seen on Fig. 3 the flow predicted and measured course have considerable deviation. This is probably due to inappropriate binding between similar and examined days. To eliminate this insufficient, the current research focuses.

Nevertheless, used methods and algorithms appears to be leading to improved performance of existing heating systems.

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References:

[1] Balate, J. *Automatic Control, 2nd edition*, BEN - technical literature, ISBN 80-7300-148-9, Prague, 2004.

[2] Dolinay V., Vasek L., Kral E. *Heat Supplies Prediction Based on Similar Days*. In Annals of DAAAM for 2010 & Proceedings of the 21st International DAAAM Symposium. Vienna : DAAAM International, pp. 227-228. ISBN 978-3-901509-73-5, ISSN 1726-9679, 2010.

[3] Incropera, F. P.; DeWitt, D. P. & Bergman, T. L. *Introduction to Heat Transfer*, Wiley, ISBN: 978-0471457275, London, 2006.

[4] Kral E., Vasek L., Dolinay V. & Varacha P. *Usage of PSO Algorithm for Parameter Identification of District Heating Network Simulation*, Proceedings of 14th WSEAS International Conference on Systems, Corfu Island, Greece, pp. 657-659, 2010.

[5] Law A.M., Kelton W.D. *Simulation Modeling and Analysis*, McGraw-Hill, ISBN: 978-0070592926, 1999.

[6] Varacha, P. *Impact of Weather Inputs on Heating Plant - Agglomeration Modeling*. Proceedings of the 10th WSEAS International Conference on Neural Networks, Mastorakis, N., pp. 159-162, ISBN 978-960-474-065-9, Prague, 2009.

[7] Vasek L., Dolinay V. *Simulation Model of Heat Distribution and Consumption in Municipal Heating Network*. International journal of mathematical models in applied sciences, <http://www.naun.org/journals/m3as/>. ISSN 1998-0140, 2010.