Simulation Model of Heat Distribution and Consumption in Municipal Heating Network

VAŠEK L., DOLINAY V.
Faculty of Applied Informatics
Tomas Bata University in Zlin
Nam. T. G. Masaryka 5555, 76001 Zlin
CZECH REPUBLIC
lvasek@fai.utb.cz, vdolinay@fai.utb.cz

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). This model is designed as a simulation model. 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 was implemented in the form of computer applications and tested on real operational data.

Key-Words: heat consumption, heat distribution, modeling, discrete simulation.

1 Introduction

Problems of distribution and consumption of heat energy in the urban agglomeration is very actual, especially in the context of finite worldwide energy resources and the constant increase in energy prices. Therefore, it is necessary to seek all paths leading to energy savings including heat energy. One of the factors that can lead to savings of energy is the effective management of distribution of the heat. Heat energy must be transported to the place of consumption in time when it is required and in the expected quantity. The time and quantity must go hand in hand with minimal distribution costs. It is obvious that the heat distribution is inextricably linked to its consumption and therefore we can talk about the management of the heat distribution and consumption.

The 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). This model is designed as a simulation model with a number of freely usable parameters.

2 Simulation Model and its Using

The model is, in contrast to the commonly used continuous models, discretized in time - time is running in simulation discontinuous steps, with a sampling period. The size of the time period depends on the speed of change of monitored values. Therefore, if using this model will be analyzed by going to the SHDC run in normal mode and not going with great speed changes, such as surges in the piping, etc., it is possible to work with the time period of several minutes. For this kind of analysis is this concept of the simulation model justified.

Intended use of the processed simulation model for management of SHDC is as follows:

Determine the conditions for a selected time interval of the SHDC control. It is usually the time interval of a few hours to one day. Conditions mean generaly everything that affects the distribution and consumption of the heat - primarily weather variables such as outdoor air temperature, sunshine, wind strength and direction, etc., as well as e.g. type of heat consumption in different parts of the distribution network, amount change in consumption during the day, etc. These conditions and factors are possible to integrate one by one and the model gradually refine.

Identification of model parameters in these circumstances. This is carried out by analyzing historical operating data recorded during periods with similar conditions. During the identification procedure artificial intelligence is used to seek for model parameters and to minimize the differences of calculated and measured values of appropriate functions - timing of back-water temperature.

Calculation of control actions for the selected time interval. When calculating the control actions in accordance of quality-quantitative control (Balate, 2008), i.e. determining the time course of temperature and flow of hot water, again with the benefit of the proposed model of SHDC. This model can simulate the behavior of SHDC on various versions of control actions, and find the option that best matches the selected purpose (evaluation) function. A detailed analysis using a simulation model for prediction of control actions will be subject to further research work.

3 Model Description

Consider "discrete quantum flow" DFQ fluid (water), which flow in the network and gradually lose its energy, depending on the current position. The volume of the quanta is determined by the quantity of water into the distribution network input on the entry for the time interval Δt in given step of simulation time. Time interval Δt identical to the sampling time interval of measured values. Amount of heat energy in DFQ is based on its quantity and its temperature.

3.1 Flow modeling

Compressibility of water in the pipe is insignificant and does not need to be include in the model.

In each simulation step the flow quantum, denote ${}^{j}DFQ_i$ in network is monitored. Shown on following picture,

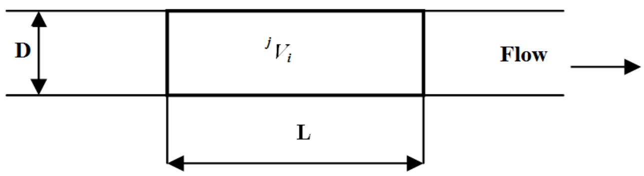

Fig.1 Discreet flow quantum

where:

- index i describe particular quantum,
- index j describe time period for ${}^{j}DFQ_i$ analysis,
- D is pipe diameter in current ${}^{j}DFQ_i$ location,
- L is current ${}^{j}DFQ_i$ length,
- ${}^{j}V_i$ is volume of ${}^{j}DFQ_i$

To monitor the flow quantum passing through the distribution network is of course necessary to respect the fundamental physical laws applicable to the fluid flow and heat energy transfer - conservation of mass and energy and the law of continuity.

The distribution network can be presented as a set of section and nodes, where each section is linked, see the following figure,

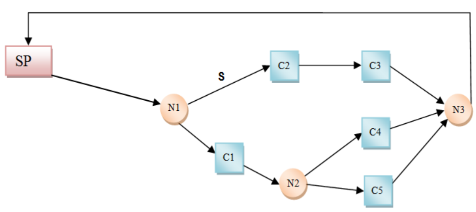

Fig.2 Example of schematic distribution network parts

where:

- C consumer,
- N note,
- S section,
- SP supply (source).

Depends on the law of continuity we have to follow several rules for flow quantum:

1. While passing through the section, the DFQ don't alter its volume, its length L in a pipe varies depending on the diameter D of the section of the current pipeline.

2. Each section is divided into the parts, which are from point of flow view and heat balance "homogeneous". While DFQ_i passing two consecutive parts p and q of section is split into the two new DFQ - DFQ_{ip} and DFQ_{iq}. DFQ_{ip} is the part of DFQ_i , which remains in first part of section - does not reach the border between parts p and q, DFQ_{iq} is contrary of DFQ_{ip} - part of DFQ_i which passed transition of p and q in current simulation step and switched into q part.

3. The above mentioned DFQ_i's splitting rules are valid also for each DFQ_i, which is entering node k - each DFQ_i is split into two parts – DFQ_{ip} and DFQ_{iq}. DFQ_{iq} is the part of DFQ_i, which reached the transmission in particular simulation step and DFQ_{ip} is the part which does not reach it. For each output section j in node k DFQ_j is created. From the law of continuity we can use this equation:

$$\sum \mathrm{Vol}(DFQ_{iq}) = \sum \mathrm{Vol}(DFQ_j) \qquad (1)$$

where:

- $Vol(DFQ)$ describe function, which presents particular part of flow quantum,
- $\sum$ on the left is processed for all section, which allows flow to come in.
- $\sum$ on the right is processed for all sections, which allows flow to come out.

3.2 Heat transfer modeling

For each flow quantum, which is at a given time in the distribution network, is in each simulation step calculated its heat balance. The heat balance is based on respect for the preservation of heat energy. The heat energy changes - decrease of heat - in DFQ_i during the time interval Δt, e.g. in single simulation step, is described in the equation:

ISSN: 1792-4235

ISBN: 978-960-474-214-1

$$\Delta^{j}Q_i = {}^{j+1}Q_i - {}^{j}Q_i \qquad (2)$$

where:

- ${}^{j}Q_i$ and ${}^{j+1}Q_i$ describe the amount of heat energy contained in the DFQ_i at the beginning of the simulation step j and simulation step j+1.

The next equation is still followed:

$${}^{j}Q_i = V_i * \rho * c_v * {}^{j}T_i \qquad (3)$$

where

- c_v is the specific heat constant for the fluid (water),
- ρ is water density,
- V_i is volume of DFQ_i and ${}^{j}T_i$ its temperature.

Presented decrease of the heat $\Delta^{j}Q_i$ in DFQ_i during the time interval Δt arises from the fact that this heat is transferred to the surroundings, either in the form of losses (supply line) or in the form of consumption (consumers).

Note.: At this point the issue of efficient use of heat delivered to the consumer is not discussed - that is another broad topic to solve.

Pipeline losses can be determined by the relationship

$${}^{j}Q_{i\,ztr} = k_p * ({}^{j}T_i - {}^{j}T_{p\,ext}) * \Delta t \qquad (4)$$

where

- k_p is the heat transfer coefficient in the section p of the input pipes,
- ${}^{j}T_i$ is water temperature for the DFQ_i
- ${}^{j}T_{p\,ext}$ is the outside temperature in section p, both in simulation step j.

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

For the heat consumed in the section r at time interval j the following equation can be defined:

$${}^{j}Q_{i\,spotr} = V_i * \rho * s_r({}^{j}T_i, {}^{j}T_{r\,ext}, \ldots) * \Delta t \qquad (5)$$

where:

- $s_r(\ldots)$ is the function describing consumption in the section r.

Determination of this function is obviously very difficult, but for the final solution of this task, especially in terms of its accuracy for that particular parts "consumers", very important. There may be applied many other 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,
- and others.

To determine the functional dependences of heat consumption on these factors is also possible to successfully use the proposed simulation model. This using of the model will be included in the identification of model parameters for given conditions.

4 Model Realization and Results

Introduced model was implemented in the form of a software application, Application was tested on data from the real process in the selected heating plant. Examples of results using this application for the identification of SHDC are shown in Fig. 3, the results for predicting the behavior of SHDC in Fig.4.

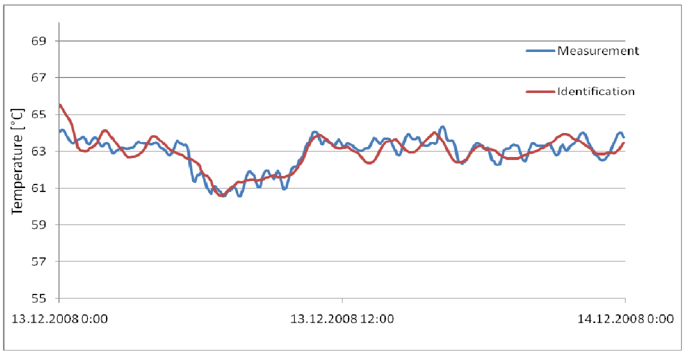

Fig. 3 Identification of SHDC - calculated and measured temperature of back-water.

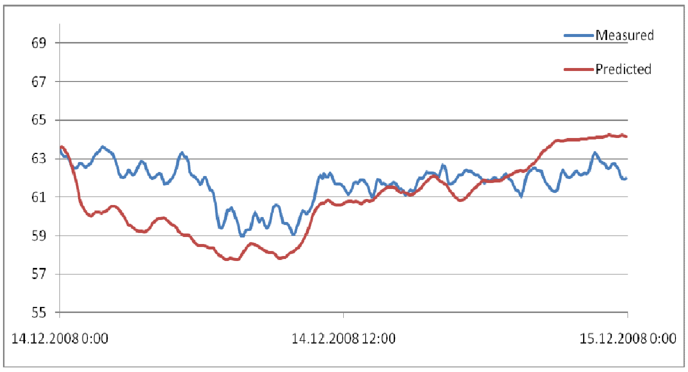

Fig. 4 Prediction of SDHC characteristics - calculated and measured temperature of back-water.

4 Conclusion

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

Introduced simulation model can be used also in different mode, which is practically very interesting and useful. It can be incorporated into the control system to predict the behavior of SHDC at a certain (limited) time in the future, to streamline the management of SHDC. This relates to the length of the sampling period in the simulation model, since that period (order of minutes) allows real-time to carry out quite complicated and extensive calculations and apply the results in real-time control system.

The improvement of the model and its use are still in progress.

5 Acknowledgment

The work was performed with financial support of research project NPVII-2C06007, by the Ministry of Education of the Czech Republic

References:

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

[2] Balate, J., Navratil, P., Chramcov, B. (2008). Qualitatively-quantitative method of heat power in the hot water supply for the district heating system. In: ARTEP 2008, TU Kosice.

[3] Broz, K. (2007). Supply of heat, CVUT, ISBN: 80-01-02521-7, Prague.

[4] Ibler, Z. sr.; Ibler, Z. jr. & Kartak, J. (2002). Technical guide of energetics 1, BEN, ISBN: 978-80-7300-026-4, Prague.

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

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