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Adaptive Modeling of District Heating Network

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Introduction

Mathematical model describes the real system or process created for the certain purpose. Modelling itself enables to watch and test the system reactions to sudden changes of parameters and external conditions. Such a model makes it possible to speed up or to slow down the system behaviour. All these experimental changes of external and internal system connections do not endanger both, security or availability of the investigated system. A good model describes the system in question in true way [1]. Therefore, it is useful to use mathematical models for prediction of the real system behaviour.

Time Course Variational System

There are a lot of systems in the surrounding world where we know about them, that they are changing, during the time, their inner relations and parameters. Such a case example may be the delivery of heat energy into the central heat distribution net (CHDN).

For example the change in number and in composition of consumers, growing usage effectiveness of thermal energy (e.g. heat insulation of buildings), construction of new heat pipelines etc. are the possible changes in the system of CHDN. For such a time variation system we should like to establish mathematical model with its ability to predict the system prospective development. In the mentioned consumption of heat energy (HE) in relation to CHDN it would be beneficial to know the expected development one or two weeks in advance.

This qualified consumption estimation could enable the supplier to optimize the control of production units, resulting in their operation at their technological optimums and so also in decreasing of the operational cost during the production of HE. Or on the contrary during the combined production of heat and electricity with the knowledge of his own technology, the producer may estimate the prospective supply of electrical energy (EE). Such energy may be offered to the distributor as the guaranteed output, which is sold in higher specific prices than the random output. It results in higher receipt for the EE.

The CHDN system ensures the supply of HE for great number of consumers. This supply is consumed in three areas: heating, furnishing of warm water and technological needs. Extent and the time course of consumption of HE in these areas are influenced by the number of outer conditions, e.g. the kind of buildings, geographical location of CHDN, number and structure of population, the kind of technology, etc., including the possible time changes of the system itself.

At present the HE production control is performed by means of qualified estimation of consumption, based on the empirical knowledge of the responsible managers. Schematically, this kind of control can be seen at the Figure 1.

The instantaneous values of the consumption, outer temperature etc., and weather forecast information are entering the HE production decision process. Taking into account the operational experience the decision making people, the short term plan of the plant operation is created. Provided mathematical model of delivery exists, it can be used as the supporting aid of decision making mechanism, enabling the quantification of the prospective requirements on the produced HE.

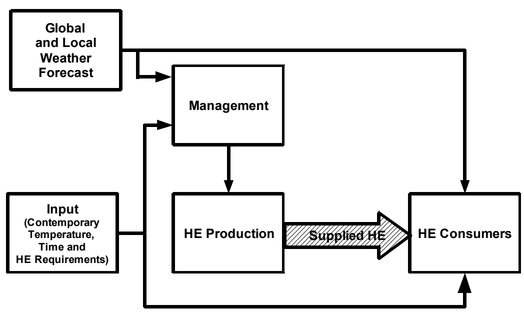

Fig. 1. The Heat Production Classical Planning Scheme

Adaptive Models

In the case of real system, we know usually a part of physical and technical bonds, incl. the external parameters, influencing the system in question.

Seeing that the static model, after certain time, does not meet the given accuracy, it is necessary to create the adaptive algorithms executing the model parameters corrections.

For these cases it is suitable to introduce the adaptive mathematical models. Such a model considers the changes between the elements of the described system resulting in corrections of calculated parameters. The principle of the model function can be explained in details on the practical example. The HE production control itself is then altered, resulting in a new scheme – see the Figure 2.

Establishing the so called first adaptive mathematical model of HE consumption, we take into account the weather forecast values and the previous measured values of HE consumption. This first model performs the calculation of estimated HE in the CHDN system consumption for the consideration of both, the HE production control and HE supplies to the consumers.

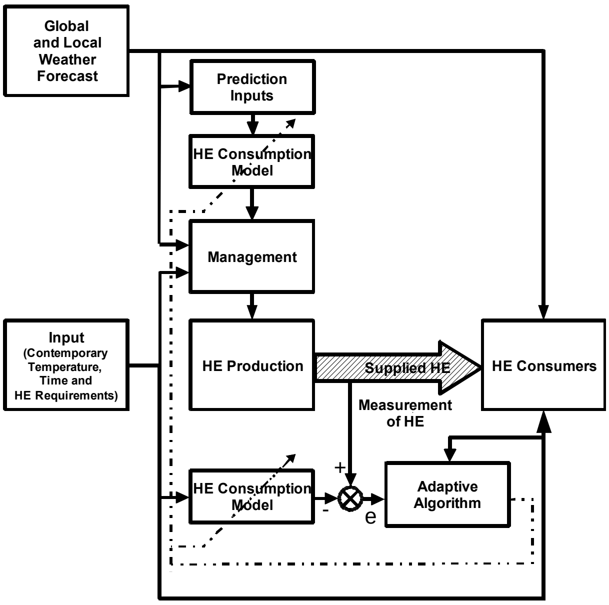

Fig. 2. The Heat Production Adaptive Model Planning Scheme

Up to now there is the control by means of prediction model.

The second mathematical model is created at the adaptive governing system, which, for its calibration uses the same parameters as the first one. The contemporary outer temperature and contemporary requirements of consumers are used as the input quantities, and then it performs the calculation of estimated and expected HE consumption. This calculated prediction is compared with the real current supply of HE into the CHDN system.

The control deviation enters the adaptive algorithm and new model parameters calculation of the HE consumption is then performed. These parameters are implemented into the first and second mathematical model simultaneously. The back feed loop tries permanently to keep the output parameters of the second model at such level, that the inaccuracy of its prediction is minimal. It is ensured by usage of a suitable adaptive algorithm. The Figure 3 describes the function of the adaptive algorithm [1].

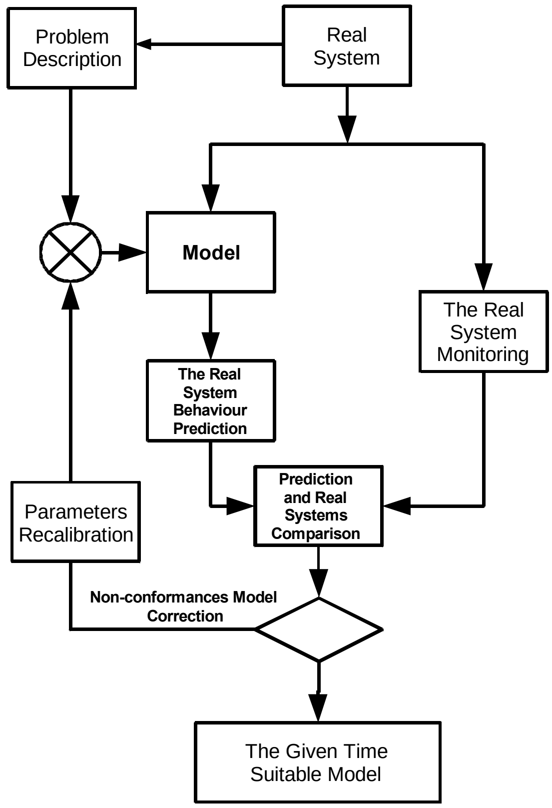

Fig. 3. The Adaptive Model Function Scheme

The advisable selection of the sophisticated adaptive algorithm may result in the quick reaction of the model to sudden changes in the CHDN system. The parameters recalibration proceeds nearly at the real time, immediately after some change in the net. The other advantage is that the changes occur off-line, without any need of the operator attention. With sufficiently powerful and intelligent adaptive algorithm are the calibrations changes always better than it may be reached by the skilled operator, working with manual recalibration, based only on the empirical experience.

Adaptive Model Expectations Practical Testing

For verification of this theory it was necessary to gain the measured data from the real system. As to a very good cooperation between the company Dalkia ČR a.s. divize Ústí nad Labem and the J. E. Purkyně University of Ústí nad Labem we could use the data from the local CHDN system. This system is power supplied by Dalkia by means of steam condensing CHDN net, delivering HE for left-bank part of the town, for nearly 100 thousand inhabitants. The greater part of the town (app.75%) is situated on the left bank of the river. The power station itself is situated at Trmice, about 5km away from the centre of the town. At present, there are installed 6 boilers at the power plant, total output app. 470MWt and 5 current generators with total installed output 88MWe. The CHDN system is connected to the source by means of three parallel steam feeders (TNI, TNII, TNIII). They form three systems of steam and condensate piping, each 7km long and of DN500, DN600 and DN700. Distribution of HE energy is then carried out by steam main pipelines, connecting the local primary nets. The CHDN system supplies app. 3 300TJ of heat energy in the form of steam per year. The CHDN system consists also of more than 1 300 end users. The CHDN system delivers the HE to app. 26 800 households and to great part of industrial companies in the town.

To make proper model design and testing there were data enough, having been monitored in 5minutes intervals. The model verification was performed on the data being gained in the year 2005. Appropriate values of the year 2006 and part of the year 2007 were used for the check.

At first, the static model of the system was created. The calculated parameters served for the year 2006 prediction. The Figure 4 compares the real course and model calculated predictions. From a simple comparison it is apparent, that at the end of the year 2006 the differences between reality and the prediction grow. It is caused by the changes in the CHDN system that was carried out during the year 2006.

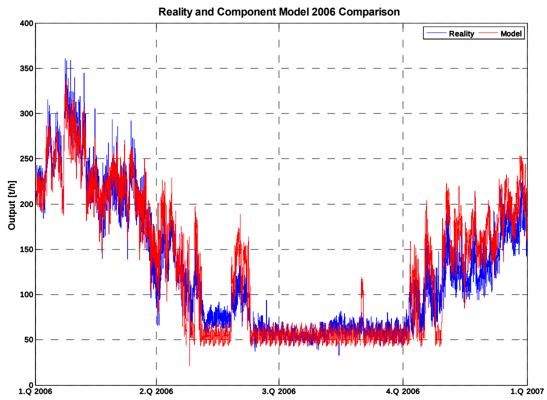

Fig. 4. The Comparison Graph of the Year 2006 Reality and Prediction

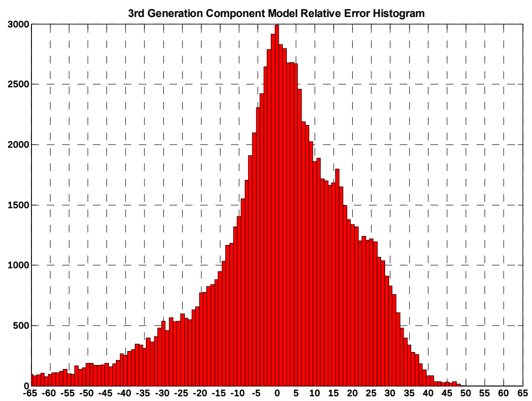

Fig. 5. Distribution of the Year 2006 Prediction Tolerances

Because the graph consists of app. 105 thousand values for one curve, it is more instructive to plot the histogram (see the Fig.5), graphing conformity between both, reality and the prediction.

With the used adaptive algorithms as a part of mathematical model, when the model reacts automatically to the changes in the CHDN system, the result is much better. The comparison between the reality and a prediction is graphed at the Figure 6.

The Figure 7 presents the histogram conformity of the real and adaptive model predicted values. We can see there, that from about 150 thousand values, about 30 thousand are situated in the tolerance range of ±1% that is more than 20% from the estimated volume. About 87 thousand values lie in the tolerance range of ±3% that is more than 50%.

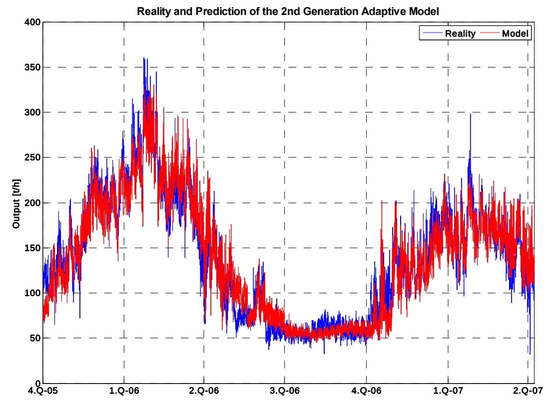

Fig. 6. The Reality and Prediction Comparison Graph of the Year 2006/2007

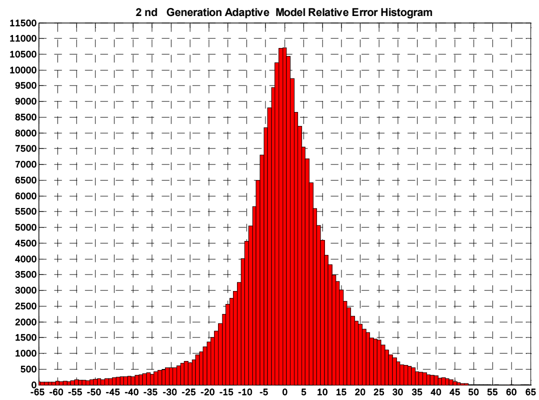

Fig. 7. Distribution of the Year 2006 to 2007 Prediction Tolerances

Conclusion

The given example has verified the suitability of the adaptive mathematical model for prediction in a time variable system. Practical usage of the proposed algorithms used for prediction of supplied volume of heat energy into the central heat distribution net enables the quick corrections in the control of power generating sources. This control will not be focused only on fulfilling of technical requirements, but there will be multi-criterion control algorithm, being able also to optimize automatically the production costs.

The results obtained from the usage of adaptive model, describing the main features of the heat energy supply behaviour, enable the correct prospective prediction, followed by the correct production planning, the plant maintenance downtimes, incl. the optimization of production process from the point view of costs.

This article should be an invitation for all producers of control systems for the implementation of adaptive algorithms into their control systems, which may become the useful tool for the management.

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The article describes the usage of adaptive mathematical model for prediction of the consumption in the system of centralised delivery of heat. This model is possible to use as the useful tool for the generating units operation planning and scheduling. It is the application of the methods of theoretical informatics in the industrial practice, namely at time the method is tested on district heating network in Ústí nad Labem thanks to the close cooperation between the Jan Evangelisty Purkyně University and the heating station Dalkia ČR division Ústí nad Labem. Ill. 7, bibl. 5 (in English; abstracts in English, Russian and Lithuanian).

Я. Шипал. Адаптивное моделирование теплосети // Электроника и электротехника. – Каунас: Технология, 2009. – № 8(96). – С. 65–68.

В статье описывается использование адаптивной математической модели, которая прогнозирует потребление в центральной системе распределения тепла. Эту модель можно использовать как инструмент объединения операционных единиц планирования и диспетчерского графика. Для применения на практике в индустрии предлагаются методы теоретической информатики, которые были успешно протестированы в теплосетях города Усти над Лабем. Тестирование теоретических моделей на практике было возможным благодаря сотрудничеству университета Я. Е. Пуркине с местной теплостанцией, принадлежащей компании «Далкия» в Чешской республике. Ил. 7, библ. 5 (на английском языке; рефераты на английском, русском и литовском яз.).

J. Šípal. Šilumos tinklų adaptyvus modeliavimas // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2009. – Nr. 8(96). – P. 65–68.

Aprašytas adaptyvusis matematinis modelis, kuris leidžia prognozuoti šilumos kiekio poreikį centrinėje šildymo stotyje. Šį modelį galima pritaikyti kaip atskirų padalinių ir dispečerinio grafiko planavimo priemonę.Teorinės informatikos metodai buvo sėkmingai išbandyti Ūsčio prie Labės miesto šilumos tinkluose. Teorinius modelius praktikoje buvo galima išbandyti tik bendradarbiaujant Jano Evangelisto Purkine universitetui ir įmonės „Dalkia" šilumos stočiai. Il. 7, bibl. 5 (anglų kalba; santraukos anglų, rusų ir lietuvių k.).