MONITORING SYSTEM FOR DISTRIBUTED ENERGY AND HEAT SUPPLY COMPLEX

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ABSTRACT

The design of monitoring system for distributed energy and heat supply is presented in the paper. The ***analysis*** of monitoring system and the phase of ***pre-design*** was done by means of Object Modelling CASE Tool, the designed system was implemented in LONWORKS HW and SW environment. The function of communication modules providing data ***transmission*** from distanced energy and heat supply system have been verified and a typical result of ***qualitative simulation*** of the distanced complex behaviour is presented.

INTRODUCTION

Comparing works which simulate buildings and their energy sources, e.g., in [1], [6], this paper turns the attention on the monitoring of energy and heat supply system. The ***energy and heat supply complex*** consists of hydraulic turbine, electric boilers, heat pumps, solar collectors and of many other needed facilities (expanders, compressors, armatures). As a prototype of such complex has been considered the energy and heat supply system of functional and building area in Herbertov - South Bohemia [2], which is covered in first approximation by 39 measuring points.

The development of the monitoring system has been rather complicated process. In the paper there are emphasised only the following interesting items and reached results :

- The merits of Object Modelling Technique (OMT) in the Analysis and in the Design of Software Modules of monitoring were verified. (Methodology and SW tools integrated in an adequate SW support system have been used covering the analytical documentation development, the initial functional scheme synthesis and the code generation phase.)
- The theory of *Qualitative Modelling and Simulation* [3] *and New_K tool* [5] for the description and simulation of the energy and heat supply complex were demonstrated with good efficiency. Respecting the needs of monitoring process information supply, the properties of the developed Qualitative model were found as sufficient. The efficiency of the development of Qualitative model and of its operation were easy proved comparing with the development and function of a classical model implemented in some standard environment , e.g. , in MATLAB.

DISTRIBUTED ENERGY AND HEAT SUPPLY COMPLEX

Herbertov's Power Source System (see **Figure 1**) consists of two parts. One part is employed as a system power source, and the other is utilised in consumption of energy produced by the system's power source. The main source of the system's power is provided by a 120 kW hydraulic turbine. This turbine utilises out the water energy from the nearby river, and in that way provides necessary electricity. Unfortunately, this turbine is not represented on the scheme, because our goal is not to study its function and state during the monitoring. Nevertheless, it would be useful in the future to add this component to the observed system, because the next phase of our project is the control of the Herbertov's Power Source System, and change in any component, especially hydraulic turbine, could cause unexpected damages or failures. As a form of prevention two electric boilers (7) with a four cubic meter expander (8) and a compressor (9) are implemented to the system. The boilers act as alternate sources of energy. Although there are certain constrains that should be considered. For example outside temperature, which depends on the season, could cause the water source, in our case nearby river, to freeze, and therefore constrains the pumping ability. To transcend this problem there is a glycol circuit (5) in the river and two heat pumps with the power of 60 kW each (6) are installed into the system. There are two ways how to operate these pumps. We could do this manually, simply by an operator, or by differential switching, which is done automatically. During the summer season, but also

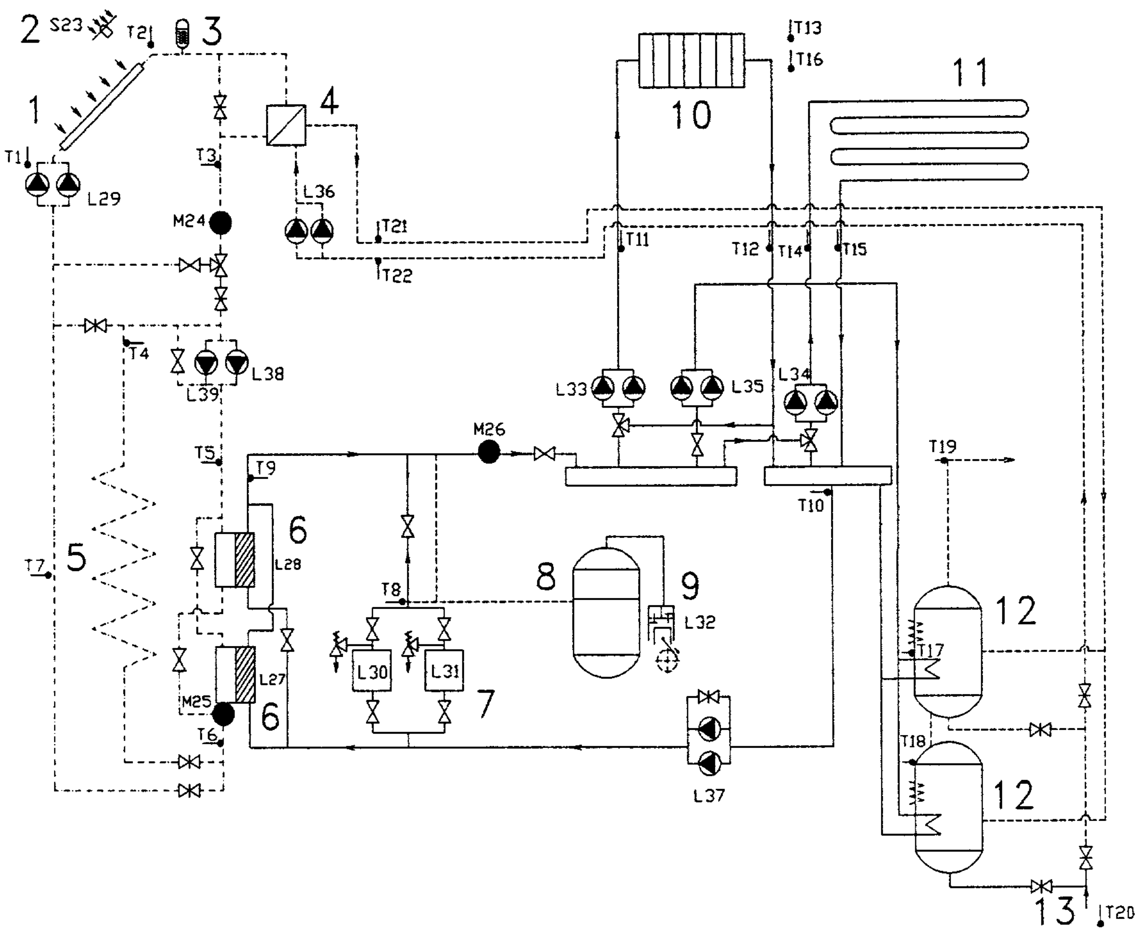

Figure 1. Herbertov's Energy and Heat Supply Complex

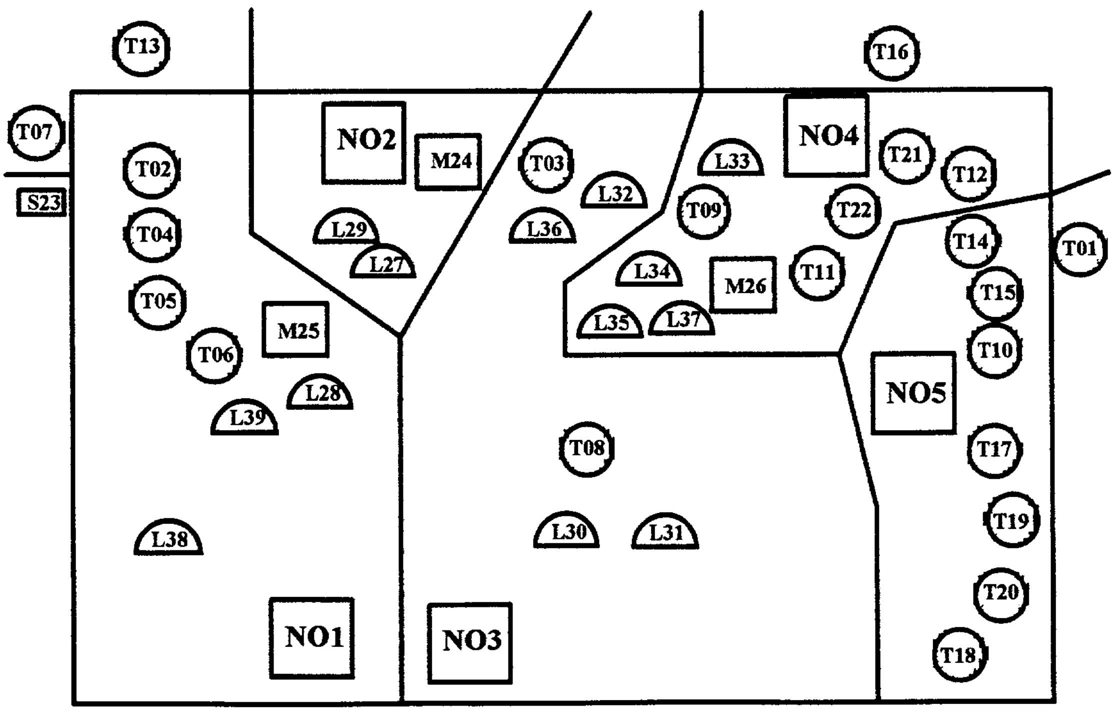

Figure 2. Structure of nodes and measurement points

in winter, we can introduce solar collector **(1)** and use it for more efficient heating of utility water. These solar collectors have surface area of one hundred square meters , while the absorption surface conveys fifty square meters. Near to solar collector is placed a pyrometer **(2)** and a solar system expansion vessel **(3)**. At the winter cycle, part of the energy produced by the power source, described above, is going to be consumed for heating of the main building **(10)**, **(11)**. In a case of non sufficient temperature in building (T13, T14) and both the heat pumps are running **(6)**, the additional electric boilers (L30, L31) are switched on. In a case that the temperature of warm service water (T18) is not adequate the regulator that compares temperature differences (T2 and T18) activates two heaters (12) connected to the water piping system **(13)**. These two, four cubic meter, heaters have a power of 20 kW. The state of the complete system is described with thirty nine variables which are connected with basic components. Namely temperatures, twenty two of them (T01 - T22), one solar irradiance (S23), three flows (M24 - M25), and thirteen logical variables (L27 - L39).
Each of these groups is assigned to one node (NO1 - NO5), through which the states of components of the system would be sent to the network via central unit. (The communication procedures between central unit and nodes have been completely provided by LONWORKS technology - see **Figure 2.**)
The variables which represent conditions of individual states are sent to the central unit (**CENTRAL UNIT**). An operator in Herbertov site could be informed of these states through the central unit monitor. This unit is going to have a capability to save a table of variable values to hard disc, and to send values to the computer in Prague (**MONITOR PRAGUE**) via modem **(M)** on demand, as well as to provide remote access to control network from the computer in Prague - (see **Figure 3.**).

DESIGN OF MONITORING SYSTEM

ANALYTICAL PHASE

The Object Modelling Technique (OMT) method combines object oriented concepts (classes with attributes, operations and associations, limited access of methods) with means of information modelling (Scenarios, State Diagrams, Data Flow Diagrams).
The OMT method uses three different views - object, dynamic and functional. SW tools which support OMT approach enable to execute analysis of systems (in our case - of the monitored system and monitoring system) and the design of the objective system by means of a simple *formulation language*. Skilled use of these tools allows to transfer the main part of pre-programming phases near to generation of code.

OBJECT MODEL

In Object model are represented basic characteristics of the energy and heat supply complex and of the designed monitoring system. As such characteristics we understand, e.g., - topological structures, attributes of objects, possible operations with attributes, associations between objects (structural and functional bonds), etc.
There are a few approaches to Object model development. One of them uses as a start point verbal formulation of the functions, structures and objective of the designed programme system. The objects (classes), associations, attributes and their qualifications are extracted (from verbal formulation) by a special mental technology. Following the OMT rules, the Object model was protected against implementation reasoning and served especially for complete understanding of monitored and monitoring systems functions.

DYNAMIC MODEL

Essential structures of Dynamic model are State diagrams. State diagram may be designed for each of operations defined in Object model.
State diagrams represent event driven information machines and describe algorithms and procedures of processing of attribute and association values and manifestations (defined in Object model). Very important is their use for the design of user interfaces. In the phase of code generation they induce the generation of basic problem oriented programme modules.

FUNCTIONAL MODEL

Functional model extends structures of Object and Dynamic models by requirements for processing of data. Essential structures of Functional model are Data Flow Diagrams.
Finishing the Functional model development, structures of databases have been done, data processing algorithms have been formed, the ways of data flows have been described and the user operations with data have been established.

THE DESIGN PHASE AND THE IMPLEMENTATION PHASE

In the ***Design phase*** were formed - Architecture and Object patterns of the Monitoring System. This phase resulted in the following object pattern decomposition : - System of Control of Nodes, - System of Control of Communication Network, - Module of Data Collection, - Database

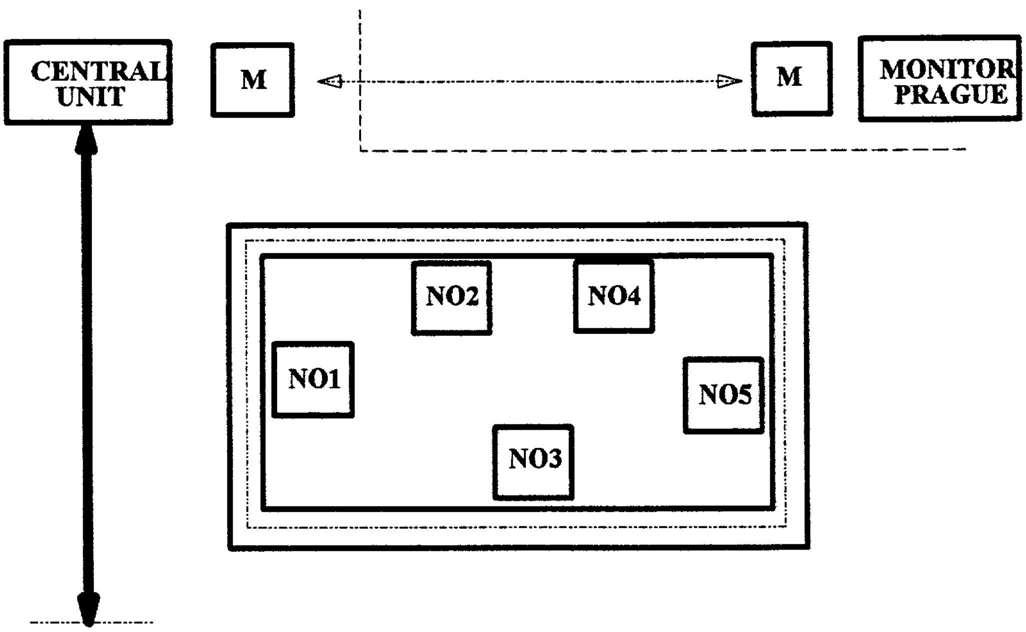

Figure 3. Structure of data Transmission System

System, - Module of Data Transmission. The objective of this phase was to achieve the level of programme code generation (using advantages of reverse engineering). (Some parts of the code were necessary to add by manual way - of course.)

The principal parts of the designed monitoring system programme were ***implemented*** within the framework of LONWORK Technology [4], within communication (between nodes) provided by network of NEURON CHIPs and in the programming environment of NEURON C.

QUALITATIVE MODEL

DEVELOPMENT AND IMPLEMENTATION

Qualitative Model is one of important parts of the monitoring system. Its merits are - *easy development*, *quick responses* to input situations and *good adaptability* in the phase of tuning of the monitoring system. In our case has been developed knowledge-based Fuzzy Qualitative Model composed in the first approximation of „IF/ THEN" type rules and after small verification has been rewritten into homogenous structure of fuzzy AND/OR networks. The methodology of Fuzzy Qualitative Model design has not been different from „classical" way : - determination of linguistic variables and their fuzzy values,- construction of membership functions, - modification of an appropriate inference mechanism, modification of aggregation procedure and - the choice of defuzzification procedure. The computation scheme was also „classical one" : - input of crisp values of system variables, - fuzzification of crisp values, - inference of output values from activated AND/OR networks,-aggregation of output values of fuzzy variables and defuzzification.

The implementation of fuzzy AND/OR networks has been done within the framework of programme system New_K [5]. The editor of this system supports formalism of fuzzy AND/OR networks and provides reliable qualitative simulation process. (Editor of New-K enables to introduce fuzzy variables, fuzzy values, membership functions and rules, in better way as Fuzzy Tool box for MATLAB and its user interface reminds some features of Nexpert Object. Simulator of New_K uses special routines providing low computation time.)

APPLICATION

The developed Fuzzy Qualitative Model was not destinated for modelling of global situations in monitored system but for representation of effects of some important and interesting phenomena nad cycles. From this point of view it may be understood as a set of local models.

These local models describe changes in energy transfer under defined conditions in monitored system and its environment. E.g., the responses of Energy and Heat Supply Complex during the

change of whether from „sunny and cold“ to „cloudy and warm“ in winter season.
Another one local model describes situations of non optimal utilisation of energy sources. E.g., in case when temperature T3 (of solar exchanger exit) is higher than T4 (glycol circuit exit) and some difficulties are in the line of pumps L38, L39, the consumption of electrical energy for heat pumps (6) increases and it is necessary to find another economic mode for time of the repair.
Local models work in New_K simulator pseudo-parallely (outputs of each knowledge network are transmitted to corresponding variables of all other knowledge networks at the same time moment) and thanks to rapid computation process it is performed interaction of the ***active*** local models. (Reaction of some local models for some input situations is very small.)
As an example of a simple local model which is represented by one knowledge network it is introduced a fuzzy AND/OR network „Increase of Radiator temperature T11“ (in the following text). For the simplicity of the network illustration (**Figure 4.**), there have been omitted differences of variables values in last time periods (Δ(T1, k, k-1) = Δ(T11, k, k-1) = Δ(T2, k, k-1)= Δ(T17, k, k-1) = Δ(T3, k, k-1) = Δ(T4, k, k-1) = 0.0 [°C], k = 0 [hod]).

Rule 1.:

Increase of Radiator temperature (T11) = ((Collector Temperature (T2) is Higher than temperature of reservoir heater 1 (T17) **AND** ((Heat pump 1 (L28) is ON) **OR** (Heat pump 2 (L28) is ON)) **AND** (Collector pump (L36) is ON) **AND** (Solar Exchanger Temperature (T3) is Higher than temperature of Glycol circuit exit (T4)) **AND** (External temperature (T1) is Standard)) **OR** ((External Temperature (T1) is Standard) **AND** ((Heat pump 1 (L27) is ON) **OR** (Heat pump 2 (L28) is ON)) **AND** (Radiator pump (L33) is ON)) **OR** ((Electrical boiler 1 (L30) is ON) **AND** (Electrical boiler 2 (L31) is ON) **AND** (External temperature (T1) is Very low) **AND** (Radiator pump (L33) is ON)).

The example of simulation process, in which the local model represented by Rule 1 is active, is illustrated on **Figure 5.** for the situation

S = ⟨ (T1=2 °C)**AND**(L27 is ON)**AND**(L33 is ON)⟩

The time of prediction is limited by 1 hour. The response of the model is immediate and human operator time for receiving an information is done by capability of graphic routine and by the time of interpretation (considering more complex graphs than in **Figure 5.**).

The whole Fuzzy Qualitative Model consists (in present time) of 9 rules (of the type Rule 1) which represent (by outputs) the following linguistic values:
- Low Increase of Radiator temperature (T11.LI),
- Middle Increase of Radiator temperature (T11.MI), - Low Decrease of Radiator temperature (T11.LD), - Middle Decrease of Radiator temperature (T11.MD), - Low Increase of floor heating temperature (T14.LI), - Middle Increase of floor heating temperature (T14.MI), - Low Decrease of floor heating temperature (T14.LD),- Middle Decrease of floor heating temperature (T14.MD), - Optimality of Electrical energy Consumption (OEC).
The inputs to these rules covers most of system variables (29 of them) considered in the description.

The design of Qualitative Model for local modelling has also other merits than simplicity and clear understandability. Good property of such Qualitative Model are also simple conditions of *computation stability.*
In case of Qualitative model for global modelling respecting Euler method of integration of linguistic values in rules, there was necessary to check time step Δt of Euler method. The condition of stability was derived in [5] as

$$|1 + \Delta t\, \lambda_M| \leq 1,$$

where λ_M was the maximising eigenvalue of matrix A of linear dynamic system

$$\boldsymbol{x}'(t) = \boldsymbol{A}\,\boldsymbol{x}(t) + \boldsymbol{B}\,\boldsymbol{u}(t),$$

which was formed as an approximation of a global model of the whole energy and heat supply complex. The conditions of computation stability, in case of local modelling, depended only on the shapes of membership functions of linguistic values.

The Qualitative model in the described present time form serves for tuning of the designed monitoring system and enables experiments of the type „What, IF“. The results of these experiments help in the synthesis of rules for interaction „human operator - monitoring system“. By this way have been formed, e.g., the rules for operator regulation of valves between points M24 and L39, L38 and similarly the operator rules for control of boilers (12).

The more exact version of Qualitative Model will be designed on the base of Artificial Neurone Networks (ANN) . The synthesis of ANN Qualitative Model will be done after first stage of the designed monitoring system operation. It means after a sufficient amount of experiments and with help of sufficient volume of measured data.
Similar works which have been done by our group with ANNs of the type MLP (for global modelling)

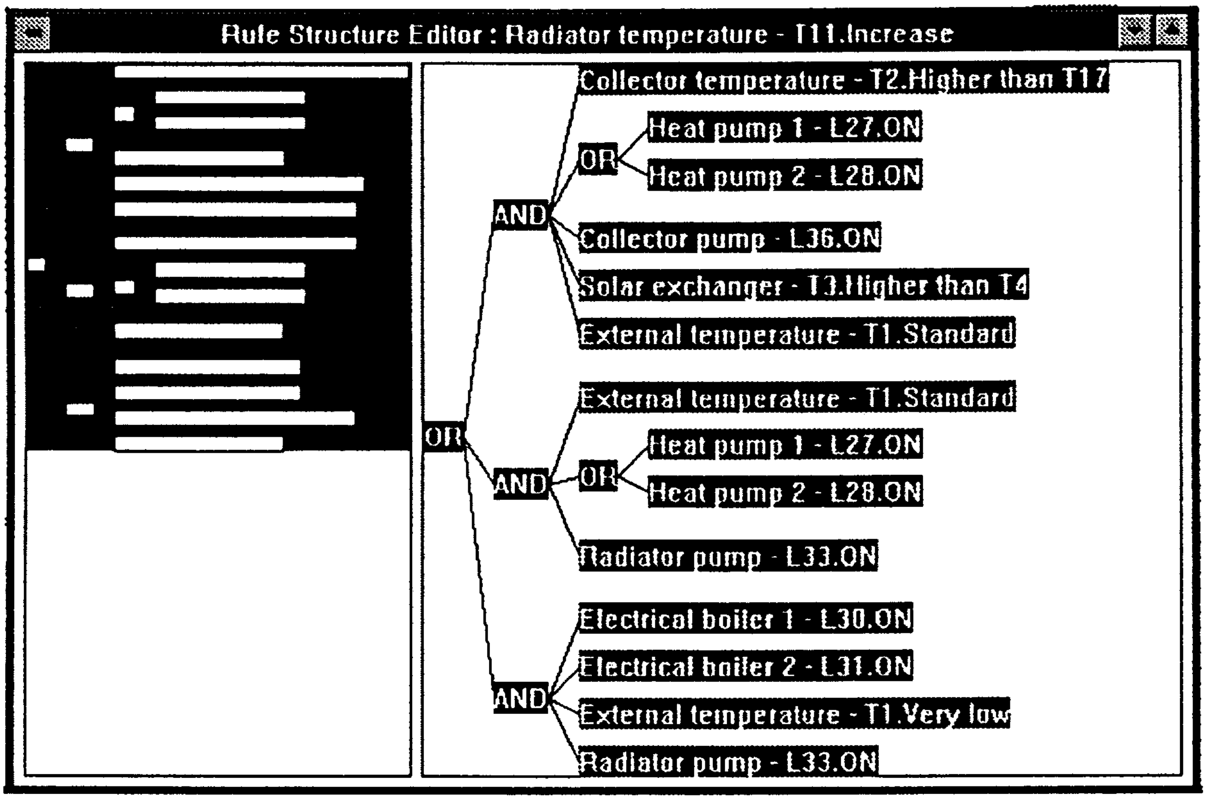

Figure 4. Rule structure for output variable „Increase of radiator temperature T11".

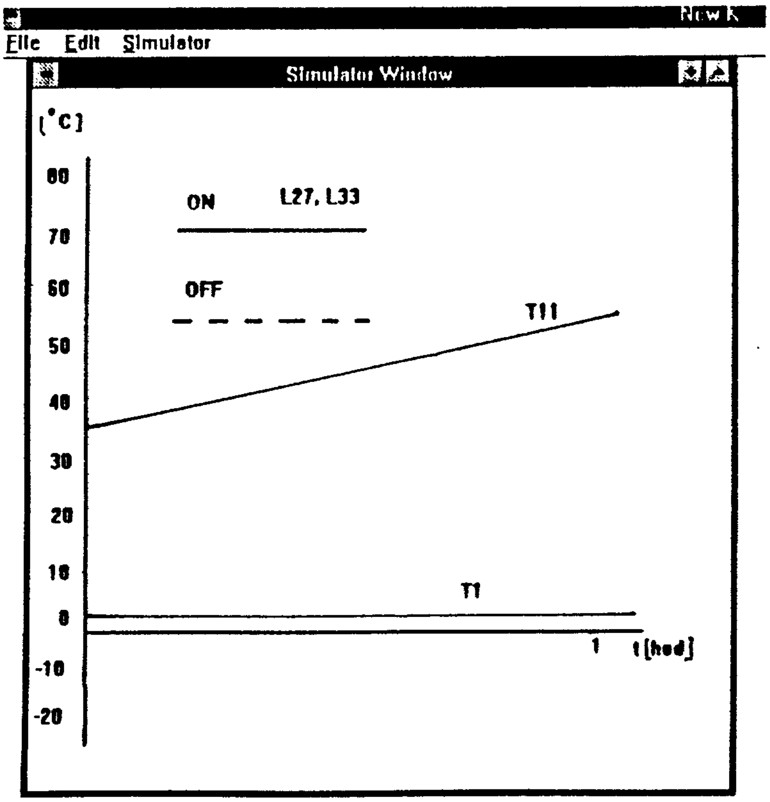

Figure 5. Response of the model for output variable „Increase of radiator temperature T11".

and with Radial Basis Networks (for local modelling) have confirmed the fact that the synthesis of ANN Qualitative Model is more difficult without the previous application of Expert Qualitative Model (described above).

CONCLUSIONS

The proposed paper dealt with the design and implementation of monitoring system for energy and heat supply system. In the paper were discussed three essential domains of problems :

- The Analysis and Design of the monitoring system by means of OMT approach.
- The synthesis of Fuzzy Qualitative Model of energy and heat supply complex and factors of Qualitative simulation process (e.g. , computation stability).
- The use of Qualitative models within the framework of the monitoring system.

The experiments with monitoring system were concentrated in recent time especially to function of communication modules providing data ***transmission*** from distanced energy and heat supply complex. Basic operation has been successfully verified. The results of experiments with Qualitative Model and with Qualitative Simulation programme has been used for human operator rules establishment in new situations induced by interaction with monitoring system. The main objective of Qualitative model application within the framework of monitoring system is at present time decrease of electrical energy consumption by more rational utilisation of solar energy and river water energy.
(No negligible role will have the monitoring system in near future in engineering education for students of 5th term (Faculty of Mechanical Engineering, CTU Prague).)

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