Intelligent control

By
Mr Torben Skov Nielsen, M. Eng.,
Assistant Professor

Mr Henrik Aalborg Nielsen, Ph. D.,
Assistant Professor

and
Mr Henrik Madsen, Ph. D.,
Professor

In this article, a new method for controlling the temperature in district heating systems will be outlined. The method is based on a recently developed control engineering principle called eXtented Generalized Predictive Control (XGPC) (see references).

The intelligent controls are now part of a computer system, called PRESS, standing for an intelligent supervision, control and optimisation of district heating systems. This system will be described in brief, and some recent results of using the system and the new controls will be outlined. So far, the obtained savings are between 3-7% for traditional district heating systems. For a system based on combined heat and power, the observed savings are higher, due to the reduced temperature levels.

Background
In the late 1980s, a group of power plant and district heating engineers in Esbjerg, in the western part of Denmark, decided to use the data already available in most district heating systems in order to make forecasts on the needed supply of heat and minimise the network temperature in general to plan and optimise the production. This initiated the development of various methods and models, followed by an implementation of the most promising principles in the PRESS computer system.

Introduction
The supply temperature is traditionally determined as a function of an actual outdoor temperature, and the wind speed is occasionally taken into consideration as well. It is obvious, however, that this will lead to a control far from optimal due to the fact that a lot of parameters are not taken into account; the behaviour of the consumers, the solar radiation, the accumulated heat in the distribution network and the temperature level in the entire distribution system. Furthermore, the direct use of the outdoor temperature in traditional controls does not properly take into account the fact that only the low frequency part of the variations of the air temperature should be considered.

The time delay from the plant to the consumer might be several hours. In the Esbjerg district heating system, the time delay is up to 12 hours. This means that to control the supply temperature, it is necessary to know the future outdoor temperature in order to determine the minimum supply temperature required.

The models and the controls built into the system take all of the above-mentioned factors into account. The main principles and methods will be described in the following.

The system
The system collects the following input data:

- plant data (supply temperature, flow, etc.)
- network data (e.g. network temperature at a number of places)
- local meteorological data (wind speed, temperature, and solar radiation)
- meteorological forecasts (of an air temperature).

In the system it is possible to plot in all data.

The control module utilises information from some of the other modules in the computer, and hence a short description of the modules is presented below. A simplified sketch of the system is shown in figure 1.

Data collection and validation module
In this module, all the input data are collected, and methods for automatic error detection and correction are built in.

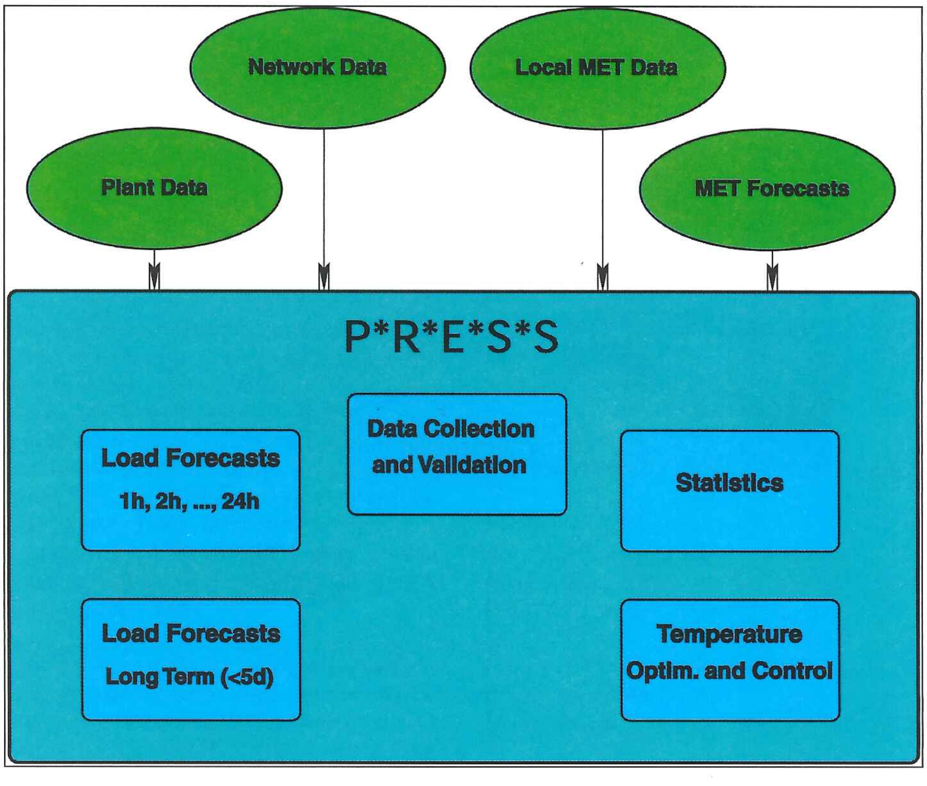

Figure 1: The PRESS-system.

Statistical module
A number of useful statistics for the district heating system are calculated. It is outside the scope of this article to mention them all, but as an example the energy signature for the total network is calculated. The energy signature describes how the heat consumption depends on the day of the week, the time of the day and the outdoor temperature. Furthermore, the influence of the wind speed and the solar radiation might be calculated.

Short-term forecast module
In this part of the system the heat load is predicted for the next 24 hours. It takes into account the accumulated heat in the system, the behaviour of the consumers, the time of day and night, the day of the week, the time of the year and the climate variables. This module also predicts the local outdoor temperature for the next 24 hours.

Long-term forecast module
This module uses available meteorological forecasts to make predictions of the heat load up to five days in advance (depending on the horizon of the meteorological forecasts).

Temperature control/optimisation module
This module contains the temperature control, which will be described in the following. Besides calculating the optimal temperature, this module also estimates the actual time delay and heat loss of a number of control points in the distribution network. It also determines critical parts of the distribution network, i.e. parts, which tend to prescribe the highest supply temperature.

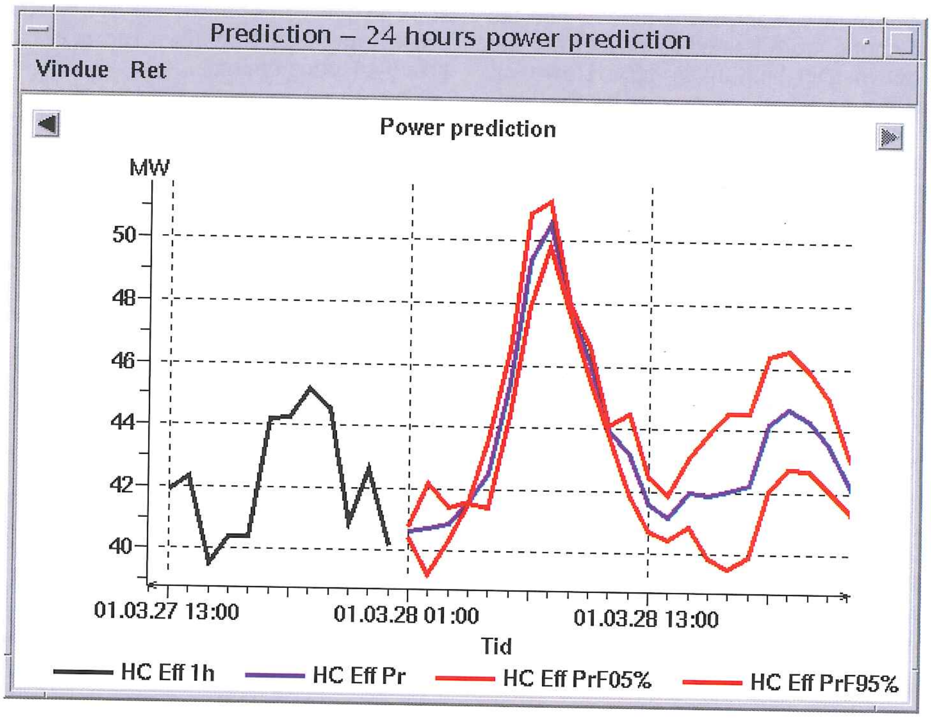

Figure 2: A plot of the 24-hour forecast of the heat load for a Danish district heating system.

Furthermore, some tools for optimisation of the use of accumulation tanks and for multiple and different production units are being developed.

All the modules are adaptive and self-calibrating. This means that a default system can be installed and after approx. two months, the models and the methods are adjusted to reflect the actual district heating system. However, a few parameters concerning the temperature control module need to be set by an expert. The built-in ability to adapt also means that changes in the district heating system are automatically reflected in the models and calculations.

A plot of the 24-hour forecast of the heat load for a Danish district heating system is shown in figure 2.

Control of the supply temperature
An efficient control of the supply temperature is an impossible or at least a very difficult task for traditional controls. This is due to the fact that a district heating system is both non-linear and non-stationary. For example, the time delay from the plant to the consumer varies with the flow pattern of the network.

The breakthrough in the control of district heating systems came with the development of the eXtended Generalized Predictive Controls (XGPCs) described in the references at the end of this article. These controls handle both non-linear and non-stationary systems with unknown and varying time delays.

The control of the supply temperature essentially consists of several controls: a so-called flow control and several temperature controls.

The flow control uses the predicted heat load and knowledge of the maximal flow in the network to determine the lowest temperature profile, ensuring that enough energy is delivered to the distribution network.

The temperature controls ensure that the distribution network is supplied with a high enough temperature at all the consumers. In practice, only a certain number of so-called critical net points are considered. The critical net points are selected so that they represent a group of consumers.

First, we will consider a single net point. The needed supply temperature at the consumer is a function of the outdoor temperature. Due to the time delay from the plant to the consumer, the predictions of the outdoor temperature from the short-term forecast module (i.e. module no. 3) are needed. This leads to the minimum allowable supply temperature profile at the consumer, which is used as a reference signal for the XGPC control.

A model is used to predict the supply temperature at the consumer as a function of the control variable, i.e. the supply temperature at the plant. The XGPC control is then used to determine the actual optimal/minimum supply temperature by following the reference signal closely. However, the supply temperature at the plant should not be changed abruptly. The XGPC control solves this by considering several horizons simultaneously, and by imposing a penalty on large changes in the supply temperature at the plant.

When predicting the future outdoor temperature and the supply temperature at the net point, the uncertainties are taken into account. The actual supply temperature is finally determined so that all the critical net points obtain a sufficiently high temperature. The temperature controls in the computer allow the possibility of controlling the temperature profile in the network in a similar way as the plants traditionally control the pressure profile.

Obtained savings
The new controls have recently been installed at Roskilde District Heating Company in the eastern part of Denmark. The installation was completed in December 2000. The savings depend on the time of the year. So far, the observed savings range from at least 3% in March to 7% in January.

For a combined heat and power plant the savings are higher due to the fact that a lower temperature causes a more optimal production of power. At Vestkraft in Esbjerg, a combined power and heat production plant, an average annual saving of 9% was observed. However, this saving was observed while using some not fully developed XGPC controls.

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For further information please contact:

Technical University of Denmark
IMM
Att.: Mr Henrik Madsen
Bygning 321
DK-2800 Lyngby

Phone +45 45 25 34 08
hm@imm.dtu.dk.