Energy 87 (2015) 343–351

Contents lists available at ScienceDirect

Energy

journal homepage: www.elsevier.com/locate/energy

Forecasting of consumers heat load in district heating systems using the support vector machine with a discrete wavelet transform algorithm

Milan Protić [a], Shahaboddin Shamshirband [c, **], Dalibor Petković [b, *], Almas Abbasi [d], Miss Laiha Mat Kiah [c], Jawed Akhtar Unar [e], Ljiljana Živković [a], Miomir Raos [a]

[a] University of Niš, Faculty of Occupational Safety, Čarnojevića 10A, 18000 Niš, Serbia
[b] University of Niš, Faculty of Mechanical Engineering, Department for Mechatronics and Control, Aleksandra Medvedeva 14, 18000 Niš, Serbia
[c] Department of Computer System and Technology, Faculty of Computer Science and Information Technology, University of Malaya, Kuala Lumpur, Malaysia
[d] Department of Artificial Intelligence, Faculty of Computer Science and Information Technology, University of Malaya, Kuala Lumpur, Malaysia
[e] Department of Information Technology, Quaid-e-Awam University of Engineering, Science & Technology, Nawabshah, Sindh, Pakistan

ARTICLE INFO

Article history:
Received 6 January 2015
Received in revised form
6 April 2015
Accepted 29 April 2015
Available online 29 May 2015

Keywords:
District heating systems
Heat load
Estimation
Prediction
Support vector machine
Wavelet transform

ABSTRACT

District heating systems are important utility systems. If these systems are properly managed, they can ensure economic and environmentally friendly provision of heat to connected customers. Potentials for further improvement of district heating systems' operation lie in the improvement of current control strategies. One of the options is the introduction of model predictive control. Multi-step ahead predictive models of consumers' heat load are a starting point for creating a successful model predictive strategy. For the purpose of this article, short-term multi-step ahead predictive models of heat load of consumers connected to a district heating system were created. The models were developed using the novel method based on SVM (Support Vector Machines) coupled with a discrete wavelet transform. Nine different SVM-WAVELET predictive models for a time horizon from 1 to 24 h ahead were developed. Estimation and prediction results of the SVM-WAVELET models were compared with GP (genetic programming) and ANN (artificial neural network) models. The experimental results show that an improvement in predictive accuracy and capability of generalization can be achieved by the SVM-WAVELET approach in comparison with GP and ANN.

1. Introduction

District heating is a utility energy service based on the provision of heat to remote customers (connected to the system via heating substations) from available heat sources [1]. It enables utilization of waste or low-cost heat, which is the main precondition for DHS (district heating system) competitiveness, when compared to onsite, individual, boilers. Another precondition is high heat density. Although some previous studies showed that sparse DHS (systems with low heat density) can be economic [2–4], their success correlates highly with energy taxation which is country specific, even in the EU. However, according to [5,6], 73% of EU 27 residents (502 million) lived in urban areas, which indicates high heat density and excellent prospects for further growth of DHSs in Europe. In Ref. [7] the potential for district heating in the EU from now to 2050 was identified, based on extensive and detailed mapping of the EU heat demand and various supply options. The results in Ref. [7] indicated that with district heating, the EU energy system will be able to achieve the same reductions in primary energy supply and carbon dioxide emissions as the existing proposed alternatives. Even in China coal boilers are still prevalent [8]. Analysis in Ref. [9] showed that a substantial reduction in fuel demands and CO_2 emissions, as well as cost can be achieved by converting the heat from individual boilers based on oil, natural gas, or biomass to district heating. Such a conclusion seems to be valid in the present energy systems as well as in a future scenario aimed towards a 100 per cent renewable energy supply in 2050, even if the space heating demand is reduced to as much as 25 per

* Corresponding author. Tel.: +381 643283048.
** Corresponding author. Tel.: +60 146266763.
E-mail addresses: shamshirband@um.edu.my (S. Shamshirband), dalibortc@gmail.com (D. Petković).

http://dx.doi.org/10.1016/j.energy.2015.04.109

cent of the present demand. District heating plants are able to resolve the conflict of must-run generation of base load power plants for control power provision; therefore, they can enhance the integration of fluctuating renewable energy sources [10].

The basic assumption in Ref. [11] was that DHS has an important role to play in future sustainable energy systems, including 100 percent renewable energy systems, but the present generation of DHS technologies will have to be developed further into a new generation in order to play such a role. One possible way for further increase of DHS competitiveness lies in the improvement of the currently used control strategy. The study in Ref. [11] suggested that intelligent control systems could be used to improve the efficiency of the DHS. Research [12] presented a scientific tool for the optimization of design and operation for complex polygeneration plants serving a number of buildings with heat, cooling, and electricity. The prevailing control strategy is based on weather compensation control, where the primary supply temperature (temperature of water from the heat source) is determined from the so-called "sliding diagram" [13]. This diagram provides the functional dependence between the momentary outdoor temperature and primary supply temperature of water pumped in DH network. Correlation between these two variables is almost linear, with two or three knee points, and often corrected by operators after years of usage.

However, district heating systems are complex and dynamic systems with high inertia and marked heterogeneity of users, and this precondition of static correlation between the outdoor temperature and heat pumped in the network does not hold. As a consequence, primary return temperature is frequently higher than needed, which is especially evident during the periods of moderately cold weather. Therefore, in order to reach the higher efficiency in DHS operation, the control strategy should be directed towards lowering of the primary return temperatures. Lowering of the primary return temperature in DHS has the following effects on the overall operation: increased electrical output from CHP-plants (usually used as heat sources), increased heat recovery from industrial excess heat and geothermal heat, lowered distribution losses and increased coefficient of performance if heat pumps are used in heat generation [14]. Economic benefit of reduced primary return temperature was estimated at 0.05 to 0.5 €/MWh for 1 °C of reduced temperature [15].

In order to get the lowered primary return temperatures, the produced and delivered heat from the heat supply units must closely correspond to the heat demanded by consumers, increased for appropriate distribution losses. Taking into account that changes in supply temperature in the heat source will be "sensible" at the peripheral parts of the network after considerable time has passed, due to transport delay (water temperature changes "travel" at the speed of water in the network) in the distribution network, the required heat to be pumped in the network should be known in advance (several hours ahead), in order to avoid excessive heat input in the network with a very important precondition that consumers get the required heat. Therefore, predictive heat load models of all, or at least the most influential, consumers in the system are indispensable as inputs for advanced model predictive control. Predictive models should provide several-hours-ahead forecasts of required heat, where the prediction horizon can be defined according to the endmost consumer in the network.

In this article, we introduce the heat load prediction models of consumers for a different prediction horizon using the data acquired from one heating substation in DHS Novi Sad, Serbia. The proposed models are developed using a soft computing approach, namely SVM (Support Vector Machine) with a discrete wavelet transform algorithm, which are presented and compared.

SVMs (Support vector machines) are a type of soft computing technique that has gained importance in different engineering disciplines [16,17]. The prediction accuracy of an SVM model heavily relies on proper determination of model parameters. Although organized strategies for selecting parameters are important, model parameter alignment also needs to be made. In the past, different researchers applied various conventional optimization algorithms for selecting these parameters, but with limited success [18–20,67]. These include the grid search algorithm [21] and the gradient decent algorithm [22,23,68]. Computational complexity seemed to be the major drawback of the grid search algorithm, which restricted its applicability to simple cases. Gradient search algorithm, on the other hand, is usually prone to local minima. In most optimization problems, multiple local solutions do exist, but evolutionary algorithms seem to be the best approach, because they are capable of providing a global solution to such optimization problems.

In this study, a short-term predictive model of consumers heat load was developed using SVMs with the discrete wavelet transform algorithm (SVM-WAVELET). Wavelet analysis was used to decompose the time series of data into its various components, after which the decomposed components can be used as inputs for the SVM model. The results indicate that the proposed model can adequately predict the heat load for different prediction horizons. SVM-WAVELET results were also compared with GP (genetic programing) and ANN (artificial neural network) results.

The organization of the remaining part of this paper is as follows: Section 2 explains the heat load data and prediction models of consumers for different prediction horizons. Section 3 presents the description of the SVM-WAVELET method and GP and ANN used as benchmark methods. The comparative results and discussion are presented in Section 4. Finally, the conclusions are presented in Section 4.

2. Materials and methods

2.1. System and data description

Collection of data used for subsequent analysis and building of the prediction models was conducted in the district heating system in Novi Sad, Serbia. The district heating system of Novi Sad is the second biggest DHS in Serbia with five heat supply units (Table 1) and one main manifold used for transferring the heat from the CHP unit "Novi Sad" towards the three supply units within the city and back (Fig. 1).

Base load for consumers connected to heat supply units "East", "North", and "South" is covered from the CHP unit "Novi Sad" via the central manifold (separator), and additional heat is provided from the heat supply units themselves (peak load).

Consumers are connected to the district heating network (214.2 km) via heating substations. There are 3795 heating substations in the district heating system. Distribution network is implemented as a three-pipe system. One pipe is used for distribution of heat for space heating, the second is used for distribution

Table 1
Heat supply units in District heating system "Novi Sad".

Name of heat supply unit	Installed power of heat supply [MW]	Fuel type
"West"	256	Natural gas
"East"	104	Natural gas
"North"	46	Natural gas
"South"	185	Natural gas
"Petrovaradin"	11,6	Natural gas