SUSTEM 2015
~International Conference~
7 & 8 July 2015 · Newcastle upon Tyne, UK

Sustainable Thermal Energy Management International Conference (SusTEM2015), July 7th – 8th, Newcastle, United Kingdom

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School of Science & Engineering

Load Forecasting and Efficient Dispatch Optimization for Decentralized Cogeneration Plant

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Introduction

Traditionally, most forms of energy have been generated by large centralized fossil-fueled generators and transported to consumers via one-way transmission and distribution networks. Environmental concerns combined with the liberalization of the energy markets have forced a rethink in the way that energy is generated and distributed, leading to the emergence of small to medium-scale decentralized generation equipment. Here, we focus on short-term forecasting of both heat and electrical loads and efficient unit commitment / economic dispatch optimization for a small/medium scale decentralized CHP plant. The plant is assumed to be equipped with local heat and electricity storage and operating in the presence fluctuating wholesale energy prices and local loads.

Optimization Platform

The economic dispatch problem we consider is, given a series of future hourly electrical and heat loads along with prices for buying/selling electricity and heat wholesale, determine an optimal plan for the hourly settings for CHP production, energy storage/retrieval and wholesale energy buying/selling that minimizes the expected economic costs and respects natural system constraints. The architecture below has been developed to support this:

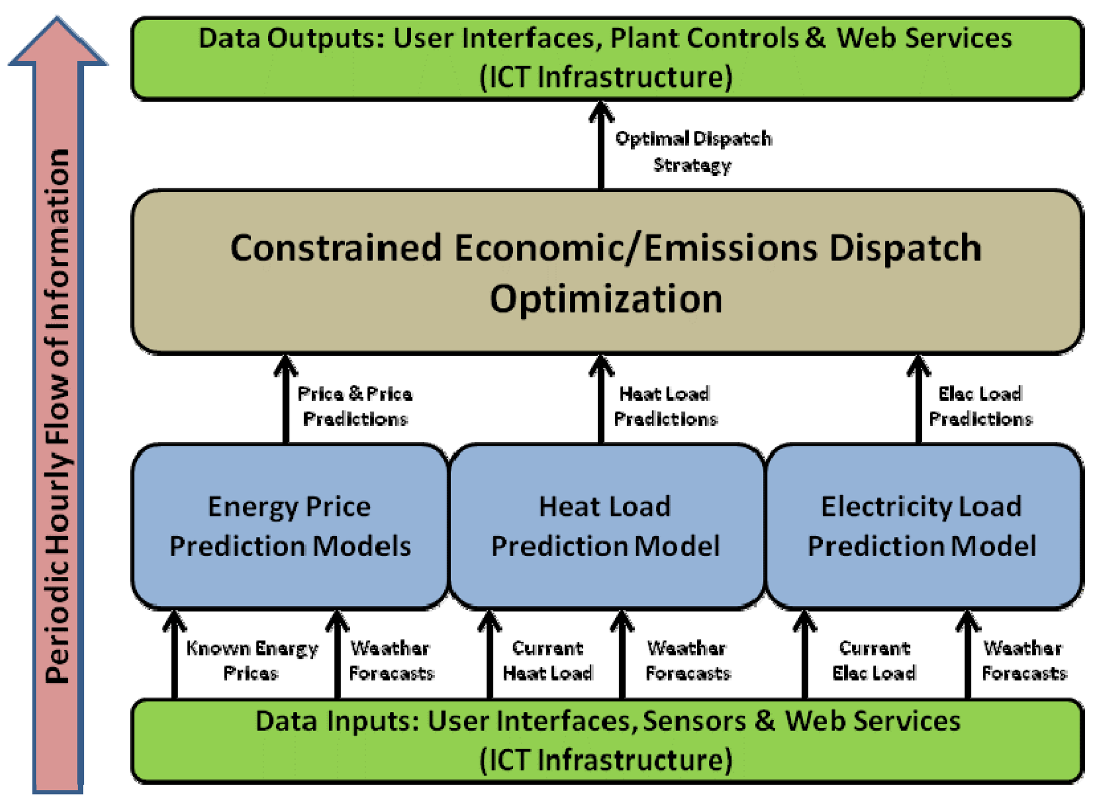

Figure: ICT Architecture for Prediction and optimization

Load Forecasting

The future heat and electricity loads are not known accurately in the economic dispatch optimization problem. For short-term heat and electricity prediction, simple but well-calibrated model structures are often as good as complicated models. In our work, the model structure is kept very simple and recursive parameter estimation is employed for parameter identification to ensure good calibration is kept. Let the variable $D(t)$ represent the demand for electricity or heat (in kWh) on the CHP plant for the hour ending at time t, and the variable $T(t)$ represent the average ambient temperature for the hour ending at time t. The model structure below was utilized:

$$A(z)D(t) = B(z)T(t) + \frac{e(t)}{\Delta}$$

In which $e(t)$ is a zero-mean white sequence, z^{-1} is the delay operator, $\Delta = z^{-1}$, and $A(z)$ / $B(z)$ are polynomials in z.

It was found that the load at the current hour was mostly correlated to the load one hour before, one day before and one week before, and is also (possibly inversely) correlated with the ambient temperature at the current hour and one hour before. This gives the structure of the A and B polynomials in predictive k-step ahead form:

$$\hat{D}(t+k\,|\,t) = \hat{D}(t+k-1) + a_1\Delta\hat{D}(t+k-1) + a_2\Delta D(t+k-24) + a_3\Delta D(t+k-168) + b_1\Delta\hat{T}(t+k\,|\,t) + b_2\Delta\hat{T}(t+k-1\,|\,t)$$

Exponentially Weighted Recursive Least Squares (EW-RLS) is employed for model parameter estimation. Further details of the adaptive predictor are given in the accompanying paper.

Compact Mixed Integer Linear CHP Model

We consider a CHP plant with a heat/power ratio β that is variable over a prescribed operating range. The relationship between boiler load L (%) and efficiency $\eta(L)$ (%) is well modelled by a quadratic of the form $\eta(L) = A + B\,L + C\,L^2$ in such a plant. A typical efficiency curve for a medium-scale CHP plant is shown below. This produces a sigmoidal relationship between the required input fuelling rate F and the load L, shown as a % age of the maximum available. For a modern CHP plant with coordinated control system, operation at low output power levels is achievable with a steam bypass valve; we approximate the fuelling costs with three affine functions, giving an error < 1.2 % over the working range of a typical boiler.

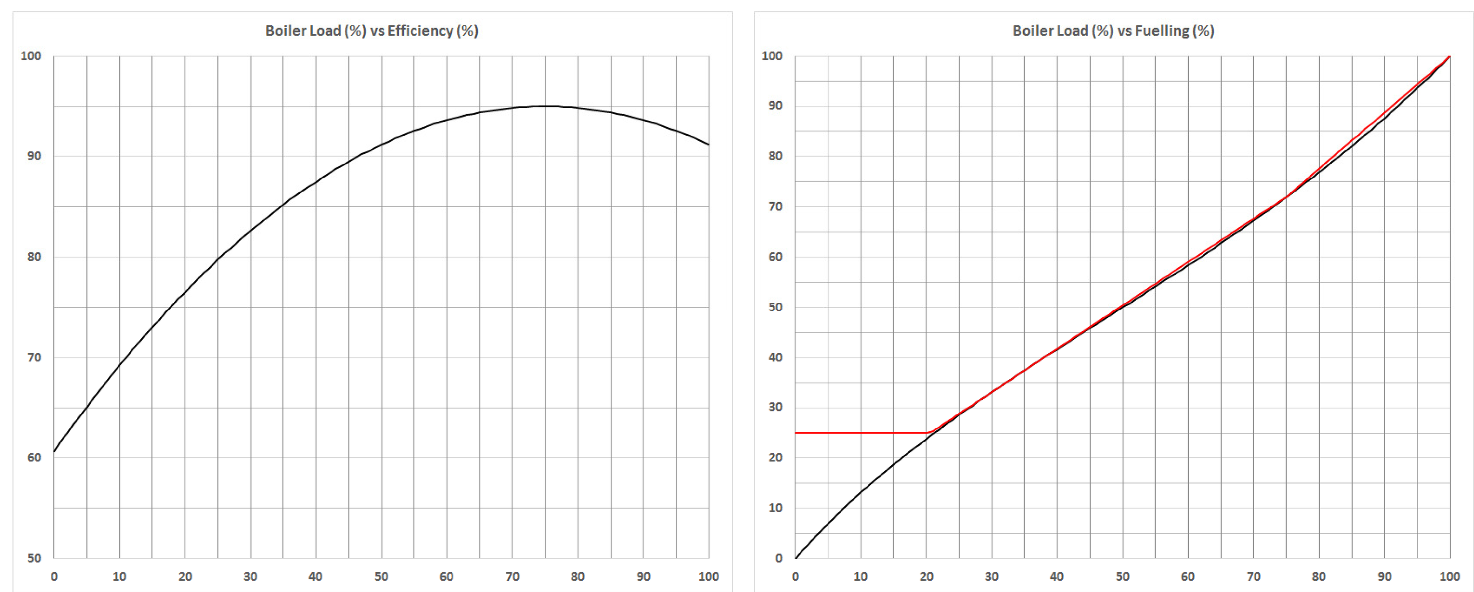

Figure: (Left): Boiler efficiency vs load, (Right): fueling as a function of load in black, piecewise approximation in red

The ‘unit commitment’ problem is integrated with the economic dispatch problem through binary indicator variables. Further details of the model are described in the accompanying paper.

Initial Findings

For testing and validation purposes, anonymized sets of hourly heat and electricity load data have been obtained along with hourly temperature measurements for the area. The average MAPE over the entire horizon was 7.855 % for heat predictions and 3.380 % for electricity predictions. Our initial tests of the model indicate that it is both efficient and accurate; further information can be found in the short papers. Our future work will concentrate upon more extensive numerical evaluations.

Acknowledgement

This research described in this paper was carried out in the context of the IDEAS Collaborative Project (Grant Agreement No. 600071) which is co-funded by the European Commission, Information Society and Media Directorate General, under the Seventh Framework Programme (FP7), Cooperation theme three, “Information and Communication Technologies”.