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ROBUST PLANNING FOR COMBINED HEAT AND POWER PRODUCTION

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Abstract: Combined Heat and Power Plants which produce simultaneously electricity and heat are known for their energetic efficiency. Associated to heat storage, they may also be a solution to adapt the electricity production to the demand. Flexibility of the generation and consumption will be indeed a driver for the development of the Renewable, and electricity prices are already used as an incentive by DSO to modulate the electricity demand. As the electricity prices vary substantially depending on the weather conditions, a real-time optimization is desirable to generate an optimal planning of the Combined Heat and Power Plant load. Moreover the heat demand cannot be exactly forecast and the planning must remain valid against this uncertainty. In this paper we present a solution based on convex optimization to produce robust planning for CHP.

Keywords: Combined Heat and Power, Heat Storage, MILP, Convex Optimization. Robust Planning.

1. INTRODUCTION

EDF is an integrated company managing an important fleet of centralized generation units (nuclear, fossil and hydro) which is also involved in the distribution side of the energy system as well as in the development distributed generation. Distributed generation may be one cornerstone of the future Smart Grids which will integrate energy demand efficiency and renewable energy (wind and solar).

To facilitate the development of the intermittent renewable generation, flexibility will be required both from the generation units but also from the consumers. Energy storage will play a central role in this future. While electricity storage is still a costly way of balancing the electricity production and consumption, heat storage is less expensive and naturally adapted for neighborhood heating needs. Associated with the fact that they are energetically more efficient, solutions to better use Combined Heat and Power (CHP) plants through optimization are worth being studied.

Dynamic Programming (DP) has been developed and tested in the case of a micro CHP (Faille, 2006) for home generation of electricity, heat and hot water. Dynamic Programming is a very generic method which can handle nonlinearity, but unfortunately suffers from the curse of dimensionality leading to long computation times, even for rather simple problems. With some added assumptions, the micro CHP problem can be reformulated as a Mixed-Integer Linear Program (MILP), which can be solved very efficiently using commercial software such as XPRESS-MP or CPLEX (Faille, 2007). EDF has thus developed the tool PILOT to optimize the planning for different kinds of energetic processes. This tool contains a modeler that builds a MILP problem for different optimization solvers CPLEX, XPRESS-MP from a graphical description of the plant and offers visualization functions. PILOT has been used for instance to optimize the heat and electricity production of a fleet of micro CHPs at a district level (Mondon, 2005).

Although a great number of problems can be formulated within the MILP framework using for instance linear interpolation methods, nonlinear optimization may be useful to integrate for instance nonlinear physical model based on the Modelica language as described in (Deneux, 2014). Such a Modelica model is used to develop a planning for a CHP in (Fouquet, 2014). In this case, advanced optimization is done using the software J-Modelica and the IPOPT solver to handle hybrid continuous and discrete nonlinear equations.

The CHP optimization depends on the price of electricity and the heat demand. In general the electricity prices result from an auction on the market and are known in advanced. The heat demand can be forecast with the help of statistical models (Bissuel, 2013), but the forecast accuracy is limited. The integration of this prediction uncertainty in the optimization framework makes the problem harder to solve, as the problem then belongs to the class of stochastic optimization problems. MILPs or DPs can be extended to multi-scenario situations, but it greatly increases the complexity of the problem to be solved. Certain stochastic optimization problems can be however reformulated in a computationally efficient framework called robust optimization (Ben-Tal et al., 2009) which is well suited to multi-period planning problems, via a technique known as affine recourse.

The present paper addresses the problem of CHP planning in the presence of uncertainty. Section 3 describes the CHP application and the different models. Section 4 describes the

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optimization problem and its solution using the PILOT software and MILP algorithm. Section 5 proposes new solutions based on Convex Optimization to enhance the robustness of the planning. The results are presented in Section 6. The conclusion gives the perspectives and future developments.

2. NOTATIONS

This section gives the notations which will be used in the equations given in Section 4. The problem is discretized in time with a sampling time of one hour for instance.

Variable		
CM	Maintenance Cost	€/h
W	Energy during a sample	kWh
P	Price	€/kWh
On	State (1= On, 0 =Off)	Boolean

Upper and lower script			
fuel	fuel	max	maximal
el	electricity	t	sample
heat	heat	Net	network
Eng	Engine	Stock	storage
Bi	Boiler n°i	wasted	spilled

3. CHP PROCESS AND CONTROL DESCRIPTION

3.1. CHP description

The CHP plant shown Figure 1 delivers hot water to a district heating network. It consists of an engine, two boilers, and two heat storage tanks in series. The engine produces 1.4 MWe at full load and heat is recovered by two exchangers: the first on the engine cooling system, the second on the exhaust gas. 2 MWth can be recovered at full load. The thermal and electric efficiencies depend on the engine load. When the heat demand is high or electricity price low, the boilers may be used. Each of them produces 1.2 MWth at full load.

The heat produced by the engine can be sent directly to the network or stored in two tanks each of 250 m3 capacity. The storage capacity is supposed to be limited to 5000 kWh. The extra heat can be released to the atmosphere in case of overproduction. This situation must be avoided.

3.2. Control Philosophy

The main objective of the control is to fulfill the heat demand. The second objective is to minimize the operating cost using the engine. The engine produces heat but also electricity which is sold to the grid. When the price of electricity is high it is worth using the engine even if the heat demand is low and storing the heat excess in the tanks. The stored heat can be released when the electricity price is lower. The optimization must take into account the limited capacity of the tanks and starts the engine at the right period.

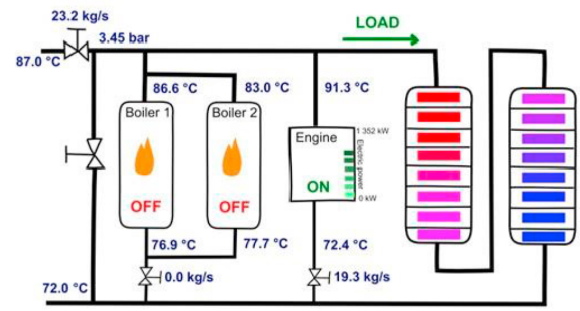

Fig. 1: Schematic diagram of a CHP

The control structure consists of three main components as shown in Figure 2. The Heat Forecast module computes the heat demand for the next 24 hours and includes the weather forecast and past process measurement. The Load optimization module, which is our focus in the present paper, computes a planning for the Engine Load and the Boiler Flow according to the heat demand forecast and the electricity price. Once validated by the Operator, the planning is applied for the next period until a new planning is computed. To compensate the mismatch between the planned and the actual power output, Engine and Boiler Control must adjust the planning. This can be done using advanced control solution like MPC as it is proposed in (Fouquet, 2015).

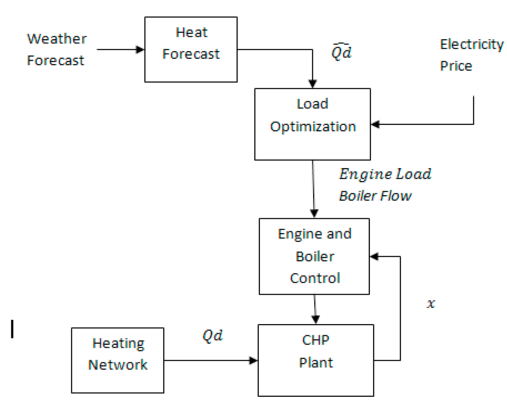

Fig. 2: Load Optimization

3.3. CHP Model

A physical based model of the power plant has been developed with Modelica and the library ThermoSysPro (Deneux, 2014). The model is integrated in a simulation platform (see Figure 3) that will be used for the testing and the validation of the control algorithms before on-site implementation. The model has 31 states and 726 algebraic variables. The main nonlinearities are due to the thermo hydraulic behavior, the stratification in the storage and efficiency curves of the engine.

A HMI has been developed to use the model: define the demand scenario, select the planning, and visualize the data. The communication between the model and the optimizer is done by means of ASCII file. The operator has three inputs at his disposal: the electric load of the engine and the two water flows through the boilers. Fuel, water and air flows to the