Energy Management System for a Co-generating Units

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Abstract. A Combined Heat and Power (CHP) node is a generating power unit where electrical and thermal power are co-generated. The presence of loads requiring at the same time electric and thermal power, allows to use for heating purposes at least part of the heat dissipated in the thermodynamic cycle.
The optimal management of a CHP node must cope with several time evolving data, for instance electric and thermal loads, costs for purchasing and/or selling power to the external electrical network etc. In this paper a linear mathematical model of a CHP node is described and used to define the optimal scheduling of the generating unit.

Key words: Cogeneration, micro-grid, Mixed Integer Linear Programming.

I. INTRODUCTION

A Combined Heat and Power (CHP) node is a generating power unit where electrical and thermal power are generated together. The presence of loads requiring at the same time electric and thermal power allows to use for heating purposes at least part of the heat dissipated in the thermodynamic cycle. In this way the integrated power source has an energy efficiency higher than that of two separated units: one for electric and one for thermal power.
Obviously, the operational planning of the integrated unit must fulfil in time both electric and thermal requirements of the loads which often have different scheduling and can, when it is economically convenient, buy or sell electrical power to the external power network. Examples of this application can be presently found in district heating and in industrial processes, but there are indications that this scheme could be extended to micro-generating units trying thus to increase the efficiency of the energy management system.
The management of this energy production unit is not an easy task when energy prices are time varying on a daily or weekly basis, thus requiring an optimal management of production scheduling.

II. MATHEMATICAL MODEL

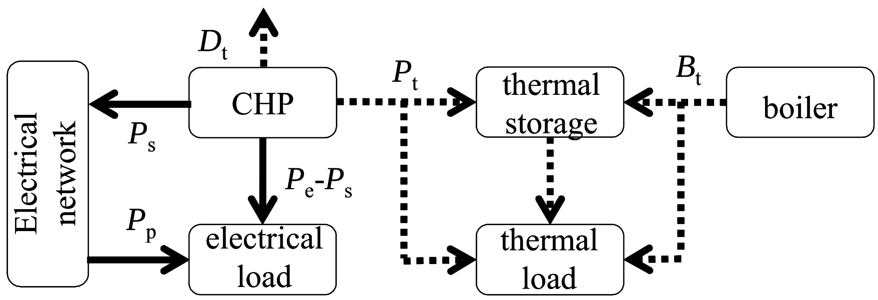

Fig. 1 –Structure of a CHP. Straight lines: electrical power fluxes, dotted lines: thermal power fluxes.

The schematic model of the cogenerating unit is represented in Fig. 1. The electrical load (U_e) can be supplied either by the CHP (P_e) and by the public electrical network (P_p); the power produced by the CHP can be also be sold to the network (P_s). The thermal load (U_t) can be supplied either by the CHP (P_t) and by the boiler (B_t). There can be also the possibility of storing thermal energy in storage tanks (S_t).
Thermal and electrical power of a CHP are linked by a linear relation

$$P_t = k_0 + k_1 P_e \tag{1}$$

The aim of the optimization algorithm is to define ON/OFF status and power production scheduling of a micro co-generating unit to minimize the linear cost function

$$O = \sum_{i=1}^{N_{ist}} \left[c_{\mathrm{e}}(i) P_{\mathrm{e}}(i) + c_{\mathrm{p}}(i) P_{\mathrm{p}}(i) - c_{\mathrm{s}}(i) P_{\mathrm{s}}(i) + c_{\mathrm{t}}(i) B_{\mathrm{t}}(i) \right] \Delta t \tag{2}$$

where O is the total cost expressed in euros, index i refers to a time interval, N_{ist} is the number of time instants, Δt is the amplitude of the time intervals which is considered equal for all of them (for instance a quarter of an hour), c_e is the cost coefficients of produced electric power, c_p and c_s are prices of purchased and sold energy.
The optimization is subject to the fulfilment of the electrical loads, expressed as:

$$P_e(i) + P_p(i) - P_s(i) - P_{tr}(i) = U_e(i) \tag{3}$$

For what concerns the satisfaction of the thermal loads, the balance equation would couple different instants in presence of stored thermal energy S_t:

$$U_t(i) = P_t(i) + B_t(i) - \frac{S_t(i) - S_t(i-1)}{\Delta t} - D_t(i) \tag{4}$$

Some binary variables must be included in the problem formulation in order to take into account the on/off status of CHP and boiler

$$\delta_e(i) P_e^{\min} \le P_e(i) \le \delta_e(i) P_e^{\max} \tag{5}$$

$$\delta_t(i) B_t^{\min} \le B_t(i) \le \delta_t(i) B_t^{\max} \tag{6}$$

where $\delta_e(i)$ and $\delta_t(i)$ are the binary on/off status at instant i of the CHP and boiler, respectively. The problem is still linear but with mixed integer variables. The problem is also subject to other technical constraints, related to the Minimum On Time (MOT) and Minimum Shutdown Time (MST).

III. OPTIMIZATION STRATEGIES

The problem defined by (1)-(6) and by additional MOT/MST constraints is linear with mixed integer set of unknowns [1]. Time intervals are not independent but correlated by (4) and MOT/MST constraints [2], thus the optimization must be performed for a given period of time (e.g. a day) rather than for a single instant. The class of mixed integer linear problems is solved by iterative methods (branch and bound coupled with interior points algorithm) and are characterized by the possibility of computing an upper and lower bound of solution at each iteration.

Different operational analysis can be performed:

- power balance and economical evaluation with fixed on/off status and power levels
- optimization of on/off status and fixed production levels
- optimization of production levels with fixed (a priori) on/off status of devices
- complete optimization: on/off instants and power production levels of each unit

The algorithm capabilities can be easily extended to manage a micro-grid of co-generating units by introducing the power transfer $P_{tr}^{kj}(i)$ between the k and j sites of the grid. The objective function becomes

$$O = \sum_{j=1}^{N_{\text{sites}}} \left[\sum_{i=1}^{N_{ist}} \left[c_{\text{e}}^{j}(i) P_{\text{e}}^{j}(i) + c_{\text{p}}^{j}(i) P_{\text{p}}^{j}(i) - c_{\text{s}}^{j}(i) P_{\text{s}}^{j}(i) + c_{\text{t}}^{j}(i) B_{\text{t}}^{j}(i) \right] \Delta t + \sum_{\substack{k=1 \\ k \ne j}}^{N_{\text{sites}}} c_{\text{tr}}^{kj}(i) P_{\text{tr}}^{kj}(i) + c_{\text{tr}}^{jk}(i) P_{\text{tr}}^{jk}(i) \right] \tag{7}$$

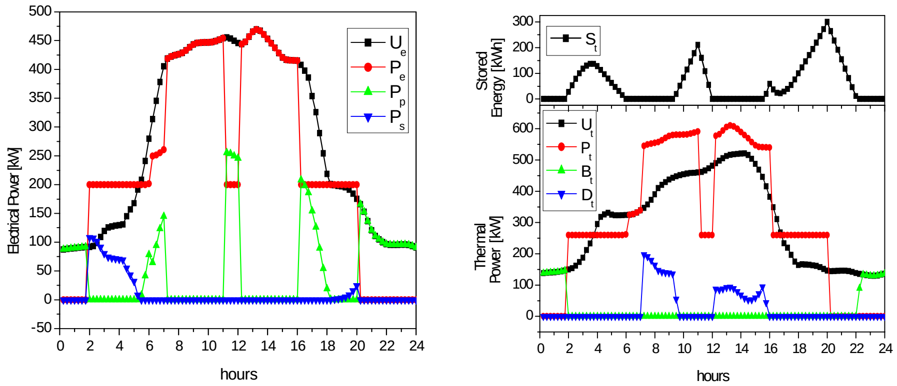

Fig. 2 – Example of optimal electrical and thermal power profiles.

III. RESULTS

Fig. 2 shows the optimal electrical and thermal power profiles for a co-generating unit of 600 kWe. A deep analysis this reference case and of a micro-grid of co-generating units will be given at the Conference.

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