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APPLICATION OF A DOUBLE STAGE OPTIMIZATION TO INTEGRATED ENERGY MANAGEMENT

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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..

These dynamic scenarios compel the use of real optimizaton strategies to rule out the production scheduling through a given time interval, usually a day or a week with a time resolution of one quarter of an hour.

The optimal generation levels of the unit can be set by the solution of a Linear Programming (*LP*) problem, but an external optimization loop must be used to decide when the units are to be switched on and off. This two stages optimization strategy has been implemented using an *interior point* method for the *LP* problem and an *Artificial Immune System* for the switching states decisions.

Details on the procedure and results on some practical cases will be resented at the Conference.

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. 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 fulfill 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 dayly or weekly basis, thus requirig an optimal manageent of production scheduling.

A *CHP* node is characterized by several type of data:

- operational data of the generating unit: nominal electric and thermal power generated, fuel consumption function, etc.;
- time evolution of cost coefficients for the purchase and selling of electric and thermal power to external customers
- time evolution of electric and thermal loads

with these data it is possible to define an optimal scheduling of the *CHP* as:

minimize total cost of the unit or, as a reverse formulation of the problem, maximize economic gain from it

using as degrees of freedom the values of power produced in different parts of the *CHP* unit

subject to:

- operational constraints of the *CHP*;
- fulfillment of electric load in time, taking into account the possibility of exchanging power with the external network;
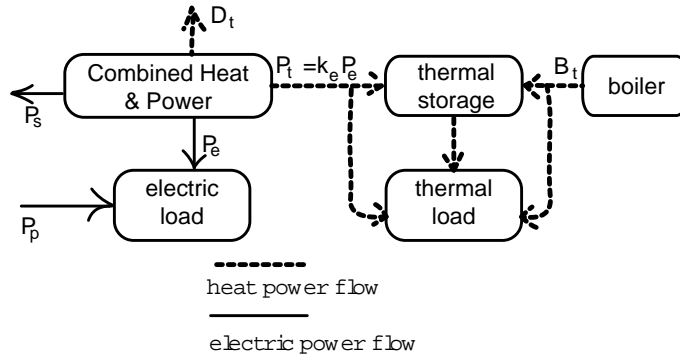- strict fulfillment of the thermal load in time.

Fig. 1 Structure of a *CHP* node with power fluxes highighted

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The outline of the structure is reported in Fig. 1 where:

- P_e is the electrical power produced by the CHP
- $P_t = k_e P_e$ is the thermal power produced by the CHP which can be used for the thermal load
- B_t is the heat produced in a boiler which is set to the purpose of fulfilling thermal load when production of electric power is neither needed nor economically convenient
- D_t is the heat produced in the thermo-dynamic cycle which can not be used in the thermal load and is thus relased in the atmosphere
- P_p and P_s are electrical power respectively purchased or sold to the external network
- S_t is the thermal energy stored
- U_e and U_t are the electric and thermal power required by the load

The degrees of freedom of the optimization are bounded by lower and upper bound, that is the CHP power must complain:

$$P_{min} \leq P_e \leq P_{max}$$

this assumption implies that a decision variable stating the on/off status of the CHP must be defined.

The optimal management of CHP and boiler units can thus be set up as a two stages optimization:

- an outer optimization strategy which decides when switching on and off the CHP unit
- an inner loop computing the optimal values of generated power through the following Linear Programming (LP) optimization problem:

$$minimize \quad O = \sum_{i=1}^{N} c_{ei} \Delta t P_{ei} + \sum_{i=1}^{N} c_{pi} \Delta t P_{pi} - \sum_{i=1}^{N} c_{si} \Delta t P_{si}$$

where O is the total cost which can assume negative values, index i refers to a time interval, N is the number of time instants, Δt is the amplitude of the time intervals which is considered equal for all (for instance $\frac{1}{4}$ 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; all economic parameters are expressed in Euro/MWh. Possible convex generating cost functions can be expressed as a combination of piecewise linear functions.

The optimization is subject to the fullfilment of the loads expressed as:

$$U_{ei} = P_{ei} + P_{pi} - P_{si}$$

$$U_{ti} = P_{ti} + B_{ti} - D_{ti} - \frac{S_{ti} - S_{ti-1}}{\Delta t}$$

and on/off status of the units is stated as:

$$\delta_{ei} P_{min} \leq P_{ei} \leq \delta_{ei} P_{max}$$

where δ_{ei} is an integer variable which can take 0 and 1 values. Additional constraints can be set on the minimum on time or minimum shutdown time and on power ramping.

The inner loop is tackled by standard LP solvers like *interior point* method while a stochastic optimization procedure is used for the outer one. In the present case, Artificial Immune Systems (AIS) are used for the definition of the on/off states of the power units, for each function evaluation a LP problem must be solved. This choice is related to their well known exploration properties which can efficiently cope with multi-modal objective functions.

The optimal management procedure has been implemented and results on dayly or weekly scheduling with real load evolution data have been assessed.

Details on the optimization method and on the implentation of the procedures will be given at the conference.