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Model predictive control for optimization of combined heat and electric power microgrid

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Abstract: This is a contribution to the economic dispatch problem of combined electrical and heat power microgrids. A mixed integer linear microgrid model has been developed; the microgrid operations optimization problem has been formulated using Mixed-Integer Linear Programming and Model Predictive Control technique has been applied to take system uncertainties into account. The proposed optimization algorithm has been applied to a tertiary site microgrid, located in Finland; the obtained numerical results have been compared with a heuristic algorithm.

Keywords: Optimization, Model Predictive Control, micro grids, Mixed Integer Linear Programming

1. INTRODUCTION

This paper is a contribution to the solution of the optimal economic dispatch problem of controllable loads and generators in an integrated microgrid , i.e. a micro grid combing different energy carriers such as heat and electricity.

Firstly, a general microgrid model integrating electric and heating networks has been developed. Based on previous work (Parisio et al. (2012)), a general scheme comprising storages, renewable energy sources and CHP plant as well as functional constraints has been designed. Despite the complexity of the microgrid structure due to coupling between different energy vectors, the comprehensive model turns to be mixed integer linear and it is suitable for microgrid operation optimizations. Namely the optimization consists in minimizing the overall microgrid operating costs, meeting predicted load demand while satisfying complex operational constraints (Ma et al. (2012). It is worth to notice that in electrical energy and heat integrated microgrids the multiplicity of connection points (such as boilers, CHP units, micro-turbines, fuel cells, immersion heaters, water pumps, and gas compressors) allows the conversion of one form of energy to another which results in additional decision variables for the optimization of microgrid operations.

One major issue in economic dispatch of microgrids is to handle the uncertainty associated with the system load, energy prices and weather profiles. A number of scientific contributions suggest MPC as an efficient tool to solve optimal dispatch problem in electrical power systems in uncertain scenarios (see for example Qi et al. (2011); Parisio et al. (2012)); however none of them took into account cogenerators systems (such as CHP) or apply to combined heat and electrical power microgrids. In this paper the microgrid operations are decided on the basis of predictions of future behavior of the system, renewable power generation and demand forecasts, including as many details as possible. Then a feedback mechanism (MPC) is introduced which compensates for the uncertainty in microgrid operations associated with the time varying load, energy prices and RES power outputs. The developed optimization algorithm has been tested on a Finnish tertiary microgrid and numerical results have been compared with a heuristic algorithm. The Finnish microgrid in one of the three pilots selected to test the outcome of the European project e-Gotham (sustainable smart Grid Open system for The Aggregated control, monitoring and Management of Energy); refer to project website for details E-Ghotam (2012).

2. SYSTEM DESCRIPTION AND MODELING

The objective of this Section is to describe the key features of an integrated microgrid and to propose a discrete-time formulation modeling the dynamics and behavior of microgrid components. The parameters, the forecasts and the decision variables adopted in the proposed formulation are described in Tables 1, 2 and 3 respectively; note that the subscript i when referring to the i-th unit and the subscripts e for electric and h for heat power have been dropped.

2.1 Loads

A combined microgrid has to guarantee a perfect balance between loads demand and power generation both for heat and electrical power. In the following model formulation two types of loads have been considered:

- critical loads, i.e. demand related to essential processes that must always be met;

Table 1. Parameters

Parameters	Description
	DG unit (electrical/heat)
N^g, N^l, N^c	number respectively of DG units, critical loads and controllable loads
$C^{DG}(P)$	fuel consumption cost curve of a DG unit
a_1, a_2, a_3	cost coefficients of $C^{DG}(P)$[€/(MWh)^2,€/MWh,€]
OM^{DG}	operating and maintenance cost of a DG unit [€/h]
OM^b	operating and maintenance cost of the power exchanged with the storage unit [€/h]
R_{max}	ramp up limit of a DG unit [MW/h]
T	horizon of the optimization problem
T^{up}, T^{down}	minimum up and down time of a DG unit [h]
x^{sb}	storage 'physiological' energy loss [MWh]
x^b_{min}, x^b_{max}	minimum, maximum energy level of the storage unit [MWh]
C^b	storage power limit [MW]
T^g	maximum interconnection power flow limit (at the point of common coupling) [MW]
P_{min}, P_{max}	minimum, maximum power level of a DG unit [MW]
η^c, η^d	storage charging and discharging efficiencies
β_{min}, β_{max}	minimum, maximum allowed curtailment of a controllable load
c^{SU}, c^{SD}	start-up, shut-down costs of a DG unit [€]
D^c	power level of a controllable load [MW]
ρ_c	penalty weight on curtailments
	CHP
N^m	number of CHP operation modes
C^{chp}	fuel consumption cost curve of a CHP unit
OM^{chp}	maintenance cost of a CHP unit [€/h]
p_e, p_h	electric and heat power of the CHP operating mode

Table 2. Forecasts

Forecasts	Description
P^{res}	sum of power production from RES [MW]
D	power level required from a critical load [MW]
c^P, c^S	purchasing, selling energy prices [€/MWh]

Table 3. Decision and logical variables

Variables	Description
δ	off(0)/on(1) state of a DG unit
P	power level of a DG unit [MW]
δ^b	discharging(0)/charging(1) mode of the storage unit
P^b	power exchanged (positive for charging) with the storage unit [MW]
x^b	stored energy level [MWh]
δ^g	exporting(0)/importing(1) mode to/from the utility grid
P^g	importing(positive)/exporting(negative) power level from/to the utility grid [MW]
β	curtailed power percentage
δ^{chp}	off/on state of the CHP unit
P^{chp}	power level of CHP unit [MW]

- controllable loads, i.e. loads that can be reduced or shed in supply constraints or emergency situations.

A continuous-valued variable, $0 \leq \beta(k) \leq 1$, associated to each controllable load c and to each sampling time k is defined. This variable represents the percentage of preferred power level to be curtailed at time k in order to keep the microgrid operations feasible or more economically convenient.

2.2 Distributed generator operations

In a combined microgrid the electrical and heating power can be generated either by DG providing only one of the two energy vectors or in combined devices such as the CHP plant that can provide both form of energies simultaneously; cogeneration systems will be described in the subsequent subsection.

Generator operations are constrained by the minimum up/down time that is the minimum amount of time for which a controllable generation unit must be kept on/off. At each sampling time k, the minimum up/down time can be modeled with the following mixed integer linear inequalities (Parisio et al. (2012)):

$$\begin{aligned} &\delta_i(k) - \delta_i(k-1) \leq \delta_i(\tau^{up}) \text{ (off-on switch)} \\ &\delta_i(k-1) - \delta_i(k) \leq 1 - \delta_i(\tau^{down}) \text{ (on-off switch)}, \end{aligned} \tag{1}$$

with i indexing all electric and heat generators , $\tau^{up} = k+1, \ldots, \min(k+T_i^{up}-1, T)$ and $\tau^{down} = k+1, \ldots, \min(k+T_i^{down}-1, T)$ otherwise.

The DG unit start up and shut down behavior can be modeled in order to take the corresponding costs into account. Thus, two auxiliary variables, $SU_i(k)$ and $SD_i(k)$ are introduced, representing respectively the start up and the shut down costs for the i-th DG generation unit at time k that are $SU_i(k) \geq c_i^{SU}(k)[\delta_i(k) - \delta_i(k-1)]$, $SD_i(k) \geq c_i^{SD}(k)[\delta_i(k-1) - \delta_i(k)]$, $SU_i(k) \geq 0$, $SD_i(k) \geq 0$ (Carrion and Arroyo (2006)). In addition, the fuel consumption cost for a DG unit is traditionally assumed to be a quadratic function of the generated power of the form:

$$C^{DG}(P) = a_1P^2 + a_2P + a_3, \tag{2}$$

2.3 Cogeneration system

The CHP or cogeneration system is a device that can simultaneously generate electricity and useful heating from the combustion of a fuel. Following Lahdelma and Hakonen (2003), the operating costs $C^{chp}(P_e^{chp}, P_h^{chp})$ are assumed convex function of heat and power production. The CHP operations mode can take value within a finite set of combination of costs, electrical and heat power: $(c_i, p_{e,i}, p_{h,i})$ for $i = 1, \ldots, N^m$, with N^m the number of all possible operation modes.

The CHP has been modeled introducing a binary variable $\delta_i^{chp}(k)$ for each operation mode which is equal to 1 if and only if the CHP is working in i-th operation mode at the k time step, zero otherwise. Thus, the electrical and heat generated power are equal to $P_e^{chp}(k) = \sum_{i=1}^{N^m} p_{e,i}\delta_i^{chp}(k)$ and $P_h^{chp}(k) = \sum_{i=1}^{N^m} p_{h,i}\delta_i^{chp}(k)$ respectively.

The model can be extended to multiple CHP plants or in the case of Combined Cooling and Heat Power (CCHP) plant and the overall model is again formulated as a MILP. Since the variables need to be mutually exclusive, the mixed integer linear inequality $\sum_{i=1}^{N^m} \delta_i^{chp}(k) \leq 1$ has to be satisfied.

The CHP fuel consumption costs are exclusively related to the N^m different generated power levels; thus CHP costs can be modeled as $C^{chp}(k) = \sum_{i=1}^{N^m} c_i\delta_i^{chp}(k)$ where the binary variables δ_i^{chp} determine the costs according to the operation modes at each time step. A term OM^{chp} models the CHP maintenance costs which are fixed costs independent from plant use.

A CHP system may contain separate electricity and heat components. Such components include condensing power plants, hydropower, heat plants and various purchase and sales contracts for heat and power. All these components can be modelled as special cases of CHP plants with either $p_{e,i} = 0$ (in power components) or $p_{h,i} = 0$ (in heat components).

2.4 Storage dynamics

The storage system is a key component in a microgrid since it allows to manage intermittent RES and peak power loads and it is particulary helpful in matching supply and demand over a 24 hour period of time. In what follows a discrete time model for electrical storage systems is described; the model has been derived relying on previous works (Parisio et al. (2012); Zhang et al. (2011)). An analogous set of equations holds for the heating network.

Let $x_e^b(k)$ the charging state of the electrical storage system at time k and $P_e^b(k)$ is the electric power exchanged with the storage at time k. It holds: $x_e^b(k+1) = x_e^b(k) + \eta_e P_e^b(k) - x_e^{sb}$, where:

$$\eta_e = \begin{cases} \eta_e^c, & \text{if } P_e^b(k) > 0 \text{ (charging mode)} \\ \eta_e^d, & \text{otherwise (discharging mode)} . \end{cases}$$

Typically $0 < \eta_e^c < 1$ and $\eta_e^d = 1/\eta_e^c$ account for the losses, and their characterization should be made according to the type of storage. Note that the sample time is assumed equal to 1 hour.

If the power exchanged at time k is greater than zero, the storage device has been charged, otherwise has been discharged. By using the standard approach described in Bemporad and Morari (1999), a binary variable $\delta_e^b(k)$ an auxiliary variable $z_e(k) = \delta_e^b(k)P_e^b(k)$ are introduced to model the following logical condition and the storage dynamics:

$$P_e^b(k) \geq 0 \Leftrightarrow \delta_e^b(k) = 1$$

and

$$x_e^b(k+1) = \begin{cases} x_e^b(k) + \eta_e^c P_e^b(k) - x_e^{sb} & \text{if } \delta_e^b(k) = 1 \\ x_e^b(k) + \eta_e^d P_e^b(k) - x_e^{sb} & \text{otherwise.} \end{cases} \quad (3)$$

Then the logical conditions are expressed as mixed integer linear inequalities. By collecting such inequalities the storage dynamics and the corresponding constraints are rewritten in the following compact form:

$$\begin{aligned} x_e^b(k+1) &= x_e^b(k) + \left(\eta_e^c - \eta_e^d\right) z_e^b(k) + \eta_e^d P_e^b(k) - x_e^{sb} \\ \text{s.t. } & E_{1,e}^b \delta_e^b(k) + E_{2,e}^b z_e^b(k) \leq E_{3,e}^b P_e^b(k) + E_{4,e}^b \end{aligned} \quad (4)$$

where the column vectors $E_{1,e}^b$, $E_{2,e}^b$, $E_{3,e}^b$ and $E_{4,e}^b$ are easily derived from the mixed integer linear inequalities modeling the 'if…then' conditions (see Bemporad and Morari (1999) for details).

2.5 Interaction with the utility grid

It is assumed that the microgrid supplies a load both in islanded and in grid connected modes. When grid-connected, the microgrid can interact with the utility grid, that is it can sell and purchase energy from/to the external grid.

Following the same procedure applied to the storage devicethe purchasing/selling microgrid behavior can be expressed in a compact form as:

$$E_{1,e}^g \delta_e^g(k) + E_{2,e}^g C_e^g(k) \leq E_{3,e}^g P_e^g(k) + E_{4,e}^g \quad (5)$$

where the column vectors $E_{1,e}^g$, $E_{2,e}^g$, $E_{3,e}^g(k)$ and $E_{4,e}^g$ are provided in Parisio et al. (2012) and the matrix $E_{3,e}^g(k)$ is generally time-varying due to the time varying energy prices.

The same set of constraints can be straightforwardly obtained for the heating network.

2.6 Power balance

The balance between energy production and consumption must be reached at each time k; hence the following equality constraints must hold, respectively for the electric and heating components:

$$\begin{aligned} P_e^b(k) = & \sum_{i=1}^{N_e^g} P_{e,i}(k) + P_e^{chp}(k) + P_e^{res} + P_e^g(k) + \\ & - \sum_{j=1}^{N_e^l} D_{e,j}(k) - \sum_{r=1}^{N_e^c} [1 - \beta_{e,r}(k)] D_{e,r}^c(k) \end{aligned} \quad (6)$$

Note that the decision variables are the electrical and heat generators' power levels $P(k)$, CHP power levels $P^{chp}(k)$, the exchanged power with the utility grid $P^g(k)$ and with the storage $P^b(k)$, the curtailments $\beta(k)$, the generators off/on states $\delta(k)$. RES generation P^{res}(k), demand $D(k)$ and the controllable power levels $D^c(k)$ are known disturbances obtained by forecasts.

2.7 Capacity and terminal constraints

To pose the overall optimization problem, additional operational constraints must be met:

$$x_{e,min}^b \leq x_e^b(k) \leq x_{e,max}^b,\ x_{h,min}^b \leq x_h^b(k) \leq x_{h,max}^b \quad (7a)$$

$$P_{min,i} \leq P_i(k) \leq P_{max,i} \quad (7b)$$

$$|P_i(k+1) - P_i(k)| \leq R_{max,i} \quad (7c)$$

$$\sum_{j=1}^{N^m} \delta_j^{chp}(k) \leq 1 \quad (7d)$$

$$\beta_{min,r} \leq \beta_r(k) \leq \beta_{max,r} \quad (7e)$$

with i indexing all electric and heat generators and $r = 1, \ldots, N^c$. The constraints above model respectively the physical bounds on the electric storage device and the heat storage (7a), the power flow limits of the DG units (7b) and their ramp up and ramp down rates (7c), the mutually exclusive condition on the binary variables describing the CHP plant (7d) and the bounds on controllable loads curtailments (7e). Notice that the binary variable $\delta_i(k)$ will be equal to 1 if the power $P_i(k)$ generated from the i-th DG unit at time k is strictly positive and equal to 0 if $P_i(k) = 0$.

3. PROBLEM FORMULATION

The microgrid economical dispatch problem consists in scheduling the generator and cogenerator units energy production, the charge/discharge of energy storages and the use of controllable loads to cover the microgrid loads demand and minimize the generators' running costs and the purchasing costs of energy from the utility grid. At each time step, the optimization algorithm takes decisions on microgrid operations (see Table 3), such as: when should each generator unit be started and stopped, when each cogenerator unit should be started and its operating mode, when the storage devices should be charged or discharged, when and how much energy should be purchased from or sold to the utility grid, when and for how long the controllable loads should be cut.

Exploiting the proposed integrated micorgrid model, the microgrid economical dispatch problem can be formulated as a MILP optimization problem that generates an optimal energy management plan over a prediction horizon. To pose the optimization problem the cost function is defined; the overall optimization problem consists in minimizing the cost function with respect to system constraints. Finally, to take system uncertainty into account the MPC scheme is posed.

3.1 Cost function

Microgrid running costs are modeled using the following cost function which comprises costs associated with energy production and start-up and shut-down decisions, along with possible earnings and curtailment penalties:

$$\sum_{k=0}^{T-1}\sum_{i=1}^{N_e^g}\left[C_i^{DG}(P_{e,i}(k)) + OM_{e,i}^{DG}\delta_{e,i}(k) + SU_{e,i}(k) + \right.$$
$$\left. + SD_{e,i}(k)\right] + \sum_{i=1}^{N_h^g}\left[C_i^{DG}(P_{h,i}(k)) + OM_{h,i}^{DG}\delta_{h,i}(k) + \right.$$
$$\left. + SU_{h,i}(k) + SD_{h,i}(k)\right] + C^{chp}(k) + OM^{chp} +$$
$$+ OM_e^b\left[2z_e^b(k) - P_e^b(k)\right] + OM_h^b\left[2z_h^b(k) - P_h^b(k)\right] +$$
$$+ C_e^g(k) + C_h^g(k) + \rho_{c,e}\sum_{r=1}^{N_e^c}\beta_{e,r}(k)D_{e,r}^c(k) +$$
$$+ \rho_{c,h}\sum_{r=1}^{N_h^c}\beta_{h,r}(k)D_{h,r}^c(k),$$

where k is the time instant, T is the length of the prediction horizon; $\left[2z^b(k) - P^b(k)\right]$ models the absolute value of the power exchanged with the storage unit. The cost function of each generator unit (2) has been approximated by the max of affine functions, as suggested in Parisio et al. (2014). As already mentioned, $C^g(k)$ can be negative, i.e. energy is sold to the utility grid, representing an earning for the microgrid system.

3.2 Model predictive control problem

The optimal schedule calculated solving the MILP optimization problem will be affected by uncertainties due to energy prices, weather and load forecasting. Thus, the formulated model will be imperfect and the system state will not evolve as predicted. To compensate the difference between prediction and actual states, the optimization problem is embedded in an MPC framework (Parisio et al. (2012)). In terms of microgrid control, this means that, at the current point in time, an optimal plan is formulated (usually for a prediction horizon of 24 hours) based on predictions of the upcoming demand, production from renewable energy units and energy prices. Only the first sample of the input sequence is implemented, and subsequently the horizon T is shifted. At the next sampling time, the new state of the system is measured or estimated, and a new optimization problem is solved using this new information. By this receding horizon approach, the new optimal plan can potentially compensate for any disturbance that has meanwhile acted on the system.

Then, this is a MPC-MILP strategy: it is the feedback control law computed through the MPC control scheme. In MPC-MILP a certainty equivalence approach is applied, meaning that the predictions are assumed to be 'perfect' in the MPC problem, i.e. unaffected by errors. The uncertainty is then compensated by the feedback mechanism.

4. CASE STUDY

The optimization algorithm has been applied on a microgrid feeding electric energy and water-based district heating to a number of community buildings in the town of Ylivieska in Finland.

The Ylivieska microgrid pilot comprises five main elements: connection to the state level grid, power station, electricity network, tertiary buildings and district heating network (see E-Ghotam (2012) for details). Experimental results on the optimization of the district heating network are here reported, since electrical network data were not yet available at the time of experiments. Fig. 1 shows a scheme of the entire district heating, focusing on energy regarding both generation and utilization side.

The power generation plant consists in:

- a steam boiler, that is the main energy source;
- a grate boiler, that is a main supporter;
- two oil boilers, characterized by high energy production costs;
- a storage tank.

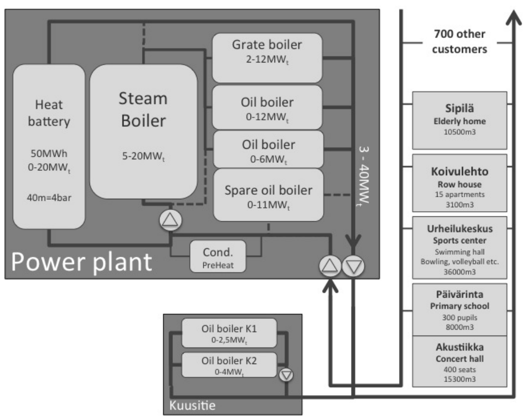

Fig. 1. District heating scheme

The available heaters don't necessarily work simultaneously; the decision to turn on or off each heat generator depends on thermal consumption and weather condition. Table 4 reports the main parameters of each heat generator in the pilot, for the fuel cost function only the linear coefficients a_2 are available.

Table 4. Table of the heaters parameters

Unit	P_{min} [MW]	P_{max} [MW]	a_2 [€/MWh]	R_{max} [€/MWh]
Steam boiler	5	20	17	5
Grate boiler	2	12	22	3
Oil boiler 1	2	12	70	6
Oil boiler 2	2	6	70	3

A Heat EXchanger (HEX) exchanges heat energy between the two isolated water circuits (power generation and aggregated loads). The storage tank supplies high temperature water to the circuit in the cases of insufficient heat production or heat generators faults. To take into account the case of a fault in the steam boiler (the main power generator of the microgrid) an additional mathematical constraint has been added; the equation below ensures that the heat available in the storage is sufficient to satisfy a fraction α (decided by the microgrid administrator) of the remaining demand:

$$x^b(k) \geq \alpha(D(k) - P_2(k) - P_3(k) - P_4(k)), \tag{8}$$

where $P_i(k)$ with $i = 2, 3, 4$ denote the power at time k of the working generators and $D(k)$ the aggregated demand at time step k.

4.1 Optimization problem for the Finnish case study

The grid of the Finnish pilot works in island mode, i.e. energy can not be purchased or sell from/to an external grid; moreover all loads are critical. For sake of simplicity, no maintenance, startup and shut-down costs are assumed. Thus, the optimization problem is written as:

$$\min_{P_{h,i}} \sum_{k=0}^{T-1} \sum_{i=1}^{N^g} a_{2,i} P_{h,i}(k) \tag{9}$$

subject to (4) (6), (7a), (7b), (7c), (8) and (1).

The solution of the optimization problem returns at each time step the power to be produced by each heater and the energy to be stored. The heat distribution network of the Finnish microgrid (operating temperatures, power losses in the net, etc.) has not been included in the model; thus the optimal thermal power values returned by the above optimization problem may actually lead to a supplied temperature insufficient to satisfy net requests. Formulas that could constraint the heat power to be generated to the desired supplied temperature are currently under study.

4.2 Control strategies comparison

To validate the results obtained with the MPC algorithm, the proposed approach is compared with a heuristic microgrid management algorithm. The implemented heuristic takes into account relevant system dynamics (such as the use of the storage unit and the inclusion of physical bounds on the storage device, the power flow limits of the units and their ramp up and ramp down rates) that have not been considered in other heuristics proposed in literature (see Parisio et al. (2014)).

The heuristic algorithm consists of the following steps, applied at each sampling time k:

(1) if the energy stored at time k is less then the 40% of the load at the same time step, missing power is added to the demand at time k;
(2) the generation units are turned on from the cheapest to the most expensive one until the demand surplus is covered;
(3) if there is still a demand surplus, storage unit is used to compensate it, if possible.

Analogously to the MPC-MILP strategy, to account for a fault in the steam boiler in the heuristic algorithm it has been assumed that energy to be stored is always generated from the other three boilers.

5. SIMULATION RESULTS

A sampling time of one hour and a prediction horizon of 24 hours are chosen. Simulations are performed over 48 hours. All simulations are run using CPLEX 12.0 and all computations are done on Intel Core 2 Duo CPU, 1.83 GHz. Optimization results are obtained in less than 1 minute.

In this simulation scenario heaters parameters in the Table 4 have been adopted. The charge storage efficiency is set equal to 0.85 (as in Zhang et al. (2011)); the value of α in (8) is set to 0.4; the initial storage level is $x_h^b(0) = 12\ MWh$ and the storage energy loss are $x_h^{sb} = 0.0153\ MWh$. All T_{up} and T_{down} are set to 2 hr.

In order to test the proposed algorithm, in a first simulation the actual demand at each time step is considered equal to the predicted value (blu pattern in Fig. 2), according to the certainty equivalence recalled in subsection 3.2 and the results of the optimization algorithm are compared with the heuristic.

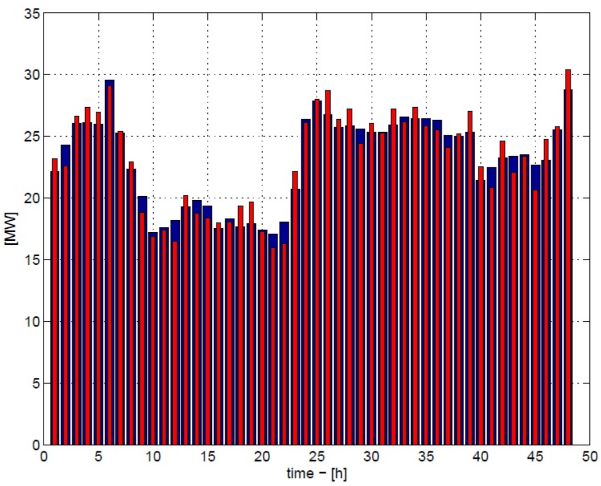

Fig. 2. Predicted (in blu) and actual (in red) requested power

In Fig. 3 the power generation and the storage energy level of the the optimal MPC-MILP strategy over a 48 hour simulation are depicted in blu; the results obtained applying the proposed heuristic strategy are reported in red. The total cost for the two control strategies considered is reported in Table 5. The cost benefit obtained using the MPC-MILP strategy compared to the heuristic proposed is

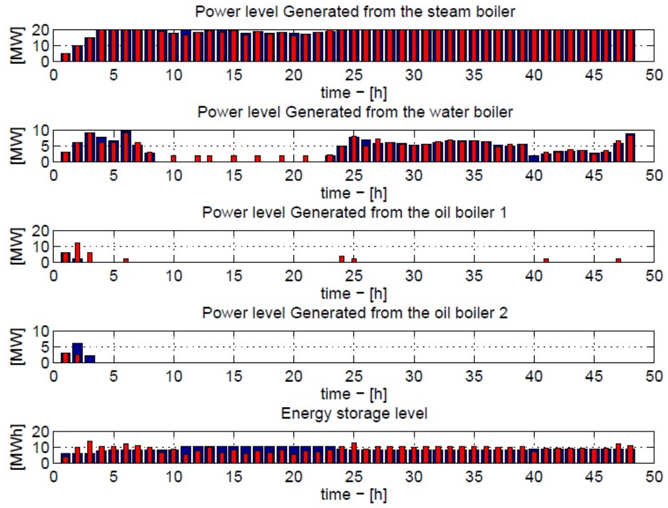

Fig. 3. Power level generated and the storage energy level using the MPC control strategy (in blu) and heuristic strategy (in red)

Table 5. Power generation costs of the MPC-MILP and heuristic strategies

Strategy	*Total cost €*
MPC-MILP	20765
Heuristic	22368

about 7.7%. The difference in cost is due to the fact that the MPC-MILP algorithm allows to exploit the forecast information on demand. In contrast, the heuristic can only match the demand at each time step. MPC-MILP schedules the production plan to generate more power than needed in the first ten hours and store the surplus into the storage tank to use it afterwards, avoiding to switch on the expensive boilers.

Another set of optimization problems has been solved assuming that at each time step the actual demand differs from the predicted value by at most 6% (as in Fig. 2). Optimal solutions returned from the MPC-MILP strategy with the actual demand different from the forecast are compared with previous optimization results. Fig. 4 reports a 48 hour simulation of the power generation and the storage energy level for this example. In correspondence of an actual demand higher than the predicted one, there is a decrease in the energy level of the storage, to compensate the amount of load not taken into account in the generation. Instead, when there is an actual demand lower than the predicted, there is an increment of storage level. This brings a variation of the power levels.

6. CONCLUSION AND PERSPECTIVE RESEARCHES

In this paper economic dispatch problem for combined energy microgrid is described. Building on previous works on electrical microgrids a mixed integer linear approach on modeling and optimization, embedded into a MPC framework for forecast compensation, has been considered. The proposed algorithm has been tested on data of a Finnish district heating network. The described MPC-MILP strategy for the microgrid optimization problem has

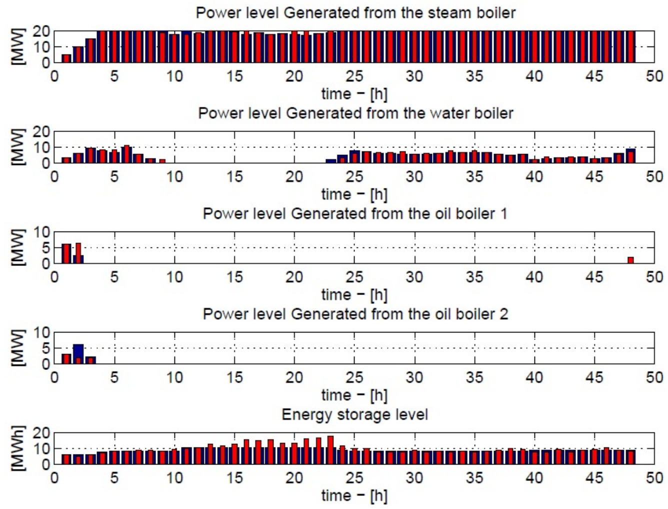

Fig. 4. Power levels and storage energy level using predicted demand equal to actual demand (in blu) and predicted demand different from the actual demand (in red)

been compared with a heuristic algorithm, to confirm its efficiency. Future studies should correlate the accurancy of the proposed model to the effectiveness of MCP strategy.

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