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Daily and Short Term Optimal Energy Management with Uncertainty

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Abstract

This paper presents a two-level control architecture for the intra-day energy management of a microgrid. The aim is to comply with an agreed energy exchange profile with the main grid, minimizing the operating cost. The higher level is entitled for the definition of the nominal profiles of the controllable devices, based on the forecasts of demand and production. The task of the lower level control is to reach the target energy exchange setpoint, correcting the scheduled setpoint of the controllable devices.

While the high level optimization consists in the solution of a mixed integer linear programming problem, the low level controller has been implemented as a daisy chaining control scheme with a PI controller.

This control architecture potentially helps to increase the reliability of the whole grid, by means of the aggregation of unpredictable energy resources and making their overall behaviour more predictable from the DSO point of view.

1 Introduction

The need to reduce the carbon footprint, to improve the energy efficiency and the power quality, flexibility and reliability led to the development of microgrids, aggregates of distributed energy resources, loads and storage devices properly managed as a single unit. The integration of different energy resources, including non dispatchable renewable sources, energy storages and cogeneration, along with the coupling with thermal system, a greater uncertainty and the low inertia poses new challenges in power system control.

This paper presents a two-level control architecture for the intra-day energy management of a microgrid. The aim is to comply with a previously agreed energy exchange profile with the main grid, that minimize the operating cost. The higher level is entitled for the definition of the nominal profiles of the dispatchable devices till the end of the day with a 15 minutes time step, based on the predefined exchange reference profile, the forecasts of the loads and of the renewable generation, and the state of charge of the storages systems. The task of the lower level control is to reach the target energy setpoint for each 15 minutes period, correcting the scheduled setpoint of the controllable devices. The control horizon is the current quarter of hour and has a time step of one minute. Unavoidable errors in the forecasts may lead the system to stray from the predicted plan, making convenient to invoke a high level re-optimization.

While the high level optimization consists in the solution of a mixed integer linear programming problem, the low level controller has been implemented as a daisy chaining control scheme: a simple proportional-integral controller computes the overall power correction needed to maintain the predefined energy exchange and splits it between the dispatchable devices according to a specified order of priority.

The paper initially shows the two-layer control architecture, with a possible implementation of the algorithms. Thereafter, a numerical simulation is provided, referring to the model of the RSE Distributed Energy Resources Test Facility.

2 Microgrid energy management

One of the most important topics regarding microgrid control is the energy management, aimed to satisfy both internal and external needs. The former are mainly ascribable to energy flows optimization, in order to identify the best energy sources and storages usage in order to minimize all the direct and indirect costs. Among the latter we can consider various interaction models of the relationship between the microgrid and third parties, such as the DSOs, aggregators and energy retailers. However, the control of the energy exchanged between the microgrid and the external grid is a common requirement.

In particular, the considered scenario deals with customer-owned microgrids: the microgrid is a unique customer of the distribution grid, with which shares a unique point of common coupling. The *Microgrid Manager* directly controls the distributed energy resources and communicates with third parties.

The tasks considered are the following:

Day-ahead optimization The day before (D_{k-1}) the microgrid manager collects the forecasts of weather (and thus renewable generation), electric and thermal demand, energy prices. Combining an economic optimization and the interaction with the market, the microgrid manager generates the usage profiles of distributed energy resources and the grid energy exchange profiles agreed upon with the energy retailer for the following day. This paper will not focus on this step because it strongly depends on the specific market model, but rather we'll consider a given energy exchange profile and a schedule for the controllable units.

Intra-day optimization The current day (D_k) the microgrid manager, according to online measurements, revises the demand and production forecasts. Then it performs an high level optimization, with the constraint of the energy exchanged with the grid in each time interval.

Low-level energy control It has to correct the setpoints of the DERs calculated by the higher control layers, in order to cope with the fluctuations of the demand and of the renewable generation. The implementation proposed aims to exchange a certain amount of energy during the time interval (so the mean power), disregarding the instant power values. Many algorithms can fit this task, from the simple priority-ordered device intervention, to a more sophisticated stochastic model predictive control.

The energy management steps suggested allow a clear task partitioning. Therefore it's possible to use different algorithms in each task, without breaking the overall behavior, making the control system modular and scalable.

2.1 Intra-day optimization

The intra-day optimization task builds a new Daily Production Plan (DPP) which specifies the set points of each controllable unit, according to the minimum cost criterion, satisfying the technical constraints and the energy exchange profile. This task performs an energetic overall optimization, including both thermal and electric domains. The input data of this task are:

- Devices models, availability and capability, even varying during the reference period
- Forecast of the renewable non controllable energy production, related to the weather forecast
- Forecast of the electric and thermal demand, related to the weather forecast
- Agreed profiles of the energy to be exchanged with the main grid along the reference period
- Devices operating costs
- Initial State of Charge (SoC) of Energy Storage Systems (ESS)

The output data are:

- Power setpoints for each controllable unit, with a typical timestep of 15 minutes
- Forecast of the SoC of the ESSs along the reference period

The intra-day optimization can be scheduled at fixed time intervals, or can be performed only on specific events, such as when an updated production or demand forecast is available or when the SoC of the ESSs diverge from the expected profile.

The optimization task is pursued adopting the HYSDEL modelling language. HYSDEL (HYbrid System DEscription Language) allows to model hybrid systems, interconnecting linear dynamic systems, automata and propositional logic rules. The HYSDEL compiler, then, translates the model in a Mixed Integer Problem, that is solved by CPLEX, a state-of-the-art numerical optimizer. These tools made it easier to model complex components, such as the gas micro turbine. It has been modelled with a finite state machine, representing its working states (standby, warmup, steady state, etc.), and each state has a particular dynamic behaviour. Also the battery implementation is simpler, allowing to represent its state of charge, with its upper and lower boundaries, as well as integral constraints, such as the battery final state of charge.

In order to keep the optimization problem simple, the network model is neglected in this phase: only the devices technical constraints are considered. Only when the DPP has been computed, it's applied to an optimal power flow model of the whole network, in order to check if the electrical constraints (node voltages, line currents) are satisfied. To solve this problem, the algorithm can act on reactive power setpoints and even, if needed, on active power setpoints.

The revised DPP is eventually sent to the devices to be applied although it can be further changed by the lower level Energy Tracker in order to fulfil the energy exchange profile.

2.2 Low-level control layer

The Low-level energy tracker has the objective to comply with the predefined energy exchange with the external grid, while dealing with the uncertainty deriving from the fluctuations of non-dispatchable generation and non-controllable loads.

This control system receives as input the precomputed optimal energy exchange E^{ref} at the point of common coupling, for the time interval τ_{HL}, together with the nominal setpoints for the n available dispatchable units $(\bar{P}_1, \bar{P}_2, \ldots, \bar{P}_n)$ and the measures from the field. Its goal is to counteract the effect of the non-predicted variations, properly modifying the value of the generators' setpoints. A typical control timestep is 1 minute.

A possible implementation of this control structure consists in the definition of a daisy chaining scheme. Initially developed to deal with controllers saturation in flight control systems (*e.g.*,[3, 4]), this configuration allows to share the neces-

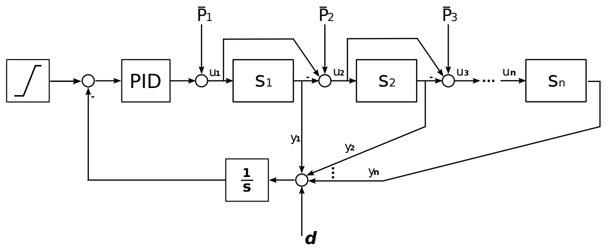


Fig. 1: Energy tracker control scheme

sary control action between different actuators, while defining a priority policy for their usage.

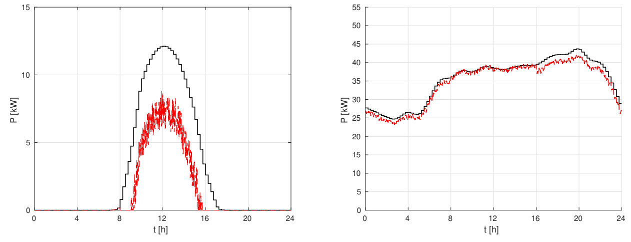
As shown in Figure 1, a simple PID controller is adopted to track the precomputed energy reference, defined as a ramp. The resulting power request is represent the input for the chain of dispatchable generators. A priority policy is defined among the n units, since every unit S_i (with $i = 2, 3, \ldots, n$) receives the control signal deprived by the contributions of the previous $i-1$ units. The reference value $\bar{P}_i$, introduced as a feed-forward input, guarantees that the production profiles do not significantly diverge from the precomputed optimal ones.

In order to obtain the requested energy exchange E^{ref} with the network at the end of the time interval τ_{HL}, the reference is defined as a ramp starting from zero with a slope equals to $E^{ref}/\tau_{\mathrm{HL}}$, while the value of the actual exchange is computed integrating the active power, P_{G}, flowing through the point of common coupling. Of course, in Figure 1, defining d as the sum of non-dispatchable generation, non-controllable loads and eventual loss of power along the microgrid, we used the fact that $P_{\mathrm{G}} = d + \sum_{i=1}^{n} y_i$.

3 Simulation results

In order to show the characteristics of the approach, we consider in this section a simulation example based on the model of the Test Facility (TF) available at the RSE research center. The TF comprises a natural gas co-cogenerator (in the following denoted by C), a storage system (*i.e.*, a battery, B), an electrical load L, and a photovoltaic system P. The TF is connected with the main grid G at the point of common coupling. The dispatchable units are assumed to be endowed with internal controllers, enforcing the production of the requested power setpoint.

The Day-ahead optimizer, considering the forecast of the photovoltaic production and the expected electrical load (represented by the black lines in Figure 2), together with the time varying costs for the production, define the optimal setpoint for the dispatchable devices, and the corresponding optimal energy exchange with the network. Figure 3 shows the resulting production profiles for B and C, while the optimal energy exchange at the point of common coupling is represented in Figure 4.



(a) **(b)**

Fig. 2: (a) photovoltaic system production forecast and real data (solid black line and dashed red line respectively); (b) electrical load consumption forecast and real data (solid black line and dashed red line respectively)

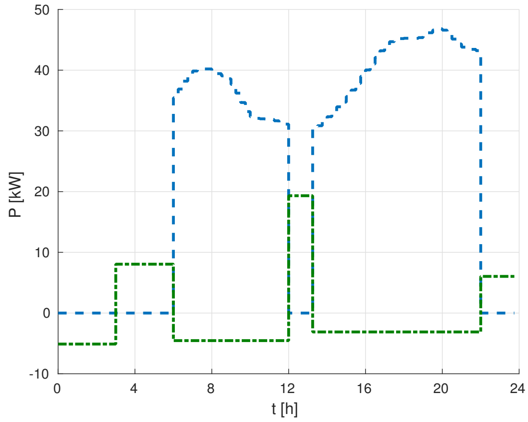


Fig. 3: Optimal production profile for the dispatchable units: C setpoint (dashed blue line) and B setpoint (dash-dot green line)

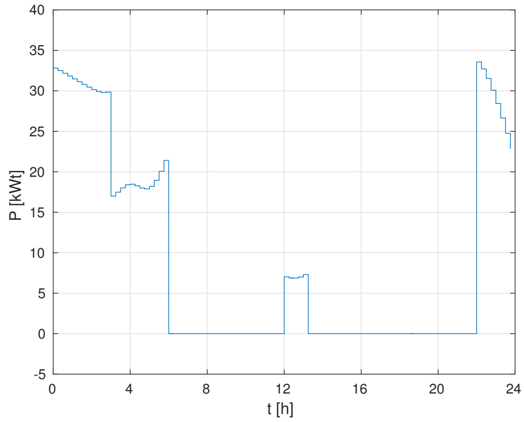
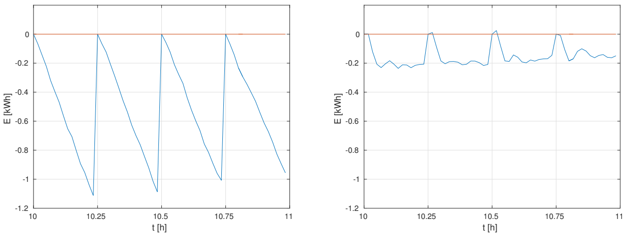


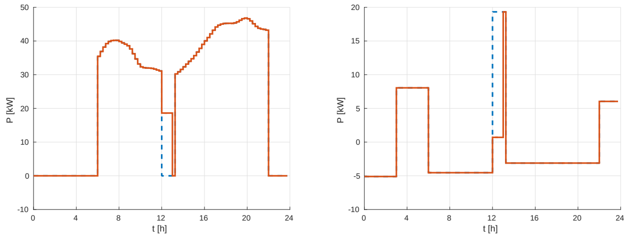
Fig. 4: Optimal energy exchange with the network

During the daily execution of the plan, the forecasts may often result, as in this example, incorrect. The fluctuation, unaccounted for in the optimization, would induce an error in the agreed exchange profile. A daisy-chaining Energy tracker, is therefore introduced to compensate such error. A reasonable



(a) **(b)**

Fig. 5: Energy exchange between the 10.00 AM and 11.00 AM cumulated in each 15min period (E^{ref}, red line, and actual exchange, blue line). Comparison for the case a) without and b) with the daisy chaining control structure



(a) **(b)**

Fig. 6: Correction of the production plan due to the Intra-day optimization, initial setpoints (dashed blue line) and updated ones (solid red line) (a) cogenerator; (b) battery

choice in this case, would be to give priority to C, requesting the battery, which has a faster dynamics to help when needed. Focusing the attention on the interval of length $4\tau_{\mathrm{HL}} = 60min$ between 10.00 and 11.00 A.M., Figure 5 shows the results, for the same data with and without the action of the energy tracker controller. While the beneficial effects are clear, the drawback of these necessary control actions resides in the modification of the state of the system, such as, in this example, the state of charge of the battery. This poses a threat for the feasibility of the optimal plan. (*e.g.*, the battery might be completely discharged when needed).

To account for this, at every instant τ_{HL} an intra-day optimization is issued with the purpose to update the nominal profiles of the dispatchable generators so as to allow the fulfillment of the agreed energy exchange with the network. Figure 6 collects the results of one iteration, *i.e.*, the nominal production profile of battery and cogenerator updated at 11.00 AM. As the figure shows, the control system increases the production of the cogenerator while reducing the battery setpoint, in order to compensate for the loss of charge due to the effect of the Energy tracker.

4 Conclusion

This paper presents a method for an efficient energy management of microgrid. The intra-day optimizer, considering the forecasted RES production and the load consumption, computes the nominal setpoint for the dispatchable generators leading to the agreed energy exchange with the network. The Energy Tracker, here introduced as a daisy chaining control scheme, allows to coordinate the production of the MG devices so that to obtain the predefined exchange even in presence of forecast errors.

This energy management system has been applied to the model of the RSE Distributed Energy Resources Test Facility where both dispatchable (batteries and a CHP) and non dispatchable (photovoltaic panels, loads) units are available. The control system operates to carry out the desired energy profile at the main grid coupling node, within an acceptable error and the simulation example shows the potential of this approach.

This control architecture potentially helps to increase the reliability of the whole grid, by means of the aggregation of unpredictable energy resources and making their overall behavior more predictable, at least from the DSO point of view. Furthermore, the flexibility of the devised framework allows for an interchangeability of different algorithms: for example more sophisticated energy tracker algorithms may be used for the low level control.

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