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Improved time representation model for the simultaneous energy supply and demand management in microgrids

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ABSTRACT

This paper analyses the operational decision making procedures required to address the simultaneous management of energy supplies and requests in a microgrid scenario, in order to best accommodate arbitrary energy availability profiles resulting from an intensive use of renewable energy sources, and to extensively exploit the eventual flexibility of the energy requirements to be fulfilled. The optimization of the resulting short term scheduling problem in deterministic scenarios is addressed through a MILP (Mixed-Integer Linear Programming) mathematical model, which includes a new hybrid time formulation developed to take profit of the advantages of the procedures based on discrete time representations, while maintaining the ability to identify solutions requiring a continuous time representation, which might be qualitatively different to the ones constrained to consider a fixed time grid for decision-making. The performance of this new time representation has been studied, taking into account the granularity of the model and analyzing the associated trade-offs in front of other alternatives. The promising results obtained with this new formulation encourage further research regarding the development of decision-making tools for the enhanced operation of microgrids.

1. Introduction

Energy production and management is receiving growing attention in recent years. The interest in energy from renewable sources also increased due to the volatile price of fossil fuels, environmental concerns and the energy security. In this field, Energy Systems Engineering involves all the decision-making procedures associated to energy supply chain from the primary energy source to the final delivery to the customer. Its main objectives are to reduce costs, to reduce the environmental impact and to satisfy the market imposed energy demand.

Traditional power grids are based on static networks where large power plants generate electricity to be used at industrial or domestic level [1]. The optimization of the associated large-scale centralized production management problem is complicated by the need to include in the model the elements required to solve the transmission problems arising from the physical distance between energy production and energy demand, although usually, the flexibility in this classical energy supply chain is very limited, due to the need to match energy production and demand in the framework of an uncertain scenario.

On the other hand, most of renewable energy producers (i.e., photovoltaic panels, wind turbines) have relatively less capacity but are installed in a more distributed manner at different locations, potentially near the energy consumers, which reduces energy transmission losses in comparison with traditional power grids. These infrastructures may be locally interconnected in order to achieve the higher degree of flexibility required to match generation and demand. In this sense, the resulting microgrids usually include an extensive number of measuring devices as energy meters [2], to obtain prompt and reliable information on energy consumptions, since the access to real-time information becomes essential to exploit the above mentioned flexibility, to improve the efficiency and reliability of the grid (reducing the incidence of adverse events, as blackouts), the proactive maintenance schedule, and finally the customer savings [3].

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Nomenclature

Indexes and sets

$i \in I$	energy production source
$j \in J$	energy consumer
$f \in F$	energy demands
$jf \in F_j$	subset of energy demands associated to energy consumer j
$k \in K$	energy storage systems
$r \in R$	power grid
$t \in T$	time intervals included in the overall scheduling horizon

Parameters

$Cons_{j,f}$	individual power requirement jf [kW]
$cpen_{j,f,t}$	penalty cost [m.u./time]
$cpro_{i,t}$	production energy cost [m.u./kWh]
$csto_{k,t}$	storage energy cost [m.u./kWh]
DT	span of the time interval [h]
$Dur_{j,f}$	duration of consumption jf [h]
$P_{i,t}^{min}$	minimum power supply of source i at interval t [kW]
$P_{i,t}^{max}$	maximum power supply of source i at interval t [kW]
$Price_{r,t}$	energy price to be sold to power grid r at interval t [m.u./kWh]
$SE_{k,t}^{min}$	minimum electricity storage of system k at interval t [kWh]
$SE_{k,t}^{max}$	maximum electricity storage of system k at interval t [kWh]
$SE0_{k,t}$	initial storage level of system k at interval t [kWh]
$XDem_{j,f,t}$	period of time in which consumption jf is active at interval t [h]
$Ts_{j,f}^{max}$	maximum initial time of consumption jf [h]
$Ts_{j,f}^{min}$	target initial time of consumption jf [h]
η_k^{in}	charging efficiency of energy storage system k
η_k^{out}	discharging efficiency of energy storage system k

Variables

$Benefit$	microgrid benefit [m.u.]
$CostPen$	total penalty cost [m.u.]
$CostPro$	total production cost [m.u.]
$CostSto$	total storage cost [m.u.]
Dem_t	total energy consumption at interval t [kWh]
$Incomes$	microgrid incomes [m.u.]
$Ld_{k,t}$	energy supplied to load system k during interval t [kWh]
$P_{i,t}$	power supply of source i at interval t [kW]
$Pg_{r,t}$	power supplied to power grid r at interval t [kW]
$Profit$	total profit along the time horizon (objective function) [m.u.]
PT_t	total power supply at interval t [kW]
$SE_{k,t}$	electricity storage level of system k at the end of the interval t [kWh]
$SP_{k,t}$	energy supplied by storage system k during interval t [kWh]
$Tf_{j,f}$	final time each consumption jf [h]
$Ts_{j,f}$	initial time each consumption jf [h]
T_t	time [h]

Binary variables

$X_{i,t}$	binary variable indicating whether or not supply i is used at interval t
$Y_{j,f,t}$	binary variable indicating if consumption jf starts at interval t
$Z_{j,f,t}$	binary variable indicating if consumption jf finishes at interval t
$W_{j,f,t}$	binary variable indicating if consumption jf is active at interval t

The simultaneous management of energy production and demand would introduce an additional degree of freedom to the grid management problem, which would permit achieving further benefits. In the case of a system incorporating renewable energy sources, these benefits include the integration of such intermittent systems at the distribution level [4], and so the reduction of the dependence of non-renewable sources. This additional flexibility can be greatly potentiated by energy storage systems, which may be used to decouple production and demand peaks, and to cope with the uncertain (fluctuating) availability of renewable resources.

For these previous reasons, the development of an efficient energy planning and scheduling model is necessary to coordinate generation, storage and use of energy to maximize efficiency by optimally adjusting production and demand. This paper proposes a general model to solve the operational decision making problem for a microgrid, considering the simultaneous management of energy production and consumption. Two particular models using discrete and hybrid time representations have been implemented to study the trade-off between both approaches, taking into account the granularity of the problem. The assessment of their performance is presented through a case study addressing the optimal management of the energy generation, storage and consumption of several appliances within a single household served by a simple microgrid.

2. State of the art

The growing interest in energy microgrids has led to the development of several mathematical models and representation schemes related to their management, as well as to their design [5], including the energy production management, the energy demand-side management and the coordinated management of energy production and demand.

One of the recurrent issues to be discussed when addressing management or scheduling problems refers to the way how the time dimension should be represented. Different alternatives can be used including discrete, continuous and hybrid time representations.

The discrete time representation is based on dividing the scheduling horizon into a finite number of time intervals, forcing all activities to start/finish at the boundaries of these time intervals. Discrete time representation is widely applied in industrial processes [6]. Although it leads to a simplified version of the original problem, this time formulation is efficient in cases in which a reasonable number of time intervals is sufficient to represent appropriately the problem under study. The size of the mathematical model and the computational time required to solve it depend, among other factors, on the length of the time interval (i.e., the number of time intervals), and the appropriate length of the time interval depends on the characteristics of each problem, such