Applied Energy 155 (2015) 485–501

Contents lists available at ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

A rolling horizon optimization framework for the simultaneous energy supply and demand planning in microgrids

Javier Silvente [a], Georgios M. Kopanos [b,c,*], Efstratios N. Pistikopoulos [b,d], Antonio Espuña [a]

[a] Universitat Politècnica de Catalunya, ETSEIB, Department of Chemical Engineering, 647 Diagonal Avenue, 08028 Barcelona, Spain
[b] Imperial College London, Department of Chemical Engineering, Centre for Process Systems Engineering, London SW7 2AZ, United Kingdom
[c] Cranfield University, School of Energy, Environment & Agrifood, Bedfordshire MK43 0AL, United Kingdom
[d] Texas A&M University, Department of Chemical Engineering, 3122 TAMU, College Station, TX 77843-3122, United States

HIGHLIGHTS

- MILP formulation is proposed to manage energy production and demand.
- Flexible demand profile has been considered by applying penalty terms.
- A rolling horizon approach is introduced to deal with uncertainty associated to production and consumption.
- This approach allows updating input parameters, in order to react to variations from the nominal schedule.

ARTICLE INFO

Article history:
Received 19 January 2015
Received in revised form 25 May 2015
Accepted 26 May 2015

Keywords:
Energy planning
Rolling horizon
Scheduling
Mathematical programming
Microgrid
Demand side management

ABSTRACT

This work focuses on the development of optimization-based scheduling strategies for the coordination of microgrids. The main novelty of this work is the simultaneous management of energy production and energy demand within a reactive scheduling approach to deal with the presence of uncertainty associated to production and consumption. Delays in the nominal energy demands are allowed under associated penalty costs to tackle flexible and fluctuating demand profiles. In this study, the basic microgrid structure consists of renewable energy systems (photovoltaic panels, wind turbines) and energy storage units. Consequently, a Mixed Integer Linear Programming (MILP) formulation is presented and used within a rolling horizon scheme that periodically updates input data information.

1. Introduction

The development of sustainable energy supply chains has led to advances in the area of Energy Systems Engineering, which involve all the decision-making procedures from the primary energy source to the final energy delivery to the costumer. The main objectives and challenges of managing energy systems are to reduce costs associated to the exploitation of the energy network, to reduce the environmental impact caused by the production and transmission of energy and to satisfy the energy demand subjected to unexpected internal and external disturbances.

Traditionally, power grids are based on centralized networks where large power plants generate electricity that is used posteriorly at industrial or domestic level [1]. This kind of energy supply chains involves energy losses in power transmission due to the physical distance between the electricity generation and consumption sites. Furthermore, the generation of energy in centralized networks usually exploits non-renewable sources (i.e., fossil fuels), which has a negative environmental impact (i.e., pollution, climate change).

Microgrids are based on the decentralized energy supply chain concept, which can integrate several renewable and non-renewable energy sources that are usually close to energy consumers. A major drawback of renewable energy systems is the apparent mismatch of the volatility of energy production from renewable sources and energy demand. Natural energy resources though, have the disadvantage of intermittent and unpredictable production, due to their dependence on natural phenomena, the forecast techniques of which are far from reliable [2]. Thus, the simultaneous consideration of energy production and demand is essential to manage appropriately a microgrid, in order to match

* Corresponding author at: Cranfield University, School of Energy, Environment & Agrifood, Bedfordshire MK43 0AL, United Kingdom.
E-mail address: g.kopanos@cranfield.ac.uk (G.M. Kopanos).

http://dx.doi.org/10.1016/j.apenergy.2015.05.090
0306-2619/

Nomenclature

Indices and sets

$i \in I$ energy production generators
$j \in J$ energy consumers
$f \in F_j$ energy demand included in the overall scheduling horizon
$f \in F_jRH$ energy demand included in the current prediction horizon
$k \in K$ energy storage systems
$r \in R$ power grids
$t \in T$ time intervals included in the overall scheduling horizon
$t \in TRH$ time intervals included in the current prediction horizon

Parameters

CH length of the control horizon (h)
$Cons_{j,f}$ individual energy consumption of each energy consumption task jf (kW h)
$cpen_{j,f,t}$ penalty cost (m.u./time)
$cpro_{i,t}$ production energy cost (m.u./kW h)
$csto_{k,t}$ storage energy cost (m.u./kW h)
DT duration of the time interval (h)
$Dur_{j,f}$ remaining time consuming of consumption jf in the current prediction horizon (h)
$Dur_{0,j,f}$ time consuming of energy consumption jf in the overall scheduling horizon (h)
it Iteration
$P_{i,t}^{min}$ minimum power supply of energy generator i at interval t (kW)
$P_{i,t}^{max}$ maximum power supply of energy generator i at interval t (kW)
PH length of the prediction horizon (h)
$Price_{r,t}$ energy price to be sold to power grid r at interval t (m.u./kW h)
$SE_{k,t}^{min}$ minimum electricity storage of system k at interval t (kW h)
$SE_{k,t}^{max}$ maximum electricity storage of system k at interval t (kW h)
$SE_{0k,t}$ initial storage level of system k at interval t (kW h)
SH length of the scheduling horizon (h)
$Ts_{j,f}^{max}$ maximum initial time of consumption jf in the current prediction horizon (h)
$Ts_{j,f}^{min}$ Target initial time of consumption jf in the current prediction horizon (h)
$Ts_{0,j,f}^{max}$ maximum initial time of consumption jf in the overall scheduling horizon (h)
$Ts_{0,j,f}^{min}$ target initial time of consumption jf in the overall scheduling horizon (h)
η_k^{in} charging efficiency of energy storage system k
η_k^{out} discharging efficiency of energy storage system k
α_k percentage of the maximum energy storage system k

Continuous variables

$Benefit$ microgrid benefit (m.u.)
$CostPen$ total penalty cost (m.u.)
$CostPro$ total energy production cost (m.u.)
$CostSto$ total storage cost (m.u.)
$Costs$ total operation cost of the microgrid (m.u.)
Dem_t total energy consumption at interval t (kW h)
$Incomes$ microgrid incomes (m.u.)
$Ld_{k,t}$ energy supplied to load system k during interval t (kW h)
$P_{i,t}$ power supply of energy generator 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 (kW h)
$\widehat{SE}_{k,t}$ linking variable determining the storage level of energy storage system k at the end of interval t in the current prediction horizon (kW h)
$SP_{k,t}$ energy supplied by storage system k during interval t (kW h)
$Tf_{j,f}$ finishing time of each consumption jf (h)
$Ts_{j,f}$ starting time of each consumption jf (h)
T_t time corresponding to time interval t (h)

Binary variables

$X_{i,t}$ =1, if energy generator i is used at interval t
$Y_{j,f,t}$ =1, if consumption jf starts at interval t during the current prediction horizon
$\widehat{Y}_{j,f}$ =1, if consumption jf starts outside the current prediction horizon
$Z_{j,f,t}$ =1, if consumption jf finishes at interval t during the current prediction horizon
$\widehat{Z}_{j,f}$ =1, if consumption jf finishes outside the current prediction horizon
$W_{j,f,t}$ =1, if consumption jf is active at interval t during the current prediction horizon

energy production and demand. Moreover, the use of energy storage systems is a common way to alleviate this mismatch and tackle the uncertainty in energy demand forecasts. Furthermore, energy storage provides the necessary tools to schedule the flexible energy demand according to time-of-use market base pricing, introducing enough operational flexibility to efficiently exploit periods of low prices, avoiding pick prices and reducing energy costs.

As mentioned above, the behavior of natural energy sources involves the consideration of uncertainty in microgrids, in order to ensure the generation of good quality and practical management decisions. Particularly, the operations management of microgrids is affected by several types of uncertainty, such as energy demand variations and weather conditions which affect the availability and production capacity of renewable energy systems. The decision making process becomes more complex if the consideration of different sources of uncertainty in the models is essential to ensure the quality of the solution or even its practical feasibility. Different types of uncertainty sources can be found, including:

(i) External sources, including uncertainty in energy demand, prices and availability of resources.
(ii) Internal sources, like fluctuations in process parameters.
(iii) Other sources, such as measurements errors or strikes.

The approaches to address scheduling problems under uncertainty could be classified into reactive and proactive. On one hand, reactive approaches focus on modifying a nominal schedule obtained by a deterministic formulation in order to adjust it to different alterations, modifications or updated system data. On the other hand, proactive approaches are based on the consideration