A System Approach to Optimize Regional Energy Systems with Power Distribution Constraints and Options

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Overview

This paper presents the ETEM-SG model, which provides a simulation of the long term development of a regional multi-energy system in a smart city environment. The originality of the modeling comes from a representation of the power distribution constraints associated with intermittent and volatile renewable energy sources connected at the transmission network like, e.g. wind farms, or at the distribution networks like, e.g. roof top PV panels. The model takes into account the options to optimize the power system provided by grid friendly flexible loads and distributed energy resources, including variable speed drive powered CHP micro-generators, heat pumps, and electric vehicles. One deals with uncertainties in some parameters, by implementing robust optimization techniques. A case study, based on the modeling of the energy system of the "Arc Lémanique" region shows on simulation results, the importance of introducing a representation of power distribution constraints and options in a regional energy model .

Methods

ETEM-SG (Energy-Technology-Environment-Model with Smart Grids) [2] is a linear programming model, which represents the optimal capacity expansion in production technology and the flow of resources in the whole energy system. In its standard version, the model is driven by exogenously defined useful energy demands, that is the demand for energy services, and imported energy prices. All technologies are defined as resource transformers and are characterized by technical coefficients describing input and output, efficiency, capacity bounds, date of availability (for new technologies), life duration, etc. Economic parameters relate to investment, operation and maintenance costs for each technology. The planning horizon is generally long enough to offer a possibility for the energy system to have a complete investment technology mix turnover. Typically ETEM-SG simulates the development of an efficient regional energy system with a planning horizon of 30 to 50 years usually divided in periods of 1 to 5 years. In each period one considers a few typical days (e.g., 6 days corresponding to the three seasons – Winter, Summer, Spring-Fall – and two week day types – working weekday, weekend-Holiday –). Each of these days is subdivided into groups of hours, to obtain finally a set of timeslices that will be used to represent load curves and distribution of demand and resource availability in different seasons and at different time of the day.

Modelling distribution options and constraints. We have introduced in ETEM-SG a representation of power distribution systems, with smart grid operations, as proposed in Ref [1]. Precisely, distribution activities and contraints in ETEM-SG represent the management of centralized and distributed loads, storage and generation units for a local/regional power system at all periods and timeslices. We assume that a distribution system is composed by one ∞-bus and various downstream buses. The ∞-bus corresponds to the substation and each downstream bus corresponds to loads and DERs connected to a distribution feeder. The model's logic is as follows: Conventional generators and wind generators proposed by ETEM-SG are located to bus ∞ and each distribution feeders corresponds to an ETEM-SG region that is connected to bus ∞. Each feeder bus hosts (i) demand corresponding to conventional loads (typically lighting), which consumes as a by-product "reactive power" whose magnitude depends on a constant power factor, (ii) flexible loads (typically EV battery charging, variable speed drive heat pumps for space conditioning), and (iii) PV generation. EV battery chargers and PV inverters can provide reactive power compensation as needed when they have excess capacity, i.e. when the sun does not shine or when the EV battery is not charging. During a given time slice, flexible loads produce value (or utility to their owners) by providing a service, such as space conditioning that maintains inside temperature within a comfort temperature zone, increasing the state of Charge of thee EV battery and the like.

The model computes thus real power, reactive power and reserves associated with each region so as to satisfy load flow, voltage, energy balance and reserve requirement constraints.

Robustification to deal with uncertainty. ETEM-SG implements robust optimization methods to deal with uncertainty. In short, Robust optimization [3,4] is an approach that essentially ensures that uncertain constraints in an optimization problem remain feasible for a whole set of possible realizations of random parameters. ETEM-SG thus proposes robust energy policies that remain "good" whatever these realizations. We have applied the robustification technique on our case study on two possible sources of uncertainty on (i) availability factors and (ii) new technology investment costs, respectively.

Results

The model has been tested on a case study corresponding to the "Léman region" in Switzerland. We consider three distribution feeders corresponding, globally, to the three power distribution companies operating in the region. The interpretation of the numerical expriments shows that:

1. ETEM-SG captures the substantial help provided by DERs for a strong penetration of renewables.

2. The consideration of power distribution options and constraints does bring significative changes in technology choices, in the space heating and transport sectors. In general the electricity consumption and local production are reduced, when power distribution losses and costs are better represented.

3. In the context of stringent emissions reduction policies, EVs with their batteries as well as flexible loads play a key role in the penetration of electricity-based technologies and intermittent productions. They facilitate the supply/demand balance for electricity by smoothing production and consumption. They also help significantly to the stability of the power distribution systems with their contribution to reactive power compensation and reserve requirements.

4. Including robustification on energy prices in the design of scenarios amplifies the VRE penetration and leads to higher diversification in the technology portfolio. The proposed approach can handle in a same modelling exercise a large set of uncertainty sources (e.g., import prices, technology costs, technology efficiency and availability, etc) without increasing dramatically CPU time.

Conclusions

When modeling local/regional energy systems, in a smart grid or, more generally, smart city environment, it becomes very important to represent the constraints, costs and capabilities that are present in distribution networks. With ETEM-SG, local/regional energy and environment planners have the possibility to propose coherent scenarios for the massive penetration of VRE power generation accompanied by the development of smart grid operations, permitting demand-response, distributed reserves as well as distributed reactive power compensation, and the like. The model is currently being tested on case studies of the Arc Lémanique region, in Switzerland, the region of Doha in Qatar, and the non-interconnected regions of the French islands (la Réunion, Corsica, etc.). The first implementations have shown the model's ability to exploit the new potential for efficiency improvement provided by smart grid integration of distributed energy resources. In particular, the scenarios demonstrate the contribution of smart grid integrated flexible loads and distributed energy resources to the efficient adoption of solar and wind generation.

References

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