PROSPECTS OF OPTIMIZED DISTRIBUTED GENERATION AND ELECTRIC VEHICLE CHARGING IN MICRO GRIDS

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Overview

The design of a likewise sustainable, climate-friendly, safe, and efficient energy supply presents both current and future society with great challenges. In order to meet this requirement, the energy sector, driven by political, economical, and social decisions, is changing continuously. This evolution thereby affects all areas of energy supply, namely provision, transport, distribution and demand. Induced by expansion of decentralized electricity generation by renewable energy sources (RES), use of storage, new load characteristics such as electric vehicles (EVs) (Flath et al. 2013), and market liberalization (Markard and Truffer 2006), as well as increased involvement of society on climate protection and market participation (Clastres 2011), the growing number and heterogeneity of actors and elements particularly increase the complexity of the electricity sector.
Apart from the implied problems, these developments offer great potential within a new design of a future power supply: More and more consumers will generate electricity by using combined heat and power (CHP) and photovoltaic (PV) systems, and will even apply either a stationary or mobile storage (EV) (IEA 2012; Flath et al. 2013), therefore becoming in most hours less dependent on centralized conventional power generation. More frequently those electricity producing consumers will be situated in electricity networks which changed from a top-down to a cell structure (Clastres 2011). Moreover they will be organized in local markets (Hvelplund 2006) with simple access for individual actors using new information and communication technology (ICT) appliances. These local grid cell systems offer an incentive to locally balance power supply and consumption, and hence reduce the degree of grid capacity utilization.
To estimate the potential of such a new design of a future power supply system, its elements and their impact on the system must be analyzed in detail. This paper therefore aims to examine individual consumers and their cost optimized scheduling of power consumption (incl. charging of the EV), generation, and storage, as well as the implications for the local grid cell.

Methods

Within the field of energy economics different kinds of models are applied to analyze power systems, allowing for a better understanding and representation of complex system processes. Simulation of electricity systems over a given time horizon facilitates a determined analysis of the complex processes within the structure, elements, and environment of the system. Focusing on the individual system elements and actors, agent-based modeling and simulation allows for the consideration of a multitude of separate influences. Hence, in this paper a new agent based model (ABM) representing a local grid cell is developed based on experiences with other developed ABMs like PowerACE (Genoese 2010). The ABM is combined with optimization models of the individual consumers' decisions to adequately represent their scheduling of consumption, generation, and storage. It consists of (i) an environment, (ii) a structure, and (iii) elements which have been modeled as follows:
(i) The environment of the ABM contains information about the underlying legal framework and the market form and its organization, as well as technical, geographical (e.g. autonomous island) and political restrictions (e.g. balancing energy regulation). The analysis in this paper uses scenarios for the environment which represent real (The French Island of Guadeloupe and a local German municipal utility network) and fictional (for a sensitivity analysis) use cases.
(ii) The structures connecting the elements of the ABM are the city or island grid at low-voltage level (< 0.1 kV), the information network, and the legal (contracts, etc.), social (e.g. neighborhood), and political affiliations.
(iii) The elements of the ABM are either edges or knots. Edges represent the power lines of the distribution network and further (e.g. informational and political) links. Knots represent the interacting agents of the model and are pure generators, consumers (with or without power generation and with or without mobile or stationary storage), pure storages, or distribution system operators (DSO) of the local grid cell.

The agents' individual optimization problems are modeled as mixed-integer linear program (MILP) for typical days (weekdays and weekends in the four seasons) over a changing time horizon (from one day to one year, temporal resolution of 15 minutes). The optimization of the agents is iterated at each time step of the ABM to be able to simulate learning effects (reinforcement learning) and reactivity. Additionally, uncertainties are considered by the configuration of the structure (e.g., lack of information) and environment (e.g. weather, affecting sunshine hours), as well as by introducing bounded rationality of agents.
The first set of behaviors and characteristics of the agents are extracted from data of different field tests and projects: The project CROME (cross-border mobility for electric vehicles) provides hundreds of patterns of use of EVs and availability for the grid (Ensslen et al.2013). Load and use of stationary storages are made available by the project iZEUS (intelligent Zero Emission Urban System) (Kaschub 2013). The power generation is deduced from the work of Schönfelder (2013) for CHP and Kaschub et al. (2013) for PV.

Results

The simulation runs start with different agent population scenarios (high medium and low technology diffusion) as initial points which were derived from technology diffusion scenarios (Flath et al. 2013). Results of the runs show that, depending on the chosen environment and agent population, grid cells can efficiently balance power consumption and generation on a local level. Also, the multi agent system (MAS) can optimize an overall cost minimizing objective for the grid cell even with individually cost optimizing consumers. The simulation runs equally identify costs for the degree of self-sufficiency and show that some of the individual consumers (mainly those with EV and stationary storage) nearly reached self-sufficiency by acting rationally and deciding on the basis of their MILP solution. Nevertheless, simulation runs with present technology diffusion scenarios still show a high dependence of consumers, and consequently grid cells on a connection to a greater power network to balance consumption and production.

Conclusions

In this paper, a bottom-up modeling process from individual consumer agent to power grid cell network is described. This approach allows the integration of a multitude of required details, but also reduces complexity where necessary. The focus is set on the modeling of consumers with an EV and stationary storage, and thereby reveals consolidated findings about how such a consumer should act in order to optimize consumption and generation. Furthermore, the subsequent integration of these agents into the MAS leads to a better understanding of the impact of consumers' decisions on local grid cells.

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