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Optimal investment and scheduling of distributed energy resources with uncertainty in electric vehicle driving schedules

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ABSTRACT

The large scale penetration of electric vehicles (EVs) will introduce technical challenges to the distribution grid, but also carries the potential for vehicle-to-grid services. Namely, if available in large enough numbers, EVs can be used as a distributed energy resource (DER) and their presence can influence optimal DER investment and scheduling decisions in microgrids. In this work, a novel EV fleet aggregator model is introduced in a stochastic formulation of DER-CAM [1], an optimization tool used to address DER investment and scheduling problems. This is used to assess the impact of EV interconnections on optimal DER solutions considering uncertainty in EV driving schedules. Optimization results indicate that EVs can have a significant impact on DER investments, particularly if considering short payback periods. Furthermore, results suggest that uncertainty in driving schedules carries little significance to total energy costs, which is corroborated by results obtained using the stochastic formulation of the problem.

1. Introduction

The definition of distributed energy resources (DER) expands on the definition of distributed generation (DG) by including both storage and controllable loads [2,3]. It carries all the potential benefits of DG, but also considers additional load shifting and demand response measures that add to the complexity of strategic DER investment and scheduling decisions in microgrids, particularly under uncertainty. New and emerging technologies add to this problem, and plug-in electric vehicles (EV) are a clear example. A large scale penetration of EVs in microgrids will introduce new technological challenges and add to electric loads [4], but will also carry a significant potential for ancillary services [5–7]. Under this scenario EVs will be considered a DER and must be included in DER investment decisions.

The problem of optimal DER investment and scheduling deals with finding the optimal DER configuration and dispatch under given energy loads, technology data, market information and weather conditions. Solutions provide optimal installed capacity and operation schedule of each DER, including renewable and conventional generation technologies, combined heat and power production, local energy storage of both electricity and heat, and demand response. This is typically done considering annualized capital costs, operation and maintenance costs, and fuel costs, as well as grid purchases under different tariff schemes. It is often the complexity of these tariff schemes, with high time-dependent power and energy rates that make DER investment economically attractive, although environmental motivations are also common [8]. Therefore, the objective function in DER investment and scheduling problems generally focuses on total cost minimization, but environmental and multi-objective approaches are also used.

Several studies have addressed DER investment and scheduling problems: In Ref. [9], a mixed integer linear program (MILP) is presented for structural and operational optimization of distributed energy systems, including transport of electricity, liquid fuels and water. In Ref. [10], a linear program is developed for high level

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design and unit commitment in a microgrid, considering explicit islanded mode periods. A MILP model, DER-CAM, is described in Ref. [1], dealing with optimal DER investment and introducing the impact of carbon taxation in optimal investment decisions. A similar model is introduced in Ref. [11], dealing with DER investments in Japan. In Ref. [12], a MILP model is presented to optimize the daily scheduling of a microgrid while introducing a diversity constraint to ensure higher reliability. The optimal design and operation of DER is also considered in Ref. [13], taking into account the design of the heating pipeline network. In Ref. [14], a genetic algorithm is used to solve the mixed integer non-linear formulation of optimal DER investment in a residential area in Beijing. The short term scheduling of DER is analyzed in Ref. [15], using signalized particle swarm optimization.

While some of these models already present a high level of sophistication and address a large number of issues in DER investment and scheduling problems, little work has been done considering EVs and vehicle-to-grid interactions (V2G) in the presence of uncertainties.

V2G is a relatively new concept and is based on the principle that if a significantly high number of EVs is available at the grid it will not only have an impact on the loads, but will also have the potential to be used as a DER. A common approach to the interface between the EVs and the grid is the use of Aggregators, so that the full V2G potential can be achieved and the EV fleet can be effectively integrated and managed [16]. Ancillary services provided by V2G can be both capacity- and energy-based, and frequency regulation is seen as a key potential service [17]. The economic viability and business models of V2G technology have already been addressed [18–20], and models have been presented regarding EV bidding and optimal charging strategies [21]. Some work has also been focused on the problem of optimally managing a microgrid including vehicle-to-grid interactions [22], and in Ref. [23], the role of the Aggregator is addressed and a mathematical formulation is presented with respect to frequency regulation. In Ref. [24], a stochastic method is developed to optimize the use of renewable sources to charge electric vehicles. However, few studies address V2G benefits while analyzing DER investments at microgrids.

In Ref. [25], DER-CAM is used to address the investment and planning decisions of DERs in the presence of EVs as a deterministic optimization problem, while the EV fleet Aggregator model considers only a single driving schedule for the entire fleet and defines a typical year by 3 typical days of hourly loads per month.

1.1. Problem statement

The work presented in this paper advances the state-of-the-art of DER investment and scheduling problems by adding to the work presented in Ref. [25]. It addresses the problem of finding optimal DER investment options considering that privately owned EVs will become widely available at and may influence other DER investment decisions in microgrids due to their V2G potential.

In previous work this was done using a less detailed deterministic model, whereas now it is addressed by proposing a novel stochastic programming formulation of the problem with a new EV fleet aggregator model and considering uncertainty in driving schedules. In particular, an updated version of DER-CAM was created to accommodate these features, also with an increased amount of data from 3 to 7 typical days of hourly loads per month for the typical year (a total of 84 typical days per year rather than 36) to better capture potential storage benefits.

The resulting version of DER-CAM is then used to perform a case study with technology costs and performance coefficients being forecasted for 2020, when it is expected that EVs may be widely available and V2G benefits within reach. Among other settings, the problem is solved both with and without considering EVs, which allows understanding how their presence and the uncertainty in their driving schedules may influence the adoption of other technologies.

The remainder of this paper is organized as follows: Section 2 introduces briefly DER-CAM and its main versions and past applications. Section 3 describes the EV fleet aggregator model proposed in this work and Section 4 introduces the stochastic formulation of DER-CAM. Section 5 introduces the data used in the case study. Section 6 discusses the optimization runs and main results obtained. In Section 7, the main conclusions are presented.

2. DER-CAM

DER-CAM is a MILP model developed by the Lawrence Berkeley National Laboratory and used extensively to address the problem of optimally investing and scheduling DER under multiple settings. Its earliest development stages go back to 2000 [26], and stable versions can be accessed freely by the general public using a web interface [27].

Along with HOMER [28], formerly developed by the National Renewable Energy Laboratory, it is one of the few optimization tools of its kind that is available for public use. It has been continuously improved to incorporate new technologies and features, and used in several peer-reviewed publications [1,29–31]. Recently, it has also been updated to incorporate EVs [25].

The key inputs in DER-CAM are customer loads, market tariffs including electric and natural gas prices, techno-economic data of DG technologies including capital and operation and maintenance costs, electric efficiency, heat-to-power ratio, sprint capacity, maximum operating hours, among others. Key outputs include energy costs, the optimal installed on-site capacity and dispatch of selected technologies, and demand response measures. Fig. 1 presents a high level representation of the energy flows modeled in DER-CAM. The purpose of the model is to find the optimal combination of technology adoption and operation to supply the services represented on the right side of Fig. 1, while optimizing the energy flows to minimize costs and / or CO_2 emissions.

Two main versions of DER-CAM have been developed: Investment & Planning DER-CAM, available for both research and the general public, and Operations DER-CAM, available only for research purposes. Investment & Planning DER-CAM deals with the assignment problem described in Section 1, and picks optimal microgrid equipment combinations based on either 36 or 84 typical days representing a year of hourly energy loads and technology costs and performance, fuel prices and utility tariffs. Operations DER-CAM deals with problem of optimal dispatch in a microgrid for a given period, typically a week ahead, with a time resolution of 5 min, 15 min, or 1 h, assuming the installed capacity is known and using weather forecasts from the web to forecast requirements.

In this paper, a new aggregated EV interconnection model is introduced for the Investment & Planning DER-CAM, and stochastic programming is implemented in the model in order to consider uncertainty in driving schedules. The model considers 84 typical day types per year.

3. EV fleet aggregator model

In previous work, DER-CAM considered EVs assuming a fixed driving pattern which was followed by the entire EV fleet. Thus, all vehicles were assumed to either connect or disconnect simultaneously, which is an important limitation. Additionally, the model only explicitly accounted for EV operations while they were connected to the microgrid, and home charging as well as CO_2