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Multi-objective energy storage power dispatching using plug-in vehicles in a smart-microgrid

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ABSTRACT

This paper describes a multi-objective power dispatching problem that uses Plug-in Electric Vehicle (PEV) as storage units. We formulate the energy storage planning as a Mixed-Integer Linear Programming (MILP) problem, respecting PEV requirements, minimizing three different objectives and analyzing three different criteria. Two novel cost-to-variability indicators, based on Sharpe Ratio, are introduced for analyzing the volatility of the energy storage schedules. By adding these additional criteria, energy storage planning is optimized seeking to minimize the following: total Microgrid (MG) costs; PEVs batteries usage; maximum peak load; difference between extreme scenarios and two Sharpe Ratio indices. Different scenarios are considered, which are generated with the use of probabilistic forecasting, since prediction involves inherent uncertainty. Energy storage planning scenarios are scheduled according to information provided by lower and upper bounds extracted from probabilistic forecasts. A MicroGrid (MG) scenario composed of two renewable energy resources, a wind energy turbine and photovoltaic cells, a residential MG user and different PEVs is analyzed. Candidate non-dominated solutions are searched from the pool of feasible solutions obtained during different Branch and Bound optimizations. Pareto fronts are discussed and analyzed for different energy storage scenarios. Perhaps the most important conclusion from this study is that schedules that minimize the total system cost may increase maximum peak load and its volatility over different possible scenarios, therefore may be less robust.

1. Introduction

The main goal of this paper is to address the power dispatching problem regarding to the minimization of six different objective functions: Microgrid (MG) total costs; usage of PEV batteries, maximum grid peak load, volatility behavior in extreme scenarios and two different criteria based on the Sharpe Ratio index. In order to evaluate suitable schedules to be applied in extreme scenarios, we make use of probabilistic forecasts to generate different scenarios. The multi-objective energy storage management problem considers PEVs as main storage units, located at SmartParks. Power

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dispatching schedule is planned to meet PEVs operational requirements, settled by its users, and trying to charge PEVs batteries when energy price is cheaper.

Energy storage has been studied over the last decades and remains a great challenge [1]. Especially in MG systems, its use has important benefits. The use of storage allows both sides, demand and production, to optimize the power exchanged with the main grid, in compliance with the electricity market and forecasts. Renewable energy generators associated with storage units are considered as active distributed generators, one of the fundamental elements of power management in MG systems. Current smart-microgrid scenarios may include different renewable energy resources and different storage units. In this regard, storage is able to increase renewable energy self-consumption and independence from the grid. A wide range of applications exist for Energy Storage Systems (ESS). Tan, Li and Wang [2] refer the following: power quality enhancement, microgrid isolated operation, active distribution systems and PEVs' technologies. ESS ensembled with non-dispatchable renewable energy generation units, such as wind and solar energy, can be mold into dispatchable units. Their use may improve dynamic stability, transient stability, voltage support and frequency regulation [3]. Furthermore, they can also be used for minimizing global cost and environment impact.

MG systems require smarter operations to well-coordinate these new emerging decentralized power energy sources. Optimization methods justify the cost of investing in a MG system by enabling economic and reliable utilization of resources [4]. Olivares et al. [5] observed that the microgrid optimal energy management problem falls, generally, into the category of mixed integer nonlinear programming problems. Because, in general, objective functions may include higher polynomial terms and operational constraints. Levron, Guerrero & Beck [6] presented a methodology for solving the optimal power flow in MG. The model solves small systems containing up to two renewable generators and two storage devices. The proposed approach grows in complexity exponentially, since each storage device contributes extra dimensions to the solution space. The mathematical formulation proposed by Macedo, Franco, Rider & Romero [7] extended the approach of Levron, Guerrero & Beck [6]. Their formulation uses a convex equivalent model which obtains an approximate optimal solution for the same microgrid system. Mariani, Sareni, Roboam & Turpin [8] researched the power dispatching problem seeking to minimize system global energy costs. A smart-microgrids DC system with flywheel energy storage was analyzed. By considering forecasts for a MG residence and solar PV production, an off-line power dispatching was performed in the search of storage planning schedules. Mohammadi, Soleymani & Mozafari [9] considered uncertainties over the forecasting of consumption and renewable energy generation. A stochastic operation management of one day ahead was performed using a Heuristic Algorithm. At the initial state 2000 storage planning scenarios were generated, using a Probability Distribution Function (PDF) to represent the uncertainty of the forecasts. Those scenarios were generated and later reduced to 20 and sorted in ascending order of probability of occurrence. Recently, Kou, Gao & Guan [10] integrated a battery ESS with a wind farm, using stochastic model predictive control scheme. Based on the forecasted wind power distributions and uncertainties, using a sparse warped Gaussian process, they sought for optimal operation regarding wind power dispatchability. The influence of wind power rapid ramp events was considered by Wang, Yu & Yu [11], looking for an optimal dispatching strategy against wind power rapid ramp events during peak load periods. An energy storage system coupled with a PV plant was implemented for correcting the prediction errors by Delfanti, Falabretti & Merlo in Ref. [12]. They tried to fulfill the lack between the injections of a PV power plant and the day-ahead market power schedule, minimizing energy imbalances.

Torreglosa et al. [13] analyzed a long-term energy dispatching, based on a model predictive strategy using on state control. Another long-term scheduling was evaluated by Tascikaraoglu et al. [14], considering a hybrid system with RER and energy storage, in the concept of virtual power plant. They analyzed the economic operation of the system in order to enable it to participate in the electricity market with high levels of reliable power production. Trovão & Antunes [15] designed two meta-heuristic approaches for multi-ESS management in electric vehicles (EV). It has been noticed that hybridization of two or more energy storage elements into EV has been improving both the vehicle driving range and the lifecycle storage elements [16]. This kind of system allows batteries to perform power-sharing decisions in real time [17]. However, the latter did not consider the whole of RER along with the storage planning and scheduling.

Some approaches in the literature incorporated the reduction of Greenhouse gas (GHG) emissions as part of a Multi-Objective (MO) Optimization Problem [18–20]. Other applications spotlighted on finding the energy and power capacities of the storage system that minimizes the operating costs of the MG, as can be verified in Fossati, Galarza, Martín-Villate & Fontán [21].

In this paper, a new multi-objective power dispatching problem is introduced, aiming to minimize global MG costs while minimizing saving batteries wear and tear, maximum peak load, volatility between extreme scenarios and schedule's total cost and maximum peak load volatility. Understanding the contributions of batteries as an objective function provides profits not only for the PEVs owners, but, also takes into account environment issues. Optimize its use not only reduces battery replacement costs for the PEVs owners but also is beneficial for the environment, since they are going to be used when needed. The proposed model also tries to obtain energy storage planning scenarios which minimize maximum power flow between the smart-microgrid and the main grid. The two latter objectives evaluate the schedule compared to its extreme scenarios and also to a wide range of possible scenarios. This is done by measuring the current expected cost compared to other possible costs using Sharpe Ratio [22]. Sharpe ratio is a useful index tool for analysis, used by investors facing alternative choices under uncertainties [23].

Different ESS have been adapted to be used over MG, some examples are: Battery Energy Storage System [6], Compressed Air Energy Storage systems [24], Flywheels [8], Thermal Energy Storage [25], Pumped-storage hydroelectricity [26], Superconducting Magnetic Energy Storage [27]. On the other hand, the use of energy storage in connection with SmartParks is becoming crucial demand as the number of PEVs, such as electric cars and plug-in hybrid, in the market is increasing [28]. Smart Grid applications, being developed, are still analyzing the benefits of this growth [29]. Power dispatching systems are incorporating vehicle-to-grid (V2G) power transactions over their schedule. Bidirectional power flow between PEVs and the grid will become essential [28,30]. As emphasized by Romo & Micheloud [31], penetration of PEVs will increase significantly in the next 20 years. As a conclusion, smart parking lots with large fleets of electric cars can provide a flexible storage reserve for a MG system, reducing energy production needs.

Most of the work in the literature deal with the concept of parameters uncertainties of ESS management. In Papadopoulos et al. [32], results from a deterministic storage planning model showed that voltage violations would be quite high without the consideration of errors in the forecasts. From a probabilistic model with uncertainties, it was concluded that the integration of micro-generation in each MG household might reduce such violations.