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A probabilistic unit commitment model for optimal operation of plug-in electric vehicles in microgrid

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ABSTRACT

This paper presents a probabilistic Unit Commitment (UC) model for optimal scheduling of wind power, load forecasts and controllability of vehicles in a microgrid using a stochastic programming framework. The microgrid is made up of microturbines, wind turbine, boiler, Plug-in Electric Vehicles (PEVs), thermal storage and battery storage. The proposed model will help the power grid operators with optimal day-ahead planning even with variable operating conditions in respect of load forecasts, controllability of vehicles and wind generation. A set of valid scenarios is assigned for the uncertainties of wind sources, load and PEVs and objective function in the form of expected value. The objective function is to maximize the expected total profit of the UC schedule for the set of scenarios from the viewpoint of microgrid management. The probabilistic unit commitment optimizes the objective function using Particle Swarm Optimization (PSO) algorithm. In order to verify the effectiveness of the stochastic modelling and make a comparison with a simple deterministic one, a typical microgrid is used as a case study. The results can be used to evaluate the effect of integration of PEVs on the economic operation of the microgrid. The results also confirm the necessity to consider the key uncertainties of the microgrid; otherwise the results could overly misrepresent the real world operation of the system.

Contents

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1. Introduction

Today, global energy demand is growing rapidly which imposes a heavy burden on the existing energy resources and impact environmental pollution and economic growth [1]. In the next 25 years energy demand will increase by 50% due to population growth and economic development [2]. These problems can be addressed by using smart grid electricity. A smart grid focuses on three major areas: demand management, distributed electricity generation, monitoring and control [32]. One of the best emerging technology of distributed generation is to take a system approach which views generation and associated loads as a subsystem or a "microgrid" [33]. Meanwhile, renewable energy sources have attracted more attention from energy suppliers. Renewable energy sources are counted as an important alternative energy for microgrids due to high oil prices, the high cost of extending transmission lines and community interest in reducing carbon emissions [3]. Although the costs of conventional energy sources are less than renewable energies the combination of some renewable energies and fossil fuels could reduce the overall cost of energy in microgrids [4]. Therefore, economically, it is important to investigate options for supplying microgrids and determine the optimum combination of energy sources in the microgird. It may be that a significant portion of global noise pollution is caused by vehicles with internal combustion engines. The issue of pollution from such vehicles is a strong motivator towards developing more environmentally sustainable vehicles, and could give rise to Investment in Plug-in Electric Vehicles (PEV)s and associated infrastructure such as grids and charging stations [5]. Recent research by [6–8] has confirmed that PEVs technology provide a worthy option for considerable reductions in emission and fuel consumption. Indeed, PEVs can be bidirectional when they connect to the microgrid as a load or a power source. However, large numbers of PEVs connected to the microgrid together at the same time and certain location could add to that load increase [6,9–11]. Therefore managed charging and discharging through PEVs will deliver an optimal solution, if peak demand support is required.

The addition of PEVs into the electricity market may negatively impact on the performance of electrical distribution such as: (i) frequency (ii) voltage (iii) load leveling [8,12,13] as well as adversely affecting the price of consumer energy [6]. However, the combining of PEVs with renewable energy sources, show significant benefits such as: (i) managed charging, (ii) emergency backup power (iii) local power quality and (iv) bi-directional power flow [14].

Due to the uncertain operation output of renewable energy sources such as wind and solar, the integration of those resources with PEVs needs to be considered as a probabilistic Unit Commitment (UC) [10]. The UC model offers sound environmental and economic arguments for energy suppliers to merge towards the combined investment in PEVs and renewable energy in microgrid infrastructure planning. It has been established that PEVs can be used for energy storage, as an energy source units and draw loads within a microgrid that has been integrated with renewable energy sources [15]. However, the controllability of PEVs' discharging and charging operations was uncertain due to inadequate prediction models. Also, renewable energy sources influence market Operations, therefore forecasted load can be determined by UC. However, stochastic loads differ from actual ones due to the complexity of smart charging and discharging to and from various energy sources and loads. UC operation with increased uncertainty has proven to be a complex system especially once integrated with Vehicle to Grid (V2G) [6,8]. In general two different approaches could be considered to solve the problems: (i) Deterministic UC and (ii) Probabilistic/Stochastic UC.

A deterministic UC approach uses a traditional approach with optimization problem reliability constraints and it needs to revisit current operating reserve requirements. However Stochastic UC allows explicit representation of uncertainty in problem formulation with minimization of expected costs and increasing relevance due to additional uncertainty from wind power.

Various approaches [9,11] have been proposed for optimization of UC operation with consideration of different scenarios such as: (i) adapting Extended Priority List (EPL) method [16] based on heuristic underpinnings. (ii) spinning reserve [17] through a controller of the microgrid to determine energy bids according to renewable power output, demand, and price prediction. (iii) a probabilistic optimization [18,19] through consideration a number of wind power scenarios. (iv) Branch-And-Bound algorithm [20] based on the premise that only a specified percentage of electric vehicles operate in charge mode and this percentage is not a fixed number but varies according to travel patterns leading to a lack of enough storage capacity. (v) an intelligent method to Time-Of-Use (TOU) [21] price in a regulated market for minimizing the electric vehicles charging cost and reduce demand in peak time. (vi) a Particle Swarm Optimization (PSO) [22] for reducing emission and costs by prediction of load through intelligent scheduling.

Despite the ongoing investigation into the difference between forecasted loads and actual loads, there is still a gap in forecasting a realistic value and, also, how to account for load uncertainty, generator outages, and wind uncertainty in the day-ahead UC.

To the best of our knowledge, there has been no comprehensive study in UC operation to quantify the effect of V2G at various operating times while considering the number of producers, and consumers such as wind turbine, PEVs, electrical battery, thermal storage, and boiler systems within a microgrid power system which is subject to device and operating constraints based on cost price.

The main contributions of this paper are as follows:

- A Unit Commitment (UC) model, developed to schedule operations for a number of producers and consumers including a wind turbine, PEVs, electrical battery, thermal storage, and boiler systems within a power system while subject to device and operating constraints. Due to uncertainties, non-dispatchable renewable energy sources and complexity in power generation and demand, this UC model used a probabilistic method through optimization of the scheduling of wind power, load