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Day-ahead resource scheduling of a renewable energy based virtual power plant

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HIGHLIGHTS

- Simultaneous energy and reserve scheduling of a VPP.
- Aggregate uncertainties of electricity prices, renewable generation and load demand.
- Develop a stochastic scheduling model using the point estimate method.

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ABSTRACT

The evolution of energy markets is accelerating in the direction of a greater reliance upon distributed energy resources (DERs). To manage this increasing two-way complexity, virtual power plants (VPPs) are being deployed today all over the world. In this paper, a probabilistic model for optimal day ahead scheduling of electrical and thermal energy resources in a VPP is proposed where participation of energy storage systems and demand response programs (DRPs) are also taken into account. In the proposed model, energy and reserve is simultaneously scheduled considering the uncertainties of market prices, electrical demand and intermittent renewable power generation. The Point Estimate Method (PEM) is applied in order to model the uncertainties of VPP's scheduling problem. Moreover, the optimal reserve scheduling of VPP is presented which efficiently decreases VPP's risk facing the unexpected fluctuations of uncertain parameters at the power delivery time. The results demonstrated that implementation of demand response programs (DRPs) would decrease total operation costs of VPP as well as its dependency on the upstream network.

1. Introduction

The virtual power plant integrates and coordinates decentralized power-generating sites, storage facilities and controllable loads via a common intelligent control center. VPPs are not only used for marketing energy quantities produced by distributed generation systems but also play a part as regards the power systems. They enable the provision of system services in the distribution and transmission network such as operating reserve capacity. The VPP aggregates the electrical output from a multitude of distributed energy resources and makes this supply available to the system operator. If requested, the VPP controls the immediate dispatch of the connected plants, thus contributing to grid reliability. The aggregation of DERs aiming at providing reserve capacity is a suitable solution for compensating the unexpected power fluctuations of intermittent renewable generations.

Various literatures have already discussed VPPs and their challenges and opportunities in optimal scheduling issues or bidding strategies in markets. The literatures having some differences with the present work in terms of the possible embedded elements (e.g. storage or CHP, etc.) are investigated in the following. In [1,2], VPP is considered as a centralized entity containing some micro-CHP units connected to a low voltage distribution network. An optimal operation approach of a VPP composed of some CHP units is presented based on a decentralized control strategy [3]. In [1–3], however, the optimal usage of CHP systems has been defined as the main goal and the key role of electrical storages and demand response resources has not been taken into account. The impact of the use of flexibility at the demand side, also referred to as demand response, on power system operation is assessed in [4]. A two-stage modeling approach is used which combines a day-ahead deterministic unit commitment model and an hourly

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Nomenclature

Sets

- dg set of DG units, running from 1 to N_{dg}
- k set of demand response program levels containing I (first level), II (second level) and III (third level)
- t set of time periods, running from 1 to 24.
- z set of zones, running from 1 to N_z.
- ω set of scenarios, running from 1 to N_ω

Binary variables

- I, J, u binary variables pertaining to startup, shutdown and unit commitment status of VPP's resources, respectively

Continuous variables

- $P_{boil,zt}$ output power of boiler in period t and zone z
- $P^{e}_{chp,zt}$ ($P^{t}_{chp,zt}$) El. (Th.) output power of CHP in period t and zone z, respectively
- $P^{s}_{dg,zt}$ scheduled power deployed by DG units in period t and zone z
- $P^{k,s}_{drp,zt}$ scheduled power deployed by the kth level of demand response program in period t and zone z
- $P^{s}_{ens,zt}$ scheduled involuntary electrical load curtailment in period t and zone z
- $P^{s}_{line,zt}$ scheduled power flow through upstream line of zone z in period t
- $P_{sh,zt}$ surplus heat power in period t and zone z
- $P_{SR,t}$ VPP's bid to spinning reserve market in period t
- $P^{e}_{st,zt}$, $P^{t}_{st,zt}$ exchanged power into/out of El. and Th. storages in period t and zone z, respectively
- $R^{U,s}_{dg,zt}$, $R^{D,s}_{dg,zt}$ scheduled spinning reserve up and spinning reserve down deployed by DG units in period t and zone z, respectively
- $R^{U,k,s}_{drp,zt}$, $R^{D,k,s}_{drp,zt}$ scheduled reserve up and reserve down deployed by the kth level of demand response program in period t and zone z, respectively

simulation in real-time. A detailed modeling approach of both the supply and demand side is taken, allowing to obtain a realistic quantification of DR benefits. The focus of [4] is on residential DR, including the scheduling of white goods appliances and battery electric vehicles (BEVs). With regard to the presented work in [4], the use of cogeneration systems has not been embedded in the model. A stochastic programming framework for solving the scheduling problem faced by an industrial customer with cogeneration facilities, conventional power production system, and heat only units is proposed in [5]. The power and heat demands of the customer are supplied considering demand response (DR) programs. Power demand and pool prices are considered as stochastic processes in the scheduling problem, however, the use of renewable energy sources has not been investigated in the model. Ref. [6] presents a stochastic profit-based model for day-ahead operational planning of a combined wind farm-cascade hydro system. The generation company (GenCo) that owns the VPP considers a portion of its hydro plants capacity to compensate the wind power forecast errors. The proposed optimization problem is a mixed integer linear programming (MILP), formulated as a two-stage stochastic programming model. In [6], however, the presence of energy storages, demand response programs and cogeneration systems has not been investigated. An optimization methodology is proposed in [7] based on a multi-objective approach to handle with day-ahead optimal resource scheduling of a VPP in a distribution network considering different reactive power management strategies. The proposed methodology determines an optimal resource scheduling considering two competing objective functions. One objective function is expressed as the minimization of the operation cost of all distributed energy resources managed by the VPP, and the other one as the minimization of the voltage magnitude differences in all buses of the distribution network. The main goal is helping the VPP's management of a distribution network with high penetration of several distributed energy resources, such as distributed generation units, electric vehicles, and capacitor banks. Despite of the comprehensive proposed model in [7], the presence of demand response programs and cogeneration systems has not been investigated. A weekly self-scheduling of a VPP based on stochastic programming has been tackled in [8] where intermittent renewable sources, storage system and a conventional power plant have been taken into account. In [9], a two-stage stochastic mixed-integer linear programming model for a VPP has been presented, where, the VPP tries to maximize its expected profit via participating in both the day-ahead and the balancing markets. In [8,9], however, the presence of cogeneration systems and demand response programs has not been investigated. In [10–12], a special price-based unit commitment method has been suggested as an appropriate solution for bidding strategies of VPPs in energy market but without considering the presence of renewable energy sources and demand response programs. In [13], a modified particle swarm optimization approach has been presented aiming at minimizing the day-ahead costs of VPP. Although the storages were modeled in [13], in the case study, these resources have been ignored and therefore, the impact of storages in VPPs has not been assessed. In [14], a full model of demand response in which demand flexibility is fully utilized by price responsive shiftable demand bids in energy market as well as spinning reserve bids in reserve market, is proposed. However, the presence of renewable energy sources has not taken into account.

The literatures having some differences with the present work in the modeling (e.g. modeling of resources, modeling of uncertainties, optimization approach, etc.) are investigated in the following. A new method to support VPP day-ahead resource scheduling in a smart grid context considering the intensive use of V2G and other distributed energy resources is proposed in [15]. The main objective is to minimize the operation costs considering all the available resources for each operation period. With full respect to the proposed method in [15] the uncertainties modeling of renewable energy sources in operation from VPPs has not been investigated. Authors in [16] propose a new market integration approach for responsive loads. Regional pockets of responsive loads are aggregated into models that describe population dynamics as an equivalent virtual power plant. This demand-side virtual power plant is then integrated into the market as a new source of spinning reserves. Despite of the comprehensive proposed model in [16], the modeling of uncertainties of renewable energy sources has not been taken into account. The economic operation of a hybrid system consisting of wind, solar, hydrogen and thermal power systems in the VPP structure is evaluated to participate in the electricity market with high levels of reliable power production [17]. An economic operation-based load dispatching strategy that can interactively adapt to the real measured wind and solar power production values is also proposed in [17]. The proposed forecasting approach, for wind and solar resources, is developed taking into account the components of the VPP concept, the required time horizon, the specifications of the site and the available data. In [17], however, the presence of uncertainties of market price and electrical demand has not been tackled. Authors in [18] propose