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Risk averse optimal operation of a virtual power plant using two stage stochastic programming

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A B S T R A C T

VPP (Virtual Power Plant) is defined as a cluster of energy conversion/storage units which are centrally operated in order to improve the technical and economic performance. This paper addresses the optimal operation of a VPP considering the risk factors affecting its daily operation profits. The optimal operation is modelled in both day ahead and balancing markets as a two-stage stochastic mixed integer linear programming in order to maximize a GenCo (generation companies) expected profit. Furthermore, the CVaR (Conditional Value at Risk) is used as a risk measure technique in order to control the risk of low profit scenarios. The uncertain parameters, including the PV power output, wind power output and day-ahead market prices are modelled through scenarios. The proposed model is successfully applied to a real case study to show its applicability and the results are presented and thoroughly discussed.

1. Introduction

Due to the increase of concerns related to environmental issues, decrease in the level of fossil fuels resources and advancement of technology, higher share of distributed energy resources is being observed worldwide. So, the DG (Distributed Generation) and RES (Renewable Energy Sources) are going to replace traditional fossil fuelled power plants to promote energy efficiency and generate green energy. The VPP (Virtual Power Plant) enables the associated RES and DG to participate in electricity markets as a single power plan [1,2].

Shimon Awerbuch in 1997 introduced the origin of the terminology VPP in his book entitled the Virtual Utility for the first time [3]. The idea of VPP is to refer the integration of small scale generation and storage technologies (that are not located at the same bus) to operate and behave as a single unit. The main goal of this entity is to maximize the benefits of the participants to take advantage of a lager capacity in the energy markets [4,5]. The CVPP (commercial VPP) and TVPP (technical VPP) are two popular types of VPP operation. The focus of CVPP is a profit maker agent which optimizes its operating schedule based on the wholesale markets. The obtained results are given to TVPP. The TVPP implements them considering the local network constraints [6]. In Refs. [7,8], some simple VPP models were considered. From a modelling point of view, a VPP usually includes dispatchable power plants, storage units and non-dispatchable generation units such as wind turbines and photovoltaic. By the end of 2011, the total renewable power capacity has increased up to 1.360 GW [9]. Besides the advantages and benefits of these renewable energy sources, the amounts of power production are intrinsically dependent on the stochastic behaviour of nature such as clouds and solar irradiation. These uncertainties would impose imbalance costs to the system operators [10,11]. In order to diminish the effects of these imbalances, different types of renewable and non-renewable generators and storage devices are combined into a single VPP. In Ref. [12], the optimization model was formulated as a two-stage stochastic problem in which, the day-ahead energy market prices and wind power generations were considered as uncertain parameters. In that paper, the hydro pumped storage was used to manage the WPP (Wind Power Plant) stochastic generations. In Ref. [13], an offering model for the VPP was presented based on a two-stage stochastic programming. In the proposed method, the VPP included a wind farm and a cascade hydro-power system. Moreover, the author assumed trading in the day-ahead energy market with predefined

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penalty for power mismatch offered by the VPP operator. However, in real applications, the VPP owner can participate in balancing and/or real-time energy markets to cope with the mismatch between day-ahead offering and its real energy production. Also the VPP consists dispatchable power plants in order to diminish the uncertainties. In Ref. [14], an offering model for a VPP based on stochastic programming is presented. Despite of the advantage of handling the uncertainties using stochastic programming, its main drawback is neglecting the probability distribution associated with the random variables. In Ref. [15], the optimal offering strategy of the coordinated wind-thermal power plants was proposed and the market risks were modelled and optimized using the CVaR model. In Refs. [16,17], a self-scheduling problem was presented, and the risk was modelled by considering the variance of the market clearing prices. However, it is known that by using CVaR and VaR, the risk management can be done more effectively [18,19].

In this paper, an efficient stochastic programming with risk management is used for optimal daily operation of a VPP that includes, CPPs (Conventional Power Plants), PV, wind farm and battery bank as the storage unit. The typical schematic of a VPP is shown in Fig. 1.

The proposed optimization problem is a MILP (mixed integer linear programming) [20], formulated as a two-stage stochastic programming model. In the first stage, the optimal decision is made for the day-ahead energy market quantity bids for each hour. In the second stage, the VPP operator will decide on the optimal operation of CPPs and battery, once the outputs of non-dispatchable generation units and day-ahead energy market prices are known. In this paper, the CVaR risk management method is used to model and control the risks of low profit scenarios. The proposed formulation investigates both day-ahead and balancing energy markets. The VPP uses trading in both day-ahead and balancing energy markets to reduce its market risks due to uncertain parameters such as wind and PV outputs and the market price by means of the CVaR risk management algorithm [5,21]. It means that the VPP uses the balancing market to correct its energy deviations with respect to its day-ahead schedule. In the other words, the VPP sells its extra energy in the balancing energy market and purchases its shortage of energy in the balancing energy market. The main novelty of the proposed method (compared to the existing literature) is the inclusion of risk measure and management for protecting the VPP operator from low profit scenarios in day-ahead and balancing energy markets when it operates non-dispatchable energy sources (such as wind and PV generators). In the proposed optimization problem and case studies, the considered uncertain parameters include the PV power output, wind power output and day-ahead energy market prices, which are modelled with different probabilistic scenarios.

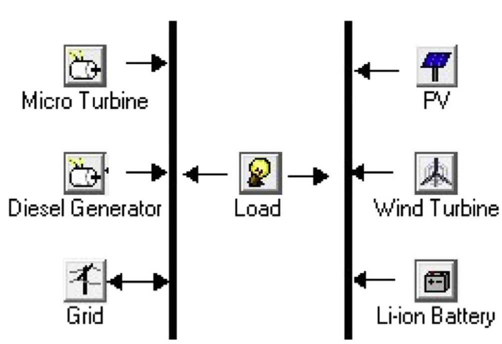

Fig. 1. A typical schematic of the VPP.

The rest of the paper is organized as follows: Sections 2 and 3 provide the model description and formulation, respectively; the simulation results of a real case study are presented in Section 4, and the paper is concluded in Section 5.

2. Model description

The studied VPP consists of a WPP, a PV, a micro turbine, a diesel generator and a battery bank. The WPP and PV outputs are stochastic and therefore, are provided by various probabilistic scenarios. In order to preserve the linearity of the model, piecewise linear approximation is used to model the quadratic CPP cost function. Through using the battery bank, the VPP operator could hedge against the volatile balancing market price risks and also reduce the operation risks of the stochastic WPP and PV generators.

In this paper, due to relatively small installed capacities of the VPP components, the VPP operator is considered as a price-taker that cannot affect the hourly market price. The day-ahead and balancing energy markets are considered for the VPP to trade the energy on an hourly basis. In a day-ahead energy market, the daily operation of the power system is determined, where the consumers and suppliers submit their bids/offers into the day-ahead energy market 10–14 h prior to the day of operation. The balancing energy market provides the opportunity for the producers/consumers to sell/purchase electricity near real time. The VPP operator could participate in the balancing market as an alternative to cope with non-dispatchable generators uncertainties (e.g., WPP and PV generators).

Stochastic generation is the means that produce electricity from renewable energy. Their production is uncertain due to the variability of weather conditions such as, sunlight, wind, and etc. Therefore, the sunlight irritation and wind speed are needed to be estimated precisely for optimal offering in the market. Moreover, there is another uncertain parameter related to the day ahead market prices. To deal with these uncertainties, different scenarios are considered for PV and wind farm outputs and also day ahead market prices.

In the rest of this section, first, the sources of the uncertainties are clearly described and next, an introduction of the some popular risk measure technique is introduced.

2.1. Uncertainties

In general, a VPP contains dispatchable power plants, storage devices, and stochastic (non-dispatchable) generation units.

In this paper, the stochastic scenario based uncertainty modelling is used for dealing with the uncertainties of unknown parameters [22]. Different scenarios for uncertain PV, WPP and day-ahead energy prices are generated based on the Monte Carlo simulations. The PDFs (probability distribution functions) for the wind speed, solar irradiation and day-ahead market prices are assumed to be Weibull, Gamma and Gaussian, respectively [23]. To handle the above mentioned uncertainties, a two-stage mathematical programming with two different kinds of decisions is used [24]. The first stage or “hear and now” decisions are made before the realization of the stochastic process; the second stage or “wait and see” decisions are made after knowing the actual realization of the uncertainties. The here and now decision is the amount of supply offer, which is submitted to the day-ahead energy market for each hour, and the wait and see decision is the operation of dispatchable power plants and the storage devices.

2.2. Risk measurement

In order to control the risk of experiencing low profit scenarios, we need to model the associated profit risk and then include it into