Energy Conversion and Management 128 (2016) 160–177

Contents lists available at ScienceDirect

Energy Conversion and Management

journal homepage: www.elsevier.com/locate/enconman

Multi-objective stochastic scheduling optimization model for connecting a virtual power plant to wind-photovoltaic-electric vehicles considering uncertainties and demand response

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ARTICLE INFO

Article history:
Received 5 May 2016
Received in revised form 17 September 2016
Accepted 23 September 2016

Keywords:
Virtual power plant
Demand response
Electric vehicle group
Multi-objective
Uncertainties

ABSTRACT

A stochastic chance-constrained planning method is applied to build a multi-objective optimization model for virtual power plant scheduling. Firstly, the implementation cost of demand response is calculated using the system income difference. Secondly, a wind power plant, photovoltaic power, an electric vehicle group and a conventional power plant are aggregated into a virtual power plant. A stochastic scheduling model is proposed for the virtual power plant, considering uncertainties under three objective functions. Thirdly, a three-stage hybrid intelligent solution algorithm is proposed, featuring the particle swarm optimization algorithm, the entropy weight method and the fuzzy satisfaction theory. Finally, the *Yunnan* distributed power demonstration project in China is utilized for example analysis. Simulation results demonstrate that when considering uncertainties, the system will reduce the grid connection of the wind power plant and photovoltaic power to decrease the power shortage punishment cost. The average reduction of the system power shortage punishment cost and the operation revenue of virtual power plant are 61.5% and 1.76%, respectively, while the average increase of the system abandoned energy cost is 40.4%. The output of the virtual power plant exhibits a reverse distribution with the confidence degree of the uncertainty variable. The proposed algorithm rapidly calculates a global optimal set. The electric vehicle group could provide spinning reserve to ensure stability of the output of the virtual power plant. Demand response could optimize customers' power consumption behaviors and improve the grid connection space of the virtual power plant. The electric vehicle group and demand response could achieve a linkage optimization effect between the generation side and demand side, achieving optimal system scheduling objectives.

1. Introduction

Due to traditional energy shortage and environmental pollution problems, renewable energy power generation has attracted increased attention. Distributed energy resources (DERs), especially wind power and solar photovoltaic power, are playing increasingly important roles in energy structures [1]. However, limited by the characteristics of small capacity, large quantity and geographical dispersion, the grid connection cost of DERs is relatively high. DER grid connection could also affect the stability of system operation [2]. Thus, the virtual power plant (VPP) is proposed as a new technology for DERs in the power market [3]. A VPP can effectively integrate, aggregate and manage DERs, including distributed generators (DGs), energy storage systems and controllable loads [4]. In particular, the rapid development of smart grid technology promotes reasonable resource configuration and provides solid support for VPP operation.

In recent years, many countries have performed VPP pilot projects. In 2007, the University of Kassel formed the largest VPP pilot project by integrating a wind turbine, a solar energy system, a biogas power plant and a hydro power plant [5]. In 2009, a smart grid project connecting electric vehicles (EVs) in Denmark took the uncertainty of large-scale wind power output into consideration and introduced VPP technology to manage the EVs' charging-discharging power [6]. In 2012, the Rhineland Group in Germany began operating the first commercial VPP [7]. In 2008, a distributed energy station in Guangdong University City, China began operation to meet the load demand of the University City [8]. In 2011, the Zhangbei wind-photovoltaic-storage-transmission project began operation in China, integrating a wind power plant (WPP),

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http://dx.doi.org/10.1016/j.enconman.2016.09.072
0196-8904/