Electrical Power and Energy Systems 82 (2016) 608–620

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

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

Stochastic operational scheduling of distributed energy resources in a large scale virtual power plant

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ARTICLE INFO

Article history:
Received 20 February 2015
Received in revised form 23 March 2016
Accepted 5 April 2016
Available online 27 April 2016

Keywords:
Virtual Power Plant (VPP)
Demand Response Program (DRP)
Scenario-based decision making method
Combined Heat and Power (CHP)

ABSTRACT

Virtual Power Plant (VPP) is introduced as a tool for the integration of distributed generations, energy storages and participation of consumers in demand response programs. In this paper, a probabilistic model using a modified scenario-based decision making method for optimal day ahead scheduling of electrical and thermal energy resources in a VPP is proposed. In the proposed model, energy and reserve is simultaneously scheduled and the presence of energy storage devices and demand response resources are also investigated. Moreover, the market prices, electrical demand and intermittent renewable power generation are considered as uncertain parameters in the model. A modified scenario-based decision making method is developed in order to model the uncertainties in VPP's scheduling problem. The results demonstrated that the optimal scheduling of VPP's resources by the proposed method leads VPP to make optimal decisions in the energy/reserve market and to play a dual role as a demand/generation unit from the perspective of the upstream network in some time periods.

Introduction

The virtual power plant concept is developed in order to improve handling and visibility of Distributed Energy Resources (DERs) for system operators and other market players by making an appropriate interface among these system components. Using this concept, DERs could be considered as a substitution for Conventional Power Plants (CPPs) in both forms of production energy and capacity. So via VPP concept:

- Each DER can increase its monetization opportunities by participating in energy market.
- Operational efficiency and other system benefits are improved utilizing whole available capacity.

Introducing smart grids technology, VPPs are also able to provide the possibility for small generation unit owners to participate in both energy and ancillary services markets. The aggregation of DERs aiming at providing reserve capacity is a suitable solution for compensating the unexpected power fluctuations of intermittent renewable generations.

Many literatures have already discussed about VPPs and their challenges and opportunities in optimal scheduling issues or bidding strategies in markets. In [1], a Decision Tree based methodology that prepares for the dispatching of power equivalent to the possible loss of the highest injection of one of the sources of the VPP (according to day-ahead hourly schedule) to the rest of its sources, on an hour-ahead horizon is proposed. An open framework providing robust solution for large scale DERs integration and control is applied in [2], where an approach for solving this problem is proposed by utilizing standards-based power system communications, application modeling based on event-driven information services and algorithms for optimized VPP control. In [3], using a novel stochastic programming approach, the participation of a VPP in the day-ahead market and the balancing (real-time) market has been considered. The uncertainties involved in the electricity price, generation of renewables, consumption of loads, and the losses allocation have been taken into account in [3]. In [4], VPP is defined as a DERs aggregator whose resources are connected to various points of a medium voltage distribution network. According to Fenix project [5], VPP is a flexible representation of a portfolio of DERs including various technologies and behavior patterns which in terms of availability could be connected to different points of distribution network. In [6–8], 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

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http://dx.doi.org/10.1016/j.ijepes.2016.04.024
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Nomenclature

Sets

s set of scenario intervals
t set of hourly intervals
z set of zones

scenario-dependent parameters

$\rho_{SR,ts}$ spinning reserve market price at hour t and scenario s
$\rho_{EM,ts}$ energy market price at hour t and scenario s
$P_{el,zts}$ total electric load power at hour t, scenario s and zone z
$P_{pv,zts}$ output power of PV modules at hour t, scenario s and zone z
$P_{wt,zts}$ output power of wind turbine at hour t, scenario s and zone z

Input parameters

$\rho^{I}_{drp,t}$, $\rho^{II}_{drp,t}$, $\rho^{III}_{drp,t}$ cost of first, second and third level of demand response program at hour t, respectively
$\rho_{ens,t}$ cost of energy not-served at hour t
$\rho_{NG,t}$ natural gas price at hour t
$\rho_{ret_{vpp},t}$ retail energy rate of VPP at hour t
$\eta_{boil,z}$ efficiency of boiler in zone z
$\eta_{chp,z}$ electric efficiency of CHP in zone z
AT_t ambient temperature at hour t
$a^{e}_{st,z}(a^{t}_{st,z})$ positive coefficient of El. (th.) storage cost function in zone z
$b^{e}_{st,z}(b^{t}_{st,z})$ positive coefficient of El. (th.) storage cost function in zone z
$E^{e}_{st,final,z}(E^{t}_{st,final,z})$ final level of energy in el. (th.) storage in zone z, respectively
$E^{e}_{st,initial,z}(E^{t}_{st,initial,z})$ initial level of energy in el. (th.) storage in zone z, respectively
$E^{e}_{st,max,z}(E^{t}_{st,max,z})$ max level of energy in el. (th.) storage in zone z, respectively
$E^{e}_{st,min,z}(E^{t}_{st,min,z})$ min level of energy in el. (th.) storage in zone z, respectively
FF fill factor of PV module
HV_{NG} heating value of natural gas
I_{MPP} current at maximum power point of PV module
I_{sc} short circuit current of PV module
$k_{chp,z}$ heat-to-electricity ratio for CHP units in zone z
K_i current temperature coefficient of PV module
K_v voltage temperature coefficient of PV module
N_{OT} nominal operating temperature of solar cell
N^{pv}_{z} number of PV modules in zone z
$P_{boil\_max,z}$ rated power of boiler in zone z
$P^{e}_{chp\_min,z}$, $P^{e}_{chp\_max,z}$ min and max operational power of CHP in zone z, respectively
$P_{r,z}$ rated power of wind turbine in zone z
$P^{e}_{st,charge,z}$, $P^{t}_{st,charge,z}$ max rechargeable power of el. and th. storage in zone z, respectively
$P^{e}_{st,discharge,z}$ $P^{t}_{st,discharge,z}$ max discharge power of el. and th. storage in zone z, respectively
$P_{line\_max,z}$ max crossed power of upstream line of zone z
$P_{thl,zt}$ thermal load power at hour t and zone z
$PMAX^{I}_{drp,zts}$ $PMAX^{II}_{drp,zts}$ $PMAX^{III}_{drp,zts}$ max amount of curtailment power in first, second and third level of demand response program at hour t, scenario s and zone z, respectively
$PMAX_{ens,zts}$ max amount of involuntary curtailment power at hour t, scenario s and zone z
$SC_{chp,z}$, $SHC_{chp,z}$ startup and shutdown costs of CHP units in zone z, respectively
$T_{C_{ts}}$ solar cell temperature at hour t and scenario s
V_{MPP} voltage at maximum power point of PV module
v^{c}_{in}, v^{c}_{out}, v_{rated} cut in, cut-off and rated speeds of wind turbine, respectively
V_{oc} open circuit voltage of PV module

Binary variables

$b_{chp,zt}$, $I_{chp,zt}$, $J_{chp,zt}$ spinning, startup and shutdown states of CHP at hour t and zone z, respectively

Continuous variables

$EP_{SR,t}$ expected value of exchanged power between VPP and spinning reserve market at hour t
$EP^{N_z}_{line,t}$ expected value of exchanged power between VPP and energy market at hour t
$P_{boil,zt}$ output power of boiler at hour t and zone z
$P^{e}_{chp,zt}$ $(P^{t}_{chp,zt})$ el. (th.) output power of CHP at hour t and zone z, respectively
$P^{I}_{drp,zts}$, $P^{II}_{drp,zts}$, $P^{III}_{drp,zts}$ electric load curtailment in first, second and third level of demand response program at hour t, scenario s and zone z, respectively
$P_{ens,zts}$ the amount of energy not served at hour t, scenario s and zone z
$P_{line,zts}$ crossed power of upstream line of zone z at hour t and scenario s
$P_{sel,zts}$ served electric load power at hour t, scenario s and zone z
$P_{sh,zt}$ surplus heat power at hour t and zone z
$P^{e}_{st,zt}$, $P^{t}_{st,zt}$ amount of charged/discharged power of el. and th. storage at hour t and zone z, respectively
$P_{SR,ts}$ exchanged power between VPP and spinning reserve market at hour t and scenario s
$SoC^{e}_{st,zt}$, $SoC^{t}_{st,zt}$ state of charge in el. and th. storages at hour t and zone z, respectively

sources and demand response programs. A new algorithm has been proposed in [9] in order to optimize thermal and electrical scheduling of a large scale VPP containing cogeneration systems and energy storages. Despite of the accurate mathematic model in [9], no specific model for renewable energy sources and their corresponding uncertainties has been investigated. In [10], a modified particle swarm optimization approach has been presented aiming at minimizing the day-ahead costs of VPP. Although the electrical storages were modeled in [10], in the case study, these resources have been ignored and therefore, the impact of storages in VPPs has not been assessed. In [11], forecast errors of wind speed and solar irradiance are modeled by related probability distribution functions and then, by using the Latin hypercube sampling (LHS), the plausible scenarios of renewable generation for day-head energy and reserve scheduling have been generated. A two-stage stochastic objective function aiming at minimizing the expected operational cost has been also implemented in [11]. Authors in [12] focus on Industrial VPP (IVPP) and its management. An IVPP can be determined as a management unit comprising generations and loads in an industrial microgrid. Since the scheduling procedure for these units is very important for their participation in a short-term electric market, a stochastic formulation is proposed for power scheduling in VPPs especially in IVPPs in [12]. An optimization methodology is proposed in [13] based on a multi-objective approach to handle with day-ahead optimal resource scheduling of a VPP in a distribution network considering different