Applied Energy 164 (2016) 590–606

Contents lists available at ScienceDirect

Applied Energy

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

Stochastic profit-based scheduling of industrial virtual power plant using the best demand response strategy

Seyyed Mostafa Nosratabadi, Rahmat-Allah Hooshmand *, Eskandar Gholipour

Department of Electrical Engineering, Faculty of Engineering, University of Isfahan, Isfahan, Iran

HIGHLIGHTS

- VPPs and IVPPs are defined for energy management of aggregated generations.
- IVPP can manage industrial microgrid containing some relevant load and generation.
- A stochastic modeling is proposed to schedule optimal generations in competition market.
- Wind generation and day-ahead and spot market prices are considered to be stochastic.
- A new DRL program selection scheme is presented in the scheduling procedure.

ARTICLE INFO

Article history:
Received 6 September 2015
Received in revised form 7 December 2015
Accepted 8 December 2015
Available online xxxx

Keywords:
Virtual power plant
Stochastic scheduling
Industrial microgrid
Demand response load
Mixed integer non-linear programming

ABSTRACT

One of the main classified microgrids in a power system is the industrial microgrid. Due to its behaviors and the heavy loads, its energy management is challengeable. Virtual Power Plant (VPP) can be an important concept in managing such problems in this kind of grids. Here, a transmission power system is considered as a Regional Electric Company (REC) and the VPPs comprising Distributed Generation (DG) units and Demand Response Loads (DRLs) are determined in this system. This paper focuses 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 this paper. By introducing the DRL programs and using the proposed modeling, the operator can select the best DRL program for each VPP in a scheduling procedure. In this regard, a suitable approach is presented to determine the proposed formulation and its solution in a Mixed Integer Non-Linear Programming (MINLP). To validate the performance of the proposed method, the IEEE Reliability Test System (IEEE-RTS) is considered to apply the method on it, while some challenging aspects are presented.

1. Introduction

1.1. Clarification of the problem

Since the penetration of Distributed Generation (DG) resources is rapidly increasing in power systems, taking into consideration of the control of the network, provision of ancillary services, and improvement of the network performance are greatly essential. Thus, providing new ways to control the generation and provision of appropriate infrastructure is required for participation in the electricity market. A possible solution to satisfy the aspects mentioned above is to use the concept of Virtual Power Plant (VPP). The set of loads, DGs, and storage of electrical energy resources aggregated together are called VPP [1,2].

The use of new control methods with DG resources in power networks while considering security levels, quality, reliability, and power availability has converted these networks to dynamic ones to determine the microgrid concept [3]. Due to the nature of the loads of these networks, they are divided into the categories of residential, commercial, and industrial loads [4]. Because an industrial microgrid normally consists of industrial loads, industrial workshops, industrial factories, and industrial parks, it is therefore of utmost importance. An industrial smart microgrid can be considered attached to the main grid in the form of a VPP to pursue several important objectives.

* Corresponding author.
E-mail addresses: sm.nosratabadi@eng.ui.ac.ir (S.M. Nosratabadi), Hooshmand_r@eng.ui.ac.ir (R.-A. Hooshmand), e.gholipour@eng.ui.ac.ir (E. Gholipour).

http://dx.doi.org/10.1016/j.apenergy.2015.12.024
0306-2619/

Nomenclature

A. Indices

N_t number of time periods
N_{sp} number of spot market price scenarios
N_p number of market price scenarios
N_w number of wind power scenarios
$N_j^{VPP_k}$ number of loads in kth VPP
N_g total number of DG units

B. Variables

$Profit_{VPP_k}$ obtained profit of kth VPP ($)
$Income_{VPP_k}$ obtained revenue of kth VPP ($)
$Cost_{VPP_k}$ obtained cost of kth VPP ($)
$Income_{DRLs}$ obtained revenue of DRLs ($)
$Income_{DGs}$ obtained revenue of DG units ($)
$Cost_{Loads}$ obtained cost of loads ($)
$Cost_{DGs}$ obtained cost of DG units ($)
$Cost_{Lshed}$ obtained cost of load shedding ($)
$\Delta L_{jwp}(t)$ value of load change for load j in time period t (MW)
$P_i(t)$ sold power of unit i in time period t (MW)
$P_{i_{wp}}(t)$ sold power of unit i in each scenario and time period t (MW)
$P_{wp}^{WT}(t)$ sold power of wind turbine WP in each scenario and time period t (MW)
$Cost_L(t)$ cost of load L in time period t ($/MWh)
$S.P.P_{wpsp}(t)$ purchased power from spot market in each scenario and time period t (MW)
$P_{wp}^{sp}(t)$ value of purchased power from spot market in each scenario and time period t (MW)
$L_{jwp}^{Shed}(t)$ load shedding value for consumer j in each scenario and time period t (MW)
u_i^{DG}, u^{WT} binary variables equal to 1 if the DG units and the wind powers are scheduled to be committed
$E_L(t)$ consumed energy in time period t for loads
$\upsilon_j(t)$ binary variable equal to 1 if load j is on in time period t
$P_{nr}^{loss}(t)$ power loss through line (n, r) in period t (MW)
$\delta_n(t)$ voltage angle at node n in period t (rad)

C. Constants

$\alpha_w, \beta_p, \gamma_{sp}$ probability of wind, market price and spot market price scenarios
$\Gamma(t)$ demand ratio in time period t
$IV(t)$ incentive value in time period t for each kWh load reduction
$L_j^0(t)$ initial value of demand in time period t (MW)
$\pi_{sp}(t)$ spot market price in time period t ($/MWh)
$\pi_p(t)$ market price in time period t ($/MWh)
$\varepsilon_p^{LT}(\boldsymbol{t})$ self-elasticity of demand considering load type LT in time period t
a^{LT}, b^{LT} constant factors of load type LT
$Penalty_{wp}(\Delta L_j(t))$ penalty value of load change for load j in time period t
$PV(t)$ penalty value in time period t for each kWh load change
$CDR(t)$ contract level of DRLs in time period t (MW)
SUC_{iwp}, SDC_{iwp} cost due to the startup and shutdown of unit $i$in each scenario ($)
λ_i cost of produced power by DG unit i ($/MWh)
λ_w cost of produced wind power by unit w ($/MWh)
ζ_j^{LT} load shedding factor for different load types
$VOLL_j(t)$ value of loss load for consumer j in period t ($/MWh)
$P_i^{\min}, P_i^{\max}$ minimum and maximum power of each DG unit I (MW)
$P^{WT,\min}, P^{WT,\max}$ minimum and maximum power of each wind turbine (MW)
L_j^{IVPP} loads in each IVPP (MW)
$L_j^{ramp\ down}$ ramp down rate of load j (MW/s)
$L_j^{ramp\ up}$ ramp up rate of load j (MW/s)
$\tau_j^{EAF(on)}$ minimum on time for EAF (s)
$\tau_j^{EAF(off)}$ minimum off time for EAF (s)
$L_j^S(t)$ maximum value of load shedding in time period t (MW)
B_{nr} absolute value of the imaginary part of the admittance of line (n, r) (per unit)
$f_{nr}^{\max}$ maximum power flow through line (n, r) in period t (MW)

Microgrids and VPPs share important features like the ability to integrate demand response; generation of distributed renewable energy; and storage at the distribution level. Some market participants share a lot with these two platforms; however, there are differences [5,6]:

- Microgrids may be in the grid-tied or grid-connected form, but VPPs are always in the grid-tied form.
- Microgrids can pose themselves as an island separated from the larger power grid, but VPPs do not recommend this type of contingency.
- Microgrids normally require some levels of storage; however, the presence or absence of storage in VPPs is possible.
- Microgrids depend on hardware innovations such as smart inverters and switches, whereas VPPs heavily depend on smart metering and information technology.
- Microgrids include a fixed set of resources within a limited geographical area, whereas VPPs can combine a wide variety of resources in large geographic areas, and match them.
- Microgrids are normally traded only in the form of retail distribution, while the VPPs can build a bridge to the wholesale market.
- Microgrids face legal and political hurdles, while VPPs can now be performed on the current structure and legal tariffs.

Because of these advantages, VPP management is taken into account here since its importance can be more manifest for industrial environments.

Here, it is supposed that the main grid is a transmission network acting under a Regional Electric Company (REC). Usually a REC has several generation units that can operate as a GENCO or as a VPP. One of the VPPs that this paper focuses on is the Industrial VPP (IVPP). Because the IVPP comprises industrial loads, then one of the main goals is to minimize the load shedding in the existing industrial network at the microgrid. This is also very important, because the industrial loads are looking for different ways to obtain the required electricity to avoid the stoppage of production cycles. This energy can be supplied by participation in the spot and balancing markets. Also, by cooperation in a suitable DRL program, IVPP can manage the interruptible loads which require an appropriate modeling in transmission systems. By solving the problem, an optimal solution will be extracted via an optimization problem satisfying different generation, load, market, and system constraints.