



Distributed generation and demand response dispatch for a virtual power player energy and reserve provision



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ARTICLE INFO

Article history:

Received 13 March 2013

Accepted 17 January 2014

Available online 11 February 2014

Keywords:

Ancillary services

Demand response

Distributed generation

Electricity markets

System reserves

Virtual power players

ABSTRACT

Recent changes in the operation and planning of power systems have been motivated by the introduction of Distributed Generation (DG) and Demand Response (DR) in the competitive electricity markets' environment, with deep concerns at the efficiency level. In this context, grid operators, market operators, utilities and consumers must adopt strategies and methods to take full advantage of demand response and distributed generation. This requires that all the involved players consider all the market opportunities, as the case of energy and reserve components of electricity markets.

The present paper proposes a methodology which considers the joint dispatch of demand response and distributed generation in the context of a distribution network operated by a virtual power player. The resources' participation can be performed in both energy and reserve contexts. This methodology contemplates the probability of actually using the reserve and the distribution network constraints. Its application is illustrated in this paper using a 32-bus distribution network with 66 DG units and 218 consumers classified into 6 types of consumers.

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1. Introduction

The specific electrical energy characteristics have led to difficulties in adapting the rules and methods used in other commodities markets to the electricity markets, causing some problems namely in the achievement of lower electricity prices [1–3].

Demand response (DR) gained increasing importance in the context of electricity markets, representing an opportunity for consumers and bringing several advantages for the whole system [4–6]. It includes all the intentional electricity consumption pattern modifications by end-use customers that are intended to change the timing, level of instantaneous demand, or the total electricity consumption [7] in response to the changes in the electricity price over time.

In the same way, yet with specific concerns and policies on environmental issues, the Distributed Generation (DG) integration in power systems has been done mainly at the level of distribution networks, with small-size units that are scattered geographically mostly based on renewable energy sources [6]. As DR and DG are distributed small-size resources, new entities responsible for the

aggregation of these resources are needed in order to reach full advantages for the participants (DG owners and consumers participating in DR programs) and for the power system and electricity market as a whole.

In fact, in the traditional operation of power systems, at the distribution level, the distribution network operators should manage their network ensuring the power supply to the consumers connected to it. With the implementation of electricity markets aside with the increasing levels of existing Distributed Generation (DG) and Demand Response (DR), additional challenges have appeared in order to integrate these resources in such competitive environments. As a matter of fact, the participation of small-size resources in the electricity markets implies the existence of aggregators due to the minimum size usually required for each resource' participation. As an example, the bids submitted to electricity markets must comply to specific rules, like the minimum power offered. Usually, the electricity markets impose the minimum power installed capacity (in Mibel the producers must have power capacity higher than 1 MW [8]) or the minimum energy volume for the bids (in Elbas the minimum energy value for producers bids is 0.1 MWh [9]). Small-size resources are not able to comply with these rules, so aggregation is required for their participation in the market. Additionally, the small-size resources usually do not have enough skills and tools to define an adequate

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Nomenclature

Indexes

i_j	node index
b	bus index
c	consumer index
g	generation index
sp	supplier index
t	period index

Parameter

θ	voltage angle [$^\circ$]
B	Susceptance [S]
Ca	fixed component of cost function [m.u./h]
Cb	linear component of cost function [m.u./kWh]
Cc	quadratic component of cost function [m.u./kWh ²]
G	conductance [S]
N_B	total number of buses
N_C	total number of loads
N_g	total number of generators
N_{sp}	total number of suppliers
N_y	total number of lines
P_{LOAD}	initial active power of load demand [kW]
P_{MaxGen}	maximum generator' active power [kW]
P_{MaxRed}	maximum consumer' reduction power [kW]
$P_{MaxSupplier}$	maximum supplier' active power [kW]
pr	reserve use probability

$P_{Required}$	reserve product required power [kW]
Q_{MaxGen}	maximum generator reactive power [kVAR]
$Q_{MaxSupplier}$	maximum supplier reactive power [kVAR]
Q_{LOAD}	initial reactive power of load demand [kVAR]
T	total number of hours in the time horizon [h]
$\bar{y}$	series admittance of line that connect [S]
$\bar{y}_{Sh}$	shunt admittance of line connected in the bus [S]

Variables

P	active power [kW]
Q	reactive power [kVAR]
S	apparent power flow [kVA]
$\bar{U}$	voltage in polar form [V]
V	voltage magnitude [V]
X	binary variable

Subscript

GCP	generation curtailment power [kW]
Gen	generator
max	upper bound limit
min	lower bound limit
NSD	non-supplied demand [kW]
Red	consumption reduction [kW]
Supplier	supplier

Superscript

e	energy product
r	reserve product

market strategy. Moreover, the participation in electricity markets requires annual fees creating barriers to the small resources. Due to the distributed characteristic of the referred resources, the aggregator should be able to aggregate resources from several geographic areas.

Taking into account these aspects, new entities have appeared in the power systems sector, as the case of VPPs, which enable small-size wind farms to sell electricity in the market, while being aggregated with other wind farms, sharing the revenues obtained by the VPP for their market participation [10]. VPPs (acronym traditionally used to represent Virtual Power Plants and lately referring to Virtual Power Players [10]) are able to aggregate several types of distributed energy resources, such as DG, storage, DR and, most recently, electric vehicles. Otherwise, small players would not be able to participate actively in electricity markets due to their reduced power capacity and to their reduced technical means to implement an economic strategy.

From another point of view, and focusing on the work presented in this paper, the VPP can manage a specific distribution network area, managing the available resources connected to its network in order to achieve the energy and reserve needs. Eventually, the referred VPP can manage other energy resources in order to participate in electricity markets.

Another important issue, regarding DG and DR resources operation, is their availability intermittence and unpredictability. In this context, adequate concerns must be given to the specification of power reserve (ancillary services) at several levels of power systems operation, in order to maintain the expected increased levels of security in their operation. In this way, the provision of ancillary services is not only an additional necessity, but also an opportunity for DG, DR, and VPPs to participate in electricity markets [5,11–13] address the integration of DG, including the storage in electricity markets.

One of the late and most relevant works of the literature regarding dispatch of energy and reserve considering DR, presented in Ref. [14] makes use of DR for reserve provision and peak shaving, including the selling of the available capacity in their distinct DR utilization patterns. The optimization problem is a unit commitment which considers the demand and generators providing energy and reserve.

With regards to the system contingences, the authors of [15] considered the participation of demand in reserve provision by a voluntary reduction of demand, focusing on the recovery period.

In what concerns the incorporation of reliability standards in the economic dispatch of joint energy and ancillary services markets, Ref. [16] illustrates its application to the standards on DR.

The present paper presents an evolution of the work published in Ref. [17] by the same authors, and proposes a methodology in which a VPP aggregates several distributed energy resources, including DR and DG, and the energy acquired to electricity suppliers, in order to fulfill their electricity needs. The VPP operates a distribution network, performing the economic and technical management to minimize the operation costs. The VPP operation of the distribution network also considers the evaluation of network constraints in the scope of a determined resources' scheduling result, and the probability of the established amount of reserve being used in the system operation. These are the main contributions of the present paper. The results of the optimization model obtained in this paper for a case study of 218 consumers can include the energy that the VPP has contracted to deliver to the electricity market. This contracted energy regards the energy and reserve participation in the mentioned electricity market.

After this introduction section, Section 2 details the main contributions of the paper and explains the proposed methodology. Then, Section 3 presents the mathematical formulation of the optimization problem. Section 4 presents an illustrative case study

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