Energy 85 (2015) 236–250

Contents lists available at ScienceDirect

Energy

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

A multi-objective optimization of the active and reactive resource scheduling at a distribution level in a smart grid context

Tiago Sousa [a,*,1], Hugo Morais [b], Zita Vale [a], Rui Castro [c]

[a] GECAD – Knowledge Engineering and Decision Support Research Center – Polytechnic of Porto (IPP), R. Dr. António Bernardino de Almeida, 431, 4200-072 Porto, Portugal

[b] AUTomation and Control Group – Department of Electrical Engineering, Denmark Technical University (DTU), Elektrovej, Bld 326, 2800 Lyngby, Denmark

[c] INESC-ID/IST Instituto Superior Técnico – University of Lisbon, Lisbon, Portugal

ARTICLE INFO

Article history:
Received 6 September 2014
Received in revised form
23 February 2015
Accepted 14 March 2015
Available online 22 April 2015

Keywords:
Energy resource management
Distributed energy resources
Reactive power scheduling
Virtual power player
Voltage stability

ABSTRACT

In the traditional paradigm, the large power plants supply the reactive power required at a transmission level and the capacitors and transformer tap changer were also used at a distribution level. However, in a near future will be necessary to schedule both active and reactive power at a distribution level, due to the high number of resources connected in distribution levels. This paper proposes a new multi-objective methodology to deal with the optimal resource scheduling considering the distributed generation, electric vehicles and capacitor banks for the joint active and reactive power scheduling. The proposed methodology considers the minimization of the cost (economic perspective) of all distributed resources, and the minimization of the voltage magnitude difference (technical perspective) in all buses. The Pareto front is determined and a fuzzy-based mechanism is applied to present the best compromise solution. The proposed methodology has been tested in the 33-bus distribution network. The case study shows the results of three different scenarios for the economic, technical, and multi-objective perspectives, and the results demonstrated the importance of incorporating the reactive scheduling in the distribution network using the multi-objective perspective to obtain the best compromise solution for the economic and technical perspectives.

1. Introduction

The introduction of DG (distributed generation) units, particularly based on renewable sources, in the distribution networks has led to a significant change in the operation and planning of these kind of networks [1]. In addition to the integration of DG units, there are other types of distributed energy resources, such as active consumers with demand response programs, storage units and EVs (electric vehicles) [2], that can cause an even more complex operation of the distribution networks.

Over these years, the smart grid has been presented as a good concept to handle with this new power system paradigm and new uncertainties, considering the decentralization of the whole power system management and control [3]. In this new paradigm, the aggregation of distributed energy resources will be essential to improve the management and control of these resources in the smart grid. For this reason, some authors introduced the VPP (virtual power player) concept as an aggregator of distributed energy resources connected to the electric network, mainly at the distribution level [4]. In order, to operate in a complex and competitive environment, VPPs will need to develop new decision support systems for helping the management and control of the aggregator resources. The complexity of this management is expected to increase geometrically with the transition from conventional vehicles to electric ones [5]. However, EVs can be useful in the scheduling as flexible load and backup system of renewable sources [6].

Reactive power scheduling is a task performed by network operators to avoid the voltage instability, to maintain the voltage levels within a proper range, and to minimize the power losses. Conventionally, centralized power plants were responsible to provide a minimum amount of reactive power to maintain the stability and quality of the system, and for this service the network operator did not remunerate them. Furthermore, the distribution network operator participated in the reactive scheduling through capacitors and tap changer transformers in order to improve the voltage profile.

* Corresponding author. Tel.: +351 22 8340500; fax: +351 22 8321159.
E-mail address: tabsa@isep.ipp.pt (T. Sousa).
[1] WebSite: http://www.gecad.isep.ipp.pt.

http://dx.doi.org/10.1016/j.energy.2015.03.077
0360-5442/

Nomenclature

Parameters

α	Objective function F_1 weight factor
β	Objective function F_2 weight factor
λ	Penalization factor
η_c	Grid-to-Vehicle efficiency
η_d	Vehicle-to-Grid efficiency
λ	Penalization factor used in the objective function F_2
μ	Membership function
B	Imaginary part in admittance matrix [S]
c_A	Fixed component of cost function [m.u./h]
c_B	Linear component of cost function [m.u./kWh]
c_C	Quadratic component of cost function [m.u./kWh^2]
c	Resource cost in period t [m.u./kWh]
E	Stored energy in the battery of vehicle at the end of period t [kWh]
$E_{Initial}$	Energy stored in the battery of vehicle at the beginning of period 1 [kWh]
E_{Trip}	Energy consumption in the battery during a trip that occurs in period t [kWh]
G	Real part in admittance matrix [S]
M	Total number of non-dominated solutions in the Pareto front
N	Total number of resources
NF	Normalization factor
S_{Lk}^{max}	Maximum apparent power flow in line k [kVA]
T	Total number of periods
$\overline{U}$	Voltage in polar form [V]
$\overline{y}$	Series admittance of line that connects two buses [S]
$\overline{y_{sh}}$	Shunt admittance of line that connects two buses [S]

Variables

θ	Voltage angle
P	Active power [kW]
Q	Reactive power [kVAr]
S	Apparent power [kVA]
V	Voltage magnitude [V]
X	Binary variable

Subscript

1	Operation cost function
2	Voltage magnitude difference function
Asyn_DG	DG unit with asynchronous generator
B	Bus
BatMax	Battery energy capacity
BatMin	Minimum stored energy to be guaranteed at the end of period t
CAP	Shunt capacitor
Ch	Charge process
Dch	Discharge process
Deg	Battery degradation
DG	Distributed generation unit
DGForecast	Forecast power of distributed generation unit in period t
EV	Electric vehicle
GCP	Generation curtailment power
i, j	Bus i and Bus j
L	Load
Max	Upper bound limit
Min	Lower bound limit
NSD	Non-supplied demand
o	*o*th objective function
obj	Total number of objectives
REF	Slack bus
SP	External supplier
Step	Step of a shunt capacitor with discrete regulation
Stored	Stored energy in the battery of the vehicle
TFR_HV_MV	Transformer that connects from high voltage to medium voltage
TFR_MV_LV	Transformer that connects from medium voltage to low voltage

Superscript

i	Bus i
s	Non-dominated solution s

The VPP will require the use of adequate optimization techniques for handling with the active and reactive power scheduling of distribution networks considering a specific objective [7]. Typically, this problem is formulated to minimize the operation cost of the available distributed energy resources [8], or just considering the DG units [9], but in a competitive environment, as the smart grid, it is also important to consider other issues than just this economic perspective. Therefore, the VPP needs to be aware about the power quality, voltage stability, and active power losses. The optimal resource scheduling problem handled by the VPP requires the incorporation of new strategies to deal with these issues. Hence, the incorporation of reactive power control is essential to enable the VPP to present an optimal scheduling that considers all the issues mentioned above.

The optimization methodology proposed in this paper is based on a multi-objective approach to handle with day-ahead optimal resource scheduling of a VPP in a distribution network considering different reactive power management strategies. The proposed methodology will determine an optimal resource scheduling considering two competing objective functions. One objective function is expressed as the minimization of the operation cost of all distributed energy resources managed by the VPP, and the other one as the minimization of the voltage magnitude differences in all buses of the distribution network. The main goal is helping the VPP's management of a distribution network with high penetration of several distributed energy resources, such as distributed generation units, electric vehicles, and capacitor banks.

The proposed methodology will obtain the Pareto front of the envisaged optimal resource scheduling problem, which it will help the decision maker to have a clear view of all non-dominated solutions of the problem. After determining the Pareto front, a fuzzy-based mechanism [10] is applied to obtain the best compromise solution for the VPP.

The results presented in the case study are expected to show that is relevant to take into account the reactive power control in the optimal resource scheduling for the distribution network's operation with the inclusion of the voltage magnitude difference function (technical perspective). In the case study, it has been used three scenarios with different reactive control strategies to evaluate the impact of the reactive scheduling into the distribution network.

This paper is structured with the following sections: after the introductory section, Section 2 presents a literature review related to the reactive optimal resource scheduling. Section 3 focuses on the proposed methodology and describes the mathematical