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Constrained consumption shifting management in the distributed energy resources scheduling considering demand response

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ABSTRACT

Demand response concept has been gaining increasing importance while the success of several recent implementations makes this resource benefits unquestionable. This happens in a power systems operation environment that also considers an intensive use of distributed generation. However, more adequate approaches and models are needed in order to address the small size consumers and producers aggregation, while taking into account these resources goals. The present paper focuses on the demand response programs and distributed generation resources management by a Virtual Power Player that optimally aims to minimize its operation costs taking the consumption shifting constraints into account. The impact of the consumption shifting in the distributed generation resources schedule is also considered. The methodology is applied to three scenarios based on 218 consumers and 4 types of distributed generation, in a time frame of 96 periods.

1. Introduction

Demand Response (DR) is usually defined as the “Changes in electric usage by end-use customers from their normal consumption patterns in response to changes in the price of electricity over time, or to incentive payments designed to induce lower electricity use at times of high wholesale market prices or when system reliability is jeopardized” [1] and it has been largely explored in the context of the operation of electricity markets at higher levels, and also for the improved technical operation of power systems, namely at the lower voltage levels [2].

Several successful implementations of DR programs in real market and power systems can be found in [3], where the DR programs’ implementation around the world is analysed in terms of electricity markets integration. In [4], it is presented a review on the DR integration in smart grids, showing the current success cases and the barriers. However, the full integration of DR in a future more competitive context can only be achieved by intensive participation of small size DR resources [5–7]. The work presented in [5] focuses on the standpoint of a distribution network operator in the context of a consumption reduction need, whereas the work presented in [6] centres on the dispatch of DR and Distributed Generation (DG) by a Virtual Power Player (VPP) for the provisions of energy and reserve. In the case of the work presented in [7] the focus is given to the tariffs’ definition while addressing the costumers’ characterization. In the referred three works it is commonly addressed the small size resources use. Several regulatory efforts have been made in order to make DR a resource comparable to ordinary generation resources, acting in all the opportunities of electricity markets. It is the case of FERC (Federal Energy Regulatory Commission) Order No. 719, which recommends to “Accept bids from demand response resources in their markets for certain ancillary services on a basis comparable to other resources” [8]. Also in Europe, important regulatory changes are being applied [9].

Virtual Power Players (VPPs) are entities that appeared in the sequence of the recent changes in electricity markets and in power systems operation [10]. These entities are able to aggregate small size energy resources and can have several classifications regarding the specific types of resources that are aggregated. A VPP can namely aggregate DR and DG resources, making possible its participation in electricity markets products intended for the participation of large players. A VPP can also own and operate a portion of a distribution network, owning or not the resources there connected [11].

It is possible to find in the recent literature several works that refer to the need of addressing the consumer preferences in the DR programs modeling and definition. The study in [12] focuses on quantifying the Europe potential for DR usage in distinct sectors of activity. With more focus on the end consumers’ activity, the

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Nomenclature

Acronyms

FERC	Federal Energy Regulatory Commission
RSE	resources schedule end time
MNP	minimum notification period duration
Z	advance notification period

Variables

$P_{DG(t,dg)}$	active power scheduled for the distributed generation source *dg* in period *t* (kW)
$P_{DR(i,t,ct)}$	demand power shifted by the consumption cluster *ct*, from period *i* to period *t* (kW)
$P^{NSP}_{Load(t,ct)}$	non-supplied active power to the consumption cluster *ct*, in period *t* (kW)
$P_{Supply(t,sp)}$	active power scheduled for the supplier *sp* in period *t* (kW)
VPPOC	Virtual Power Player Operation Costs (m.u.)

Parameters

BI	total number of backward consumption shifting periods from each period *t*
BT	total number of backward consumption shifting periods in the time horizon
$C_{DR(t,i,ct)}$	cost of the consumption shifting to the consumption cluster *ct*, from period *t* to period *i* (m.u./kW h)
$C^{a}_{DG(t,dg)}$	quadratic cost component of the distributed generation *dg*, in period *t* (m.u./kW h)
$C^{b}_{DG(t,dg)}$	linear cost component of the distributed generation *dg*, in period *t* (m.u./kW h)
$C^{NSP}_{Load(t,ct)}$	cost of the non-supplied active power in the consumption cluster *ct*, in period *t* (m.u./kW h)
$C_{Supply(t,sp)}$	cost of the power from supplier *sp* in period *t* (m.u./kW h)
CtN	total number of consumption clusters
DgN	total number of distributed generation types
FI	total number of forward consumption shifting periods in a specific period *t*
FT	total number of forward consumption shifting periods in the time horizon *T*
$P^{Base}_{Load(t,ct)}$	initial consumption of each consumption cluster, in period *t* (kW)
$P^{Max}_{Load(t,ct)}$	maximum consumption of each consumption cluster, in period *t* (kW)
$PMax_{DG(t,dg)}$	maximum available capacity from the distributed generation *dg* in period *i* (kW)
$PMax^{i}_{DR(t,ct)}$	maximum consumption shifting by the consumption cluster *ct*, to period *i* (kW)
$PMax^{t}_{DR(t,ct)}$	maximum consumption shifting by the consumption cluster *ct*, from period *t* (kW)
$PMax^{t\to i}_{DR\ (t,i,ct)}$	maximum consumption shifting by the consumption cluster *ct*, from period *t* to period *i* (kW)
$PMax_{Supply(t,sp)}$	maximum available capacity from the supplier *sp* in period *t* (kW)
SpN	total number of consumption suppliers
T	total number of periods in the time horizon
α^{Max}_{DG}	maximum contribution of the distributed generation to the energy supply (%)
α^{Max}_{DR}	maximum total consumption reduction in each single consumption cluster (%)

Indexes

ct	consumption cluster index
dg	distributed generation type
i	consumption shifted period index
sp	electricity supplier
t	consumption shifting period index
t0	beginning of the scheduling horizon

work presented in [13] brings a framework that integrates demand and supply resources at the microgrid level. The consumers' standpoint importance is recognized; however, their behavior and preferences are not highlighted. A study on the residential consumption DR potential at distribution networks level is presented in [14], taking into consideration the season and the consumer household type.

Focusing on the consumption devices and energy management appliances, the work presented in [15] explores its potential benefits. The opportunities related to thermostatically controlled loads are also of great importance [16]. Otherwise, from the network standpoint, the work in [17] illustrates the effect of load shifting in the system reliability indices, applying load shifting procedures to seven individual load sectors. Additionally, the methodology proposed in [18] refers to the contribution of DR to reliability issues recognizing the uncertainty associated to the consumption.

The increasing use of renewables-based energy resources, namely at the distribution levels, are also a current challenging and promissory resource. The work presented in [19] addresses an optimal energy resources' scheduling considering the realistic simulation of DG units for technical validation of the schedule results. In [20] one can find a methodology that aims the integration of distributed resources in multiple microgrids. The referred challenges are also related to, for example, the avoidance of wind curtailment situations [21]. In this context, the adequate integration of small size distributed energy resources based on renewable natural sources is a key part of smart grids and microgrids [22]. These concerns also include technical concerns as the case of power quality issues [23]. A study regarding the real implementation of DR and DG can be found in [21].

The mentioned works generally refer to the quantification of the DR potential and DG penetration in distinct systems and/or environmental conditions. The methodology proposed in the present paper goes further on making possible to the consumers to define several consumption shifting and reduction preferences. It also allows the DG resources to be adequately managed together with DR. DG and DR resources' characteristics are taken into account as input parameters and constraints of the optimization model that is developed in order to perform the joint DR and DG's resources scheduling.

The methodology proposed in the present paper is intended to be used by a VPP that aggregates DG and DR resources. One of the main contributions of the present paper concerns the methodological aspect. It has been considered that consumers can reduce the consumption in a certain period and/or shift some of the consumption to several periods before and after the original period. Several time constraints were implemented, as detailed in Section 2. From the DG side, it has been considered the maximum contribution that a certain type of DG can have in the performed resource scheduling. Other main contribution has to do with the definition and implementation of an optimization problem that aims at scheduling the available DR and DG resources. The DG and the DR resources are dispatched according to their operating constraints but also to their prices. The optimization problem aims at minimizing the VPP operation costs, i.e. the remuneration that must be paid to the DG sources and to the DR resources. In this way, whenever a