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REDEFINING THE NEW ROLE AND PROCEDURES OF POWER NETWORK OPERATORS FOR AN EFFICIENT EXPLOITATION OF DEMAND SIDE RESPONSE

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Abstract

Technological advances are contributing irreversibly towards a new way to own, manage, operate and plan electric power networks, especially at medium- to low-voltage levels. In this context and as part of this, a much more massive, efficient and effective role of demand-side response (DSR) is a hypothesis increasingly realistic and viable. DSR providers can contribute significantly in the management and increased use of networks and in the provision of certain ancillary services.

The aim of this paper is to identify the most effective and efficient schemes and to discuss the most needed regulatory redesigns to maximize the potential contribution of DSR services. We focus the discussion on the interplay among the three vertices of the triangle formed by the DSR intermediaries (retailers), the TSO and the DSO. At the same time, our aim is to optimize and rationalize the business model to reduce redundancies and capitalize on economies of scale.

1 INTRODUCTION

The active participation of the demand side in power systems has always been considered an important requirement for their well functioning, particularly of liberalized ones (e.g. Borenstein, 2005; Joskow, 2008). This active participation -from now on, demand-side response or DSR- means that consumers are able to change their load in response to signals sent by different agents in the power system. These signals may be based on price -generally instrumented through time-of-use (TOU), real-time pricing (RTP) or critical peak pricing (CPP) schemes-, or on volume

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-when e.g. system operators mandate partial or total load shedding, or directly control the customer load, based upon a previous agreement with the customer.

This response of demand allows for optimizing generation resources, either from the economic or environmental point of view, for lowering the cost of ancillary services, and even also for enhancing competition in liberalized systems, thus improving their efficiency.

In addition, DSR may bring important benefits for networks system operators (NSOs): by allowing the demand side to be responsive to price or volume signals, the transmission system operator (TSO[1]) and the distribution system operator (DSO) have an additional instrument to manage short-term problems in their grids, to improve quality of service, and to reduce grid losses, and also to reduce the need for future investments, which are in some cases constrained.

In those markets where retail has been liberalized, DSR constitutes an additional factor enabling retailers (or energy services companies or any other sort of aggregators[2]) to create added value

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[1] The term TSO (common in Europe) is often used to make reference to an entity that owns and operate the transmission grid as opposed to the ISO (Independent System Operator, frequent in the US) which operates but does not own the transmission network. For our concerns, however, it is not critical to distinguish between both schemes (because we assume the property of the transmission network will not condition this discussion).

[2] In the common jargon, one of the most common ways to refer to the demand side response intermediaries is as "aggregators". One of the reasons behind this denomination is that it is equally valid in the case of fully deregulated and unbundled systems as in those ones in which this separation has not taken place (particularly in the case of distribution and retailing), as it is the common case in the electricity markets in the American continent. We focus our discussion on the first scheme, and in this context we assume that both figures, aggregator and retailer, represent de facto the same thing, an intermediary that trade consumers' assets and needs in the electricity market. In this sense, a DSR aggregator would be an agent who trades with the DSR consumers' flexibility and, in a fully deregulated and liberalized scheme, it is difficult to conceive an agent playing just this role without also trading the consumers' energy demand needs. And conversely, except for the case of vertical integration considerations, we do not find a reason

for customers, and thereby further reinforcing the case for retail liberalization. Finally, DSR is also beneficial for the final customers, by allowing them to take advantage of variable competitive market prices to reduce their bills and increase their utility, and by increasing their awareness about the different costs of electricity production.

There have been many studies, both qualitative and quantitative, of the costs and benefits of DSR -see e.g. DOE (2006), Joskow and Tirole (2006); Borenstein (2007), Walawalkar (2008), Cappers (2010) for different approaches- most of which conclude that DSR is generally beneficial for the system. However, since the beginnings of the deregulation process, DSR has been considered only interesting for large customers. Among some other reasons, it is still an open question whether the cost of real-time metering and billing for smaller customers (small commercial and residential, generally) makes it profitable to extend this scheme to all customers. But in the last few years technological advances have opened the door for extending this possibility also for small commercial and residential customers. One of the problems usually cited is that small customers are too risk-averse to like to be exposed to real market prices, and in fact most of the evidence shows that in liberalized retail markets consumers tend to prefer hedged contracts, or flat or simple tariffs (e.g. Littlechild, 2003 or Ofgem, 2012). This again might change through technology: the development of advanced "energy boxes", which automatically optimize consumption subject to certain constraints, may help consumers hedge their exposure to price volatility, and in fact some studies (Faruqui and Sergici, 2009) show that small customers do respond to price signals.

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why current retailers, which already have access to energy clients, will renounce to try to seize the flexibility and business opportunity that DSR solutions offer. First, since they would be letting go an opportunity to increase their margins, and also because they would prevent losing clients in hands of others which bet on DSR deployment. Therefore, hereafter we will just use the name "retailers" to refer to the DSR intermediaries.

The needed regulatory push

The other problem for extending DSR to small customers is the need to modify accordingly the regulation of the power system (EURELECTRIC, 2010), (Meeus et al., 2010), (EDSO, 2012). The efficiency of DSR mechanisms, like that of any other activity relating to the supply of electric power, is critically conditioned by the regulatory design to which such mechanisms are subject. The vast majority of the economic analyses conducted to evaluate the potential effectiveness of these tools assume that regulatory design and market (particularly the operation/secondary markets design) entail no adverse impact whatsoever on the added value afforded to the system by their implementation. Unfortunately, however, actual experience shows that this is indisputably the factor that exerts the greatest influence on the efficiency of any mechanism implemented in the context of electric power.

Although some proposals have been put forward on the regulation required for DSR (e.g. Centolella and Ott, 2009), they have generally been limited to those systems where small retail is not fully liberalized. The regulatory framework is however more complicated in those systems where small customers can choose their retailer, which will play a large role in DSR schemes. This complexity may be an additional, not usually mentioned barrier for the development of DSR (FERC, 2009). For example, although in most power systems TSOs already have ancillary services mechanisms in place that in principle should let them taking advantage of DSR possibilities, the procedures that will rule the DSOs DSR purchases it is a fully open issue.

Consequently, the purpose of this paper is to contribute to the necessary reflection on the configuration of a regulatory scheme able to maximize the many advantages for electricity systems of implementing DSR, with special focus on residential and small commercial ones, assumed to be connected to the distribution network. In addition to attempting to minimize the friction between regulation and DSR, the design proposed aspires to enable the DSR services to contribute to the development and improvement of other related activities, primarily the technical management of the electricity system (optimization of grid operation and stability and security of supply) and electric power retailing. Thus, among other issues, we will discuss first the best manner to design them, and second, the protocols needed to coordinate both grid operators, TSO and DSOs.

Although the whole discussion is built around DSR services, most of the analysis and recommendations could also be applied to any other sort of distributed energy service, as e.g. storage, electric vehicles, etc.

Next, we first very briefly introduce the potential value that DSR services can provide both retailing companies and network system operators. Right afterwards, we will delve into an in-depth discussion of the key regulatory issues that need to be addressed and we will develop a number of proposals to improve the current designs.

2 THE VALUE OF DSR FLEXIBILITY FOR RETAILERS AND NETWORK SYSTEM OPERATORS

DSR should turn into a key tool for generators and retailers to balance their energy programs and schedules while at the same time appear as an extremely promising resource for network operators to minimize the cost of guaranteeing the desired levels of security and quality of service as well as reducing network losses and the need for new network reinforcements.

A sketchy list of possible services provided retailers by making use of DSR to TSOs and DSOs is provided in Table i, as identified in the FP7 European ADDRESS Project (2009).

Table i. DSR services for NSOs

#	Function	DSO	TSO
1	Maximum load limitation/Load reduction	X	X
2	Frequency control/Power reserve		X[3]
3	Network restoration/Black start	X	X
4	Power flow control/Network congestion solution	X	X
5	Voltage control and Reactive power compensation	X	
6	Power system voltage stability		X
7	Islanded operation/micro grids	X	X
8	Reduction of system losses	X	X
9	Optimised development and usage of the network	X	

As it can be seen both operators may share interest for common possible services provided by retailers by making use of DSR, and some of the services required by one of the Operators may affect the other (mostly the DSOs). A relevant issue to be tackled is therefore the interaction of TSOs and DSOs in the use of such services.

The upcoming regulatory paradox: regulated entities competing with and in the market

The full deployment of DSR resources (especially when provided by small customers connected to the distribution networks) will require an extremely challenging redesign of the regulation governing electric power systems. In this new environment, these regulated monopolies will have to compete not only with energy market agents, but also among themselves to acquire DSR services. Thus, to take the most of DSR, it will be necessary not only to regulate the processes through which the different actors (particularly the regulated ones, the NSOs) will conduct their acquisitions, but also the way the NSOs will interact and coordinate.

In the next sections, we analyze in three steps the main issues which in our view will have to be addressed: we will first focus on some regulatory improvements that should be considered concerning exclusively the TSO vis-à-vis DSR, then we will face the major challenges concerning

[3] TSO may have rules which prevent aggregated loads from participating in frequency control services.

the regulation of DSOs and we will close discussing the need for coordination between TSOs and DSOs[4].

3 REGULATORY DEVELOPMENTS REQUIRED

3.1 Transmission System Operator

TSO visibility of DSR providers at low-voltage levels

To properly achieve its role a TSO is interested first in monitoring the online behavior of all generation resources and consumptions of demand that may affect the transmission network and the overall security of the system. Traditionally almost all the generation resources (relatively few large generation plants) were connected directly to the transmission grid. Therefore monitoring their behavior and monitoring the demand of large consumers connected to the transmission grid and monitoring the behavior of the demand at the frontier's connection points with the distribution grid was enough for the TSO to feel comfortable. The use of interruptible load as an additional resource to be managed for balancing and security purposes was limited to large consumers connected and monitored within the scope of the transmission network.

However the appearance of a large amount of relatively small generation plants connected to the distribution grid worries TSOs since they are out of the scope of their monitoring and control areas. They are not "visible" for them. On the other hand demand side management advances offer them the possibility to count on a new interesting resource to fulfill their obligations.

In an extreme case TSOs will like to enlarge their "visibility" to any kind of generation connected to the grid. For sure in that case TSOs will have to resort on a geographical hierarchization of the information and of the control centers because of the large number of production installation that may be involved. Since DSOs will probably require in the future (within the "smart grid" paradigms) control centers to monitor and control their distribution networks, it seems that it

[4] The analysis of technical procedures (connections, communications infrastructure and so on) falls outside the realm of the present study and consequently is not addressed.

make sense that TSOs monitoring needs for that kind of generation will be provided directly by this local DSOs control centers in an appropriate aggregated form (maybe distinguishing among kind of technologies, among the transmission grid node they linked to, etc.). DSR, as long as it begins to be massively deployed, will impact on demand behavior and therefore will be subject to the same TSO visibility requirement (through the DSOs).

Moreover, thinking of TSOs looking for DSR services contributing to solve nodal or zonal imbalances (due to network constraint conditions) that might appear at the transmission network level, the TSO should predefine these nodes/zones to allow retailers bidding their DSR services accordingly. Therefore, retailers should be able to distinguish among their DSR consumers, assigning each one of them to their corresponding zone/node. Then, retailers should differentiate in their energy programs declared before gate closure the expected load in each of the zones, so it would be possible for them to subsequently submit nodal or zonal bids.

Pricing of imbalances

In most European power systems, the imbalance settlement is currently solved through a dual imbalance pricing methodology, where a different price is applied to positive imbalance volumes and negative imbalance volumes for each given balancing period.

For a given period, e. g. a half of an hour, if a certain balancing entity[5] (the so-called Balancing Responsible Parties) is holding an imbalance on the same direction than the total system imbalance, either positive or negative, the settlement price of the imbalances is computed as the average weighted price of the balancing actions adopted by the system operator in this direction, over this considered period. Additionally, this value is adjusted by a multiplier $1 + k$, intended to raise this price for the negative imbalances -or reduce it for the positive ones- and make it even

[5] Imbalances are measured only for the so-called Balancing Responsible Parties (BRPs), netting is allowed for deviations within a same balancing party.

more punishing for imbalanced parties. The day-ahead price is applied for the imbalances, either positive or negative, that happen to oppose the total system deviation.

This dual imbalance pricing itself, reinforced by the use of the factor *k*, is supposed to provide incentives to the market agents to try to avoid deviating from their scheduled programs. It is assumed to be a measure intended to improve system security, but it also implies some adverse effects on the development of the DSR solutions.

Effectively, consider for example the case of a DSO which has previously acquired flexibility to certain consumers connected to its network. If for any reason, it requires these consumers to reduce their load with respect to the one declared before gate closure, this latter or their corresponding retailers could be penalized.

Since the reason behind the implementation of dual imbalance pricing is to safeguard system security (under the assumption that a single pricing methodology reduces the incentives for the agents to avoid deviating from their day-ahead programmes) and it is rather straightforward that an imbalance that responds to a DSO command should in any case be aimed to guarantee system security, regulation should therefore avoid penalizing this imbalances.

Finally, as it the case in the Iberian electricity market, in some reserve market designs the TSO just accepts balancing bids that imply the ability to deviate in the same amount either positively o negatively, i.e. no distinction is made and only one price is calculated, instead allowing bids to increase production and different ones to decrease it. This kind of constraints should be removed to effectively allow DSR flexibility playing a significant role in these TSO markets, since it is obvious that the ability for small consumers to decrease their expected consumption is much larger than the other way around.

System operator's interruptibility service

As noted earlier, TSOs get to contracting agreements with interruptible loads to resort to at rather short notice. While these procedures are often not particularly transparent and detailed, they would require scant amendment to enable retailers to acquire the same supplier status as other actors.

Publication of clear and transparent regulations would therefore be desirable to establish the conditions under which demand (via retailers) can opt to participate in the service: firstly and most relevantly, the demand (not addressed in the present regulations) originating in the use of DSR tools.

In this regard, a procedure should be established to certify the minimum values of power consumed under normal circumstances by each customer portfolio offered by retailers, to be able to evaluate their actual contribution to system interruptibility.

Force majeure

The system operator (or any of the distribution grid operators) may occasionally need to resort to DSR tool capacity to limit or even interrupt supply to (at least some) consumers above and beyond the pre-arranged levels. This possibility must be envisaged in the operating procedures, which should clearly define the emergency situations in which such action would be permitted, as well as the (regulated) consideration payable to the consumers affected.

3.2 Distributors

Since up to now, the ability to resort to DSR for DSOs to support the operation of their networks has been at least negligible, as a general rule, it can be stated that currently there are no relevant experiences of ancillary services managed by DSOs. Their network management is mainly based on acting directly on the networks, e. g. changing the load flows trying to deviate the potential surcharges through alternative circuits, but not on managing certain loads unless in case of emergency events, in which they guide their operation decisions by security protocols that in principle are agreed with the regulator or at least are subject to *ex post* supervision.

The obvious reason for this has been the lack of technology able to provide DSOs with alternative solutions to the ones that traditionally have been at their hand. The deployment of the DSR tools (together with other DER related sources) will finally provide DSOs with a good amount of resources to enhance the efficiency of their operation. And as we will next discuss, in so far as there will be excess enough, the possibility to implement any competition mechanism will therefore appear and DSOs will be able to choose the most efficient way to develop their duties.

Therefore, in principle the idea should be that ideally DSOs could develop ancillary services mechanisms analogous to the ones already managed by TSOs, but with certain particularities, see discussion below).

Due to many straightforward operative reasons, as it is not expected that DSO will require to resort to DSR flexibility on a regular (not hourly but even not daily) basis, it would not make sense to implement short-term auctions similar to the balancing markets operated by TSOs. Besides, the fact that one of the (expected) major contributions of DSR is to optimize not only the low- and medium-voltage grids operation but also the expansion, the proper mechanism (also to contribute to the required transparency) is for the distributor to call for medium- to long-term bids from the retailers operating on its grids and having customers who offer services such as load modulation, interruptibility and even hierarchical restoration of power (similar to the TSOs' balancing or even black start services).

Therefore, DSOs can ask the retailers to provide them with the ability to manage loads in certain locations of their networks when needed. This way, as it has already been introduced, they could minimize the cost of complying with the quality of service objectives imposed by regulators or postpone investments in network reinforcements in these locations. For example, this is of special interest particularly in those areas in which electricity demand is significantly higher in short periods of time, as for instance seaside towns, where electricity load increases dramatically in holiday times.

Once they have already acquired these services, they initiate and manage DSR actions on their distribution grids and may even exercise remote control over the load limiters installed in consumers' meters when warranted by circumstances.

Enhancement of the regulatory supervision

As distributors are regulated firms, the procedures whereby they contract or acquire DSR services must be subject to a series of basic criteria:

- Any process in which a DSO channels an activity that affects free market users must be subject to regulator supervision, so as to guarantee total transparency and equanimity of results at all times.

- The incentives must be attractive enough to encourage DSOs to take advantage of the added value that DSR can provide to their operation and planning procedures, but at the same time sufficiently moderate to ensure that under no circumstances DSOs may be induced to place their financial stability or service quality at risk.

Provided that in some cases the DSO resorting on these services could be an alternative option to other solutions (for instance investing in more networks), proper incentives should be designed in its remuneration scheme in order to incentivize DSOs to opt for the appropriate option. For instance a “pass-through” kind of regulation for these costs could deactivate the DSO choosing the more economical solution.

Consequently, on the one hand, DSO purchase of DSR services should be subject to a specific operating procedure. On the other, the methodology for remunerating investment should enable distributors to earn additional revenue for making use of DSR tools to minimize their operation and planning costs. Standards should also be established as necessary to include DSR measures in service quality measures, so that consented outages do not impact service quality indices.

The developments required to delimit and incentivize DSR activities among distributors are analyzed below. The discussion addresses procedures that regulate actions, and the criteria that govern the mechanisms for remunerating distribution network operation and management. The focus in all cases is on the financial incentives needed to encourage the actors to optimize the use of the DSR facility.

3.2.1 Regulation of distributors' DSR actions: operating procedures

Need for defining areas in the distribution networks

Again, as we have discussed for the case of the TSO, DSOs will have to define differentiated areas within their networks, so retailers can assign their corresponding clients and afterwards offer DSR flexibility when and where requested. The configuration of these areas will have to be properly justified by technical reasons and if possible large enough to gather sufficient critical mass to allow competition.

Enhancing regulator monitoring to avoid the need for further unbundling

European legislation prohibits distribution companies from conducting supply-related business and requires them to unbundle both the operations and the accounts of their regulated (distribution) and unregulated (retail) businesses. This restriction should not by any means be viewed as a limitation to distributors' acquisition of DSR services, but it does pose the need to redefine their role in regulation.

The regulatory design applicable to distributors should be expanded to cover two complementary fields: firstly by developing a specific operating procedure to regulate the load limitation service to be managed by each distributor in its area, and secondly by establishing the necessary incentives to make resorting to DSR tools economically attractive to distributors.

In much the same manner that the existing regulations govern the system operator's management of the interruptibility service, distributors' participation calls for rules formulating specific operating procedures to regulate the ways in which they conduct and channel their DSR activities.

Essentially, these procedures should ensure that:

- The DSR resources purchased by distributors are acquired transparently and impartially, i.e., in public auctions supervised by the regulator. The bidders would be the system retailers.

- The product purchased by distributors in such auctions is clearly defined and at the avail of the system operator at all times.
- The conditions under which the distributor may implement DSR actions are clearly specified, along with the timing involved and the information flows to be established with the retailers (and consumers) providing the service.
- Regulator supervision suffices to guarantee that distributors purchase DSR services from retailers under conditions in which all are treated equally (e.g., guaranteeing that the group's own retailer is not favoured).

DSR service purchase mechanisms

As noted, regulation should guarantee the distributor's absolute impartiality when resorting to DSR services. The mechanism proposed to contribute to transparency is for the distributor to call for bids from the retailers operating on its grids and having customers who offer services such as load modulation, interruptibility and even hierarchical restoration of power.

The primary aim is to prevent the distributor from purchasing these services from its own retailer at prices higher than offered by competitors. This, counter-intuitively, is not a problem, for the distributor is unable to transfer this cost to grid tariffs (see later the discussion on the financial incentives included in the remuneration mechanisms for distributors). If consideration for regulated activities is properly defined, the group as a whole has nothing to gain when its distributor pays its retailer a higher than market price, because the retailer's earnings translate into the distributor's loss.

The problem is not short-term, but long-term balance. If the DSR service is ultimately implemented as designed, it would be very difficult, not to say impossible, to compete on the retail market without offering such tools. Consequently, the distributor may attempt to purchase them from its group retailer only (regardless of price) to thereby build an unsurmountable entry barrier for the competition.

The primary aim of the auctions is to channel distributor purchases at a given time (so all potential competitors can plan their participation) and at the same time to ensure that both the product and the prices finally paid are transparent, public and challengeable.

Consequently, detailed regulation must be provided for the following:

- Products: the characteristics of the products purchased by distributors must be sufficiently standardized to guarantee that auctions are suitably competitive.
- Timing: both the minimum amount of time for announcing the auction (grace period) and the duration of the agreements must be closely supervised by the regulator.

Finally, one last problem will in all likelihood have to be addressed. In light of the enormous inertia of retail markets and consumers' aversion to changing suppliers, the majority retailer on each distribution grid is likely to belong to the same business group as the distributor. Therefore, rules should be considered to prevent potential unfair practices (such as bidding under the market price, knowing that the loss would ultimately be offset by the distributor's gain). One alternative might be to link the auctions called by different distributors, requiring retailers, which will (and if that is not the case, should) normally supply customers outside their own grids, to submit one and the same price in all auctions. This measure reduces the retailer's incentive to discriminate between its own and other distributors[6].

[6] Ultimately, if in a certain area of the distribution network there are not enough guarantees that a market mechanism could result in an efficient price due to lack of competition (e.g. if a high percentage of the potential DSR providers in the area are customers of a single retailer), there would be no other choice for the regulator than trying to agree with both the DSO and the retailer on a standardized contract set at a "reasonable" price.

3.2.2 Financial incentives

One of the main paradoxes of the DSR tool-mediated business is that many of its potential customers (purchasers) run natural monopolies (grid operation) whose activities must therefore be strictly regulated.

In this regard, one of the major challenges facing regulators is to design mechanisms that encourage these operators to become involved in the service, in the form of incentives that make their participation in and development of the potential of DSR tools a profitable enterprise (CEER, 2011). But at the same time, this must not jeopardize the grid operators' necessary stability, or allow them to raise entry barriers for retailers or to generate cross-subsidies between their competitive and regulated activities.

The mechanism for recovering the investment needed to conduct regulated business must be adequate and send the right signals to the actors involved (distributors, retailers and consumers) so that all respond to the incentives by maximizing the resulting benefits. Internalization of the expected profit must also be allowed in all other investments to build an intelligent grid.

Such profits are expected to come from two sources: On the one hand DSR tools should enable distributors to enhance their grid management efficiency in two key ways: by reducing grid losses and by meeting their service quality objectives at a lower cost. And on the other, in the longer term, the ability to manage consumer demand at peak times may eliminate or at least postpone the need to make new grid investments (particularly in the future when substantial integration of non-manageable energy sources is foreseeable).

Losses

Ohmic loss in distributors' grids rises with the square of the electric current carried. Therefore, one direct consequence of the possibility of modifying demand profiles by flattening peaks is a decline in such losses.

One proper way to regulate DSO activities in this regard is to affect its remuneration by a parameter linked to for instance the annual percentage of losses[7]. From the standpoint of making the most of the added value that DSR can bring to the electricity system, this approach is sufficient, for it rewards distributors for furthering the modification/rationalization of demand patterns with DSR tools.

Service quality

At present service quality is in most cases measured in terms of installed capacity equivalent interrupt time and installed capacity equivalent outages in transmission systems. Consequently, if the DSR service is to be incorporated and made attractive for distributors, DSR actions should under no circumstances be considered to be programmed or unforeseen outages and therefore should have no effect whatsoever on the calculation of either existing or future (deriving from amendments to the present rule) quality indices.

This constitutes a key step forward in determining each consumer's utility function in respect of supply quality. Users for whom certain minimum quality standards are the chief consideration will have the same guarantee as at present, whereas customers able to accept less demanding standards may adjust their optimal level to a market procedure that will optimize their value for money ratio.

Return on investment in distribution grids

Taking as a starting point that it is not going to be subject of discussion in this paper that the criterion for remunerating distribution consists of linking it to the calculation of incremental costs for the standard grid, see Mateo et al. (2011), the most efficient way of introducing incentives is by calculating each distributor's payments in terms of the expansion and maintenance required by their grids, omitting from this reckoning the beneficial effect of

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[7] For instance, the existing Spanish legislation as set out in Annex II to Royal Decree 222/2008 of 15 February provides for a yearly loss incentive ranging from -1 to +1 % of the preceding year's payment.

implementing DSR tools. The standard grid model, then, should evaluate distributors' costs without taking account of their ability to avoid new investment costs by acquiring DSR services.

Such an approach grants distributors full credit for the optimal grids that they must have in place to meet quality requirements. Remuneration will be independent of demand side management services (i.e., the standard grid will not take account of the potential of such new DSR services). Therefore, the distributor will be able to raise its earnings if it manages to lower costs to below the value established by the model (by reducing the need for new grid reinforcement, for instance) thanks to these new services.

This incentive should be regulated in the same way as traditional incentive regulation (RPI-X), in which a factor, X, is set (and re-adjusted after a number (five or ten for instance) of years has lapsed) to incorporate improvements in efficiency in subsequent updates. Analogously, a period of years (sufficiently long for the incentive to be effective, and sufficiently short to be able to convey the benefits of this improved efficiency to consumers) should be established, after which the new configuration should be incorporated into the standard grid model.

3.3 TSO and DSOs: The need for strong coordination to make the most of DSR

3.3.1 Boundary conditions

The role of the network system operators (NSOs), i.e. the TSO and the DSOs, and how their relationships with the rest of the system agents should be arranged and regulated (to allow the maximization of the DSR beneficial impact for the overall electricity system efficiency) are undoubtedly the most intricate issues to be discussed.

The main complication lies essentially in the following facts:

- TSOs and DSOs are linked through the grid, so often TSO's managing decisions have an impact on DSOs duties and the other way around. The first consequence of this is the critical need for strong coordination and clear definition of hierarchical procedures. And moreover, from both point of views, the best alternative to manage a system operation event is not necessarily coincident: as we will try to illustrate next in section 3.3.4, the value of a particular DSR action in the TSO utility function can be different from the one that represents in the DSO's.

- Electricity network and system operation are by nature monopolistic activities, so all the procedures developed by the NSOs should be under the strict supervision of the regulator, and at the same time, they should not get involved in the market game (i. e. any purchase of flexibility should be made under special circumstances assuring total transparency).

As previously mentioned, ancillary services mechanisms have only been implemented at high voltage level, so the actions taken by TSOs have barely had no impact on DSOs operation (except in emergency cases in which major load shedding had to be implemented). The development of DSR, together with the increasing penetration of distributed generation in their networks turns to be a major challenge for DSO, since they will have much more alternatives to efficiently operate and plan their grids. But DSR is not just a source of flexibility at local, low voltage level: as above stated, it is expected that it can also suppose a key contribution for the overall system operation. Therefore, in the upcoming scenario it will be crucial to design efficient procedures to assure the NSOs coordination.

3.3.2 The importance of respecting each others' "jurisdictions"

One of the main novelties behind the implementation of DSR will be that for the first time there will be a factual opportunity to send discriminated operation signals to low voltage consumers, and as stated, this will completely change the way DSOs will have to manage their grids. These consumers will be able to modify their previously scheduled (or estimated) consumption and moreover, they will be able to do it at short notice, responding in principle to their retailers' commands.

These DSR actions could eventually change the load flows in the distribution grids, what might affect to the stability of the networks if DSOs are not properly informed, with sufficient prior notice.

Therefore, in order to guarantee system security, it will be of major relevance to design operation procedures to coordinate the TSO with the different DSOs, in which the hierarchy of powers is clearly defined. While the first one is responsible of the overall system security, and particularly at the transmission level, DSOs have the responsibility of assuring the supply to the consumers connected to their networks.

This fact leads us to the following recommendations for the design of the business architecture, that affect differently to the balancing markets and the balancing services (particularly the interrumpibility service).

3.3.3 The essential coordination of NSOs' balancing services acquisitions

While there are no forceful reasons to significantly modify the current design of the balancing markets to allow the participation of DSR, on the contrary there are numerous ones that justify that the purchases of DSR solutions for balancing services of TSO should be in any case, if not channeled through DSOs, at least coordinated with them by implementing common auctions.

The two main reasons we just mentioned to justify that no change in the current design of balancing markets will be required (particularly in the way the market is currently being cleared and prices are calculated) are not valid when dealing with the purchase of balancing services: first, as aforementioned, these services are usually thought to provide the TSO with the ability to resort to short-term flexibility, notified at short notice, and additionally, contrary to the case of balancing markets, it is much more common that the DSO needs when resorting to these services are much more local, oriented to solve eventual grid stresses in certain node of the network. This means that first there will be not much time for the DSO to react when the orders are announced and that the demand response called by the TSO will be much more concentrated in certain areas of the distribution network.

This might have a doubly harmful impact: the distribution network security could be severely hampered and also, in case the DSO could act to prevent potential damages for its networks of sudden shifts, the actual response of the demand could not be the one expected and required by the TSO, something that would be particularly inacceptable in an emergency situation, as it is commonly the case when TSOs resort to this services.

Next, we add a good reason to back this design. And afterwards, we will close the discussion of the architecture design with an example aimed to illustrate the proposed model.

Avoiding duplicities

First, even under the assumption that the distribution network topology has no impact on the actual results of the actions taken at the low voltage level (see below for a discussion on this issue), this scheme will prevent any single customer (or retailer) from selling the same product (capacity to modulate or even interrupt demand) to different actors. The TSO may consider necessary to count on load interruptibility in certain nodes of the transmission network, and therefore it would be interested in acquiring this service from the consumers connected to each of them. At the same time, the DSO managing the distribution network connected to one if these nodes may have similar interests in being able to resort to reducing at short notice the demand in its network under certain circumstances. It is pretty straightforward to notice that in many occasions both network operators will have the necessity to resort to the interruptibility services at the same time.

Although it is true that this problem could in principle be solved by establishing efficient protocols of coordination and cooperation between both network operators, real life shows that this is more than often very difficult to implement, leading to a fuzzy regulation without the necessary hierarchical structure to guarantee the optimization of the resources.

3.3.4 Maximizing the DSR efficiency at local levels: illustrative case examples

Preliminary considerations

On the role of retailers

Retailers, as mentioned before, pool the DSR services agreed to with their customers and offer them to operators at different points on the grid. Since the consumers involved are residential and small commercial ones, we will assume they maintain commercial relations with the retailer only, who not only applies the discounts justified by its own savings, but also notifies them of the grid operators' stated needs[8].

The relationship formed materializes with the consumers' consent to retailer intervention in their power load management, subject to the pre-arranged terms. Consumers set the DSR actions they are willing to undertake, establishing allowable limits, the priority desired for service restoration in the event of grid outages and so on.

Retailers may send short- or long-term signals to their customers. An example of the former would be when the retailer, envisioning a scenario of particularly high energy prices, announces to its customers that they may lower their monthly bill by lowering their demand at peak times on the following day.

This sort of agreement can be established in advance: for instance, when consumers consent to having their demand limited for intervals lasting no more than one hour three times monthly in return for a discount. This sort of agreement enables the retailer to manage its supply portfolio more flexibly.

On the NSOs boundaries

To clearly establish the context in which the discussion that follows will take place some initial considerations should be made:

[8] This in turn calls for the design of a fairly complex protocol to ensure fluent communication between TSO/DSOs and retailers. Such communication is particularly relevant when the DSO resorts to DSR tools in cases of emergency. Under these circumstances, since DSOs must act independently and nearly instantaneously, compliance of the requirements agreed to by consumers and retailers must be guaranteed. For instance, if partial outages are needed to keep the grid from collapsing, DSR tools can be used to institute selective interruptions, resorting to customers who previously notified their retailer of their willingness to participate in the scheme. In such cases distributors must aim their actions at the right consumers and abide by the provisions laid down in retailer-consumer arrangements.

- For sake of simplicity and clarity it will be assumed that a DSO will operate on the area of a single TSO. Different DSOs may exist in the area covered by such TSO. It will be assumed also that a retailer may be managing resources connected to different DSOs (but a single TSO as stated previously).
- TSOs and DSOs are assumed to be regulated entities.
- The frontier between the Transmission network and the distribution network obey, up to now, not only to technical reasons but also to historical and regulatory reasons. Therefore those frontiers differ very much from one system to the other. However the decision upon where this frontier is set seems not to interfere in the discussion below.

While the TSO can be willing to contract DSR flexibility to no matter which consumers connected to a transmission network node, i.e. assuming every MW reduced has equal value for its purposes, the DSO, since it is aware of the distribution network state in each particular situation, can have a different valuation of the different contribution of the consumers connected to the distribution network linked to the transmission network node in question. This consideration, as well as the previously discussed, are illustrated with the examples description that follows[9].

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[9] The case examples developed next aim at illustrating the role the regulated agents (grid operators) should play in the future regulatory design, i. e., with whom they should deal and under what conditions (under regulator supervision to ensure transparency and non-discrimination), but consciously refrains from attempting to define the most efficient format for the contracts that govern such purchases. Decisions on which products to purchase and how they are defined are left to the discretion of the actors involved. Each distributor, then, will be able to determine what to purchase and how much to pay for it, depending on its specific objectives in each area. That notwithstanding, an example is set out to briefly illustrate what such transactions would involve. The products defined are but a few of the many that are expected to appear once the market is operational. The actors' own initiatives will most certainly develop the transactional models that prove to be the most efficient for all concerned.

The example is based on the highly simplified grid shown in the figure.

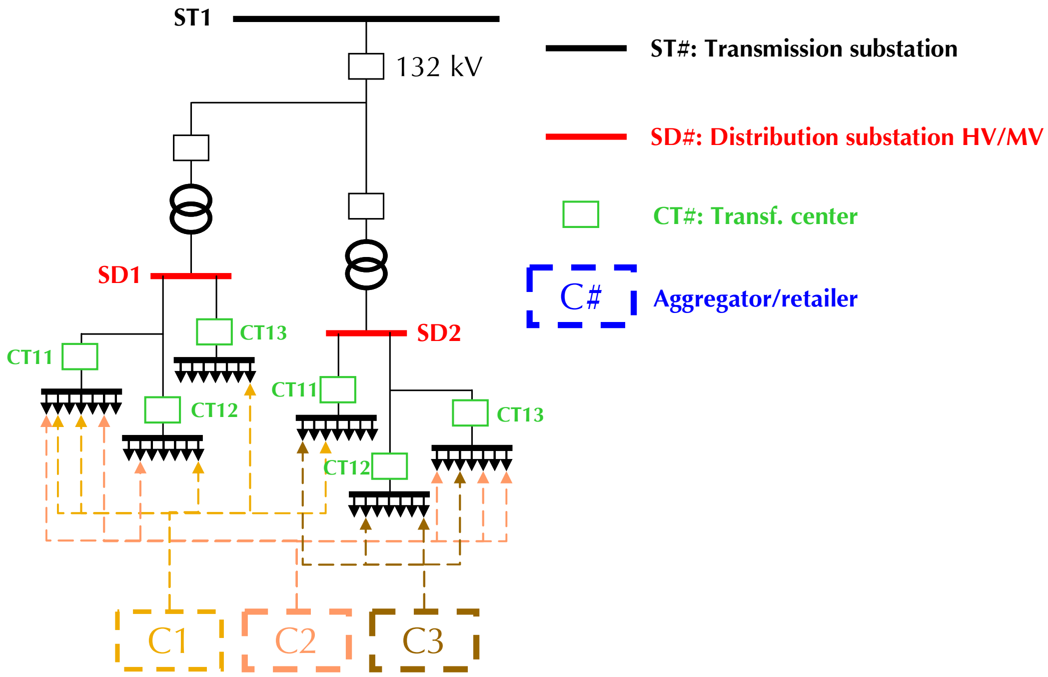

Figure 1. Simplified grid considered in the case example

Assume a node on the transmission grid consisting in a transmission substation TS1 to which a 132-kV radial distribution grid is connected. This distribution grid in turn branches into two distribution substations, DS1 and DS2, that feed two essentially domestic distribution areas. The domestic customers connect into each of these substations across a sizeable number of transformer stations.

Assume also that 30 000 customers, who have a combined load of 150 MVA (the assumed demand factor is 0,33), are connected to substation DS1, with a capacity of 50 MVA[10].

These customers have a choice of three different retailers as power suppliers, all of which offer the possibility of installing DSR tools in their homes.

[10] The figures used in this example were chosen for the purposes of illustration only: they are not intended to estimate, even roughly, real-life situations.

The following describes some of the DSR relationships that may arise in the framework previously set out. Further to the discussion in the body of the paper, the example addresses some of the reasons that would justify each actor's participation.

Network operators' needs

DSO's need for DSR

The distributor takes advantage of the flexibility afforded by DSR tools in two stages:

- Firstly, its substation DS1 is subject to overloads due to increased summertime demand. DS2, in turn, is in no danger whatsoever of overloads. In order to save on the additional investment required to reinforce substation capacity, the distributor would be keen on limiting demand at times when the substation is in danger of saturation. Example 1 below shows how this could be done.

- Secondly, the loss coefficient in the grids connected to DS2 is high, due to their specific characteristics and an especially "spiky" demand. Since the lower the loss, the higher the earnings, the distributor considers the possibility of remunerating consumers (through their retailers) in distribution area DS2 to flatten their demand curves throughout the year. This alternative is not discussed in this note.

TSO's need for DSR

At the same time, the TSO foresees possible transmission grid imbalances unless it is able to lower the summertime load on its ST1 node. To optimize grid management, it considers concluding agreements that would allow it to alleviate demand on that node by at least a given pre-established percentage, a certain maximum number of times throughout the summer.

The TSO notifies the distributor of its needs. The latter, in view of both the TSO's and its own needs, calls an auction one year in advance (for instance: this period could be longer, but in any case it must be sufficient to enable retailers to plan their commercial strategies).

Examples of purchase of DSR services: partial limitation of maximum demand capacity

Example 1: the distributor purchases services to avoid overloads on its equipment

Assume that the distributor foresees the risk of a 5-MVA overload on DS1 during the summer (defined as appropriate). It therefore decides to attempt to purchase the following product:

Capacity to limit demand in distribution area DS1 (for instance) during five two-hour peak periods in the month of August, giving four hours' notice. Consumers may, in the two hours following the notice, decline to participate in the service, subject to the penalization established in the agreement.

To this end, the retailer must calculate how much of a cut-back on the connected load it must request to obtain the desired reduction. Assuming the demand factor to be constant and equal to 0,33, it should purchase 15 MVA. Since the best price will be offered by those for whom flexibility has the lowest cost (i.e., by customers who do not consume their full capacity at peak times), it must evaluate the factor to be used in this case, which will be smaller (assume 0,25: no one is better positioned to estimate this value).

Under these terms the quantity risk deriving from the transfer function between capacity limitation and effective demand limitation would be assumed by the distributor .

In this specific case, in which the distribution grid operator pursues a fairly short-term specific response to avoid an overload, or even total outage at a given node or zone, an agreement of this nature is better suited to its objectives.

The result would be, then, that the distributor should offer to purchase 20 MVA in the auction. This, assuming a mean capacity of 5 KVA and a mean reduction of 2 KVA per customer, translates roughly into involving around 10 000 customers in the reduction.

At a demand factor of 0,25, the above result may be interpreted to mean that three quarters of these customers (7 500) offer something whose value in principle is zero, and only one fourth actually modify their consumption patterns. This reflects on a reality inherent in the way today's access tariffs are calculated, for it shows that one fourth of the customers, whose weight in peak demand is what generates the need to redimension the system (in this case, the substation), are in fact being subsidized by the other three-fourths.

The retailers operating in the distribution area involved (in this case, DS1 only) would offer a supply curve (price/DSR-interruptible MW) from which the distributor would purchase the amount wanted, providing the price does not exceed the previously calculated maximum. If the price of purchasing the DSR service is higher than the distributor's expectations, it would be better advised to invest in reinforcing the substation.

Further to the communication protocols and algorithms under development in the context of the DSR projects, once the service has been purchased from (what is expected to be) a sufficient number of consumers, the DSO may send a signal that limits the maximum demand capacity of all the participating customers connected to a given transformer station. This signal may consist in lowering their demand to the same pre-arranged maximum for all of them, 3 KVA for instance.

Take any given day in the month of August when a potential overload on substation DS1 at 9:00 p.m. is predicted to generate a need to reduce expected demand by at least 4 MVA. Before 5:00 p.m., the distributor would send a preliminary notice to all consumers participating in the service. At 8:30 p.m. it sends a signal to the consumers connected to TS11 and TS12, limiting their demand to 3 KVA and waits for fifteen minutes to receive information on the effectiveness of the signal, measured as the effective reduction. If insufficient, it sends the signal to the DSR consumers connected to TS13.

Example 2: the distributor purchases services to meet its own and TSO needs

Take the following example: in addition to the needs defined in Example 1, the TSO calls for capacity to lower the demand on node TS1 during the summer (defined as appropriate) by up to 7 MVA (for the sake of simplification, under the same conditions, i.e., five peak periods in the month of August, with four hours' prior notice). The distributor therefore decides to attempt to purchase the following product:

Capacity to limit demand in distribution areas DS1 and DS2 (for instance) during five two-hour peak periods in the month of August, giving four hours' notice.

The auction is similar to the previous case, with one difference. Since it makes no difference to the TSO whether demand is lowered in area DS2 or DS1, the distributor would call for bids in both. The retailers operating in the distribution areas involved would submit their supply curves (price/interruptible MW) for each (DS1 and DS2).

Initially, if the areas are large enough and similar enough (which would be the usual case), the cost of the product should be the same in both. Therefore, the distributor may prioritize purchase of the service in area DS1, where it has a problem of its own, acquiring 5 MVA there and 2MVA in DS2. This would be the price it should convey to the TSO.

If for some justifiable reason the result of purchasing the service asymmetrically in the two areas (5 and 2 MVA) were higher than if no distinction were made between the two, the distributor may still purchase more service in area DS1 if it is in its interest to do so, but it should not be able to pass the extra cost of acquiring the service at a higher price on to the TSO.

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