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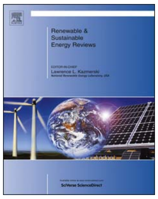

Managing electric flexibility from Distributed Energy Resources: A review of incentives for market design

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ABSTRACT

In many electric systems worldwide the penetration of Distributed Energy Resources (DER) at the distribution levels is increasing. This penetration brings in different challenges for electricity system management; however if the flexibility of those DER is well managed opportunities arise for coordination. At high voltage levels under responsibility of the system operator, trading mechanisms like contracts for ancillary services and balancing markets provide opportunities for economic efficient supply of system flexibility services. In a situation with smart metering and real-time management of distribution networks, similar arrangements could be enabled for medium- and low-voltage levels. This paper presents a review and classification of existing DER as flexibility providers and a breakdown of trading platforms for DER flexibility in electricity markets.

Contents

1. Introduction . . . 238
2. From traditional to smart electricity systems . . . 238
3. Distributed Energy Resources as flexibility service providers within electricity systems . . . 239
    3.1. Consuming DER: residential loads . . . 239
    3.2. Bi-directional DER: electrochemical storage and EVs . . . 240
    3.3. Producing DER: micro CHP and PV units . . . 241
4. Markets for electric flexibility trading . . . 241
    4.1. DER trading for ancillary services . . . 241
    4.2. DER trading for system balancing and network congestion management . . . 241
    4.3. DER trading in spot markets and generation capacity markets . . . 241
5. Incentives for efficient operation of Distributed Energy Resources . . . 242
    5.1. Price based methods for DER management . . . 243
    5.2. Direct load control for DER management . . . 243
    5.3. Techno-economic alignment of incentives . . . 243
6. Discussion . . . 243
    6.1. The transition towards decentralized system operation . . . 243
    6.2. Settlement of incentives and control: which roles for different actors? . . . 245

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1364-0321/

7. Conclusions 245
Acknowledgements 246
References 246

1. Introduction

Traditionally low voltage grids have been designed to transport electricity towards residential users for consumption. However, due to the increased penetration of Distributed Energy Resources (DER), low voltage grids are increasingly used as carriers of bidirectional electricity flows. The penetration of DER such as distributed generation (DG), electric storage and electric vehicles (EVs) significantly affect the operations of distribution grids [1,2]. In Germany for example, the growth of Solar Photovoltaics (PV) reached a level of 38 GW installed in 2013 and affected grid stability in some local areas [3]. Large numbers of PV installations are noticed in The United States (US) within California, Arizona and Hawaii [4]. Other examples of DER rises are a significant growth of EVs in Norway – where EVs stood for 12.5% of new car sales in 2014 – California – with almost 130.000 plug-in vehicles on the roads by the end of 2014 – and CHP in Denmark [5–7].

On one hand, this DER development is positive due to reductions in CO_2 emissions with sustainable DG, decreased use of transmission lines, increased self-consumption and the increasing independence of customers from central grid power [8]. However, regardless of those, DER is potentially problematic for grid stability and reliability due to congestion and voltage issues [9,10]. These concerns are mostly posing effects on the distribution network, which is under supervision of the Distribution System Operator (DSO) in Europe or integrated service utility (in some places in the US). The German example shows that due to local electricity over production at the sunny moments of the day, reliability of supply is endangered in distribution grids [11–13]. In France, realistic forecasts count on 450.000 Plug-in Electric Vehicles on the road by 2020 [14]; if this objective is reached, simultaneous charging of these EVs could stand for between 5 and 20% of the annual peak load [14].

Existing research describes effects of DER penetration from both a technical and economic perspective. For example, [9] and [15] discuss the impact of PV penetration on grid stability and the improvements that storage would provide. An holistic approach of DER management has been briefly discussed for the Norway sector [16]. Possibilities exist to use the vehicle to grid systems for benefits of the overall electricity system as described by [17,18]. Research highlights especially the difficulties for the DSO with increasing penetration of DER. The effects of DER on the financial position of the DSO has been presented [19] together with the possible new roles of the DSO [20,21]. A approach on how DSO charges should be set up to incorporate DER has been described [22] as well as methods to remunerate DSOs with high penetration of DER [23]. Research showed that there are problems to be solved especially for distribution pricing [24,25] and therefore an approach for such network tariff design with high DER penetration has been presented [1].

DER can provide value in smart grids with their electric flexibility [26], however a review of DER sources, their technical limitations for providing electric flexibility together with possibilities for economic trading of flexibility services is lacking. Consequently, this paper presents a review and classification of existing DER as flexibility providers and a detailed breakdown of trading platforms for DER in electricity markets.

Finally, this review ends with policy recommendations for management of electric flexibility from DER. Depending on system status and policy objectives, some arrangements might better serve system purposes than others. Due to its scope, this paper is of interest for policymakers in both liberalized and vertical integrated electricity sectors, next to electricity suppliers, network managers and emerging actors like aggregators and Energy Service Companies (ESCOs).

This paper starts with a description of general changes in the electricity system in Section 2. Section 3 presents a review of the most common Distributed Energy Resources and their technical characteristics. Section 4 presents an overview of markets for flexibility trading. Next, Section 5 reviews incentives for DER management like tariffs, contracts and direct control. After, the discussion in Section 6 presents other important factors that should be taken into account for effective market design. Lastly, in Section 7 the conclusions are presented.

2. From traditional to smart electricity systems

The development from traditional to smart systems is seen world wide, with examples in Europe [27], United States, China [28], Australia [29] and Brazil [30]. These developments in electricity sectors challenge the traditional centralized management of electricity systems. The increased penetration of renewable energy sources (RES), the distribution of electricity production, the penetration of Distributed Energy Resources and the move towards smart-metering and demand response call for a different approach on electricity consumption and production.

Supportive Feed-in-Tariffs in for example Germany incentivized the installation of small solar panels in the residential and commercial sector. In 2014 Germany had 38 GW capacity of Solar PV installed, with a large part, (more than 60%) located at low voltage levels [11]. Other examples of rapidly developing residential solar PV segment are found in Belgium (where 1 out of 13 households are equipped with a PV system), Denmark, Greece and the United Kingdom [11]. Likewise, large numbers of PV installations are noticed in The United States (US) in California, Arizona and Hawaii [4]. Electricity generation is thus increasingly placed at the distribution grid as an alternative of at the transmission grid level. This affects the distributed nature of electricity generation [8].

Demand response is a term that refers to "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" [31]. Distributed Energy Resources (DER) e.g. Electric Vehicles (EVs), combined heat and power (CHP) units, electric water heaters and storage units are potentially providers of flexibility services, also referred to as demand response (DR). Different from the traditional view of electricity use at the distribution level, residential electricity consumers could be activated to respond on a trigger, which could be for example a price. In order to enable DER participation with the provision of demand response, smart metering together with alternative contracting and pricing methods are important requirements [27,32]. Furthermore, from a technical perspective, investments in distributed intelligence, distributed automation and in-home energy management could further facilitate the efficient operations of appliances connected at the distribution grid.

However, in this paper, we focus on incentive design that can affect the operations of different DER and the resulting business cases for DER flexibility provision.

Renewable energy resources create important system benefits if they replace conventional generation resulting in decreased overall emissions. However, for system operation, RES increases risks because of unpredictable production patterns. Therefore RES require flexibility services like back up generation to supply for balancing needs of the non-supplied demand. Next to those traditional methods of system balancing, demand response and storage can potentially supply the system with flexibility services. Storage units are potentially beneficial for electric energy time-shift, power supply capacity and transmission congestion relief [33].

Next to the previous named developments regarding the variability of RES generation, the distributed nature of generation and the change of demand from static to responsive, other developments affect the way in which distribution grids require decentralized management. An important one relates to the electrification of transport with the electric vehicle (EV). The EV development is important because EV charging may significantly increase electricity consumption at distribution grids during peak periods, potentially jeopardizing security of supply due to congestion and voltage issues [34,35].

3. Distributed Energy Resources as flexibility service providers within electricity systems

As described in the previous section, Distributed Energy Resources (DER) e.g. Electric Vehicles (EVs), combined heat and power (CHP) units, electric water heaters and storage units are potentially providers of flexibility services. Technically, an electric flexibility service can be defined *as a **power adjustment** sustained at a given **moment** for a given **duration** from a **specific location*** within the network. Thus, a flexibility service is a service characterized by five attributes (see Fig. 1): its *direction* (a); its *electrical composition* in power (b); its *temporal characteristics* defined by its *starting time* (c) and *duration* (d) and its base for *location*.

Some DER may have a single direction (for instance typical household loads, such as water heaters, dishwashers and electric heaters), while others have bidirectional capabilities and could both act as consuming and producing units (e.g. EVs and storage units).

Furthermore, the electrical composition is of importance in order to state for what system flexibility needs DER could serve, which calls for a differentiation between *power* and *energy* resources. The former have a rather low energy/power ratio. Those DER can provide the electricity system with a high power value, but are not able to maintain this power level for a long period of time. The latter have a high energy/power ratio and are more appropriate to maintain a change in power level for a longer period of time. The power resources are consequently better suited for short-term markets (e.g. on the ancillary service markets) while energy resources are better suited for long-term markets like balancing mechanisms and trading DR in the bulk electricity market.

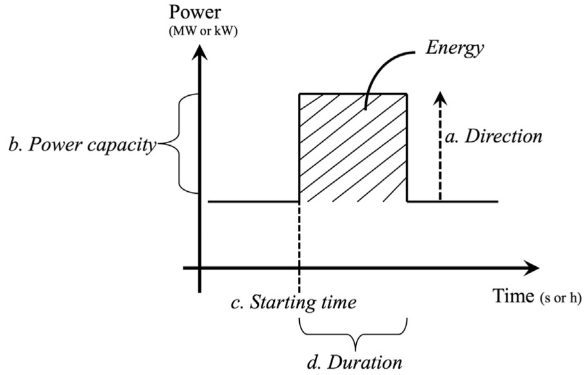

Fig. 1. The attributes of an electric flexibility service (except for the attribute location) [36].

In order to compare the different DER on this criterion, we define the *max power temporal ratio* t_r (expressed in time) as the maximum duration a DER can sustain its maximum power variation with respect to its nominal power. For some DER types, this parameter can be computed by dividing the allowed energy range by the maximum power capacity (e.g. considering a stationary battery with a charging/discharging power equal to 10 kW and an energy capacity equal to 50 kW h, we find $t_r = 5$ h). For some other DER, it may be related to physical characteristics (for instance for a water heater with thermic inertia, we may find t_r=30 min). The lower this value, the more the DER can be considered as a *capacity type* DER, and vice-versa. This variable is intended to provide insights on differences between DER categories, although there is not a singular value for all DER in such category, simply because this is technology specific. Obviously, individual power and energy ratings are also of paramount importance; they will characterize the contributions of each individual DER. However, because DER will be gathered into aggregations to provide grid services, we find that t_r is more insightful to characterize DER abilities to provide capacity- or energy- related grid services.

Furthermore, the availability (in time) is a constraint that distinguishes the average number of hours during which DER could provide services to the system. Some resources may only be available during specific periods of time – for instance EVs are most likely to be available from 6 PM to 6 AM. In order to compare the flexibility providing units on this criterion, we compute for each of the DER the ratio a_r defined as the average number of hours during which the unit is available divided by the total number of hours in a week. As for the previous criteria, we aim to provide insights in expected values to compare different DER, although in reality similar DER may offer different availability times. Besides the average availability over one week, the specific period of time when the DER is available is also a crucial parameter. However, because this criterion is case dependent on the respective end user, we are not able to provide representative general estimations for this parameter.

Additionally, the activation time refers to the aspect that some resources may be able to adjust their power much quicker than other sources. Generally, almost all electric appliances have a fast activation time, ranging from the order of a second to one minute, except for CHP units which have longer ramping times [37]. Lastly, the location of DER is of importance for the supplied nature of the required demand response. For example, locational specific demand response could be of interest for local congestion management or distributed generation (DG) optimization. Table 1 provides an overview of common DER and their characteristics. The table is divided in different types of DER; consumption, bi-directional and generation.

3.1. Consuming DER: residential loads

New generation LED lightings could adapt their power consumption to required grid power variations [38]. Future LED systems could undergo system power variations up to 35% while humans would only perceive a variation of 15% in light intensity [38]. This would be particularly interesting for public lighting. On the contrary, older lighting systems do not have those abilities

Table 1
Different DER and their technical characteristics.

	DER	Flexibility direction	Flexibility characteristic (power vs energy)	Availability ratio	Predictability	Technical response time	Grid[a]	Ref.
Electrical Consumption	Lighting loads (W)	Unidirectional (downward)	New LED systems: energy types older lightings: power types	$0.2 < a_r < 0.5$ during peak hours	Good	Second	DS	[38–40]
	Dispatchable, residential loads (washing machines, dishwasher)	Unidirectional (downward)	Power type $5\text{ s} < t_r < 5\text{ min}$	$a_r < 0.1$ low *max power ratios* t_r due to max off time	High	Second	DS	[39,40]
	Electrical heating/ Cooling (continuous loads)	Unidirectional (downward)	Power type $t_r \approx 15\text{ min}$	$0.4 < a_r < 1$	High	Second	DS	[40,41]
Bi-directional	Electrochemical Energy Storage (EES) (kW-MW)	Bidirectional	Power & Energy types $4\text{ s} < t_r < 10\text{ h}$	$a_r \approx 1$	Perfect	Second to Minute	DS or TS	[42,43]
	Electric Vehicle (kW)	Unidirectional or Bidirectional	Power & Energy types $30\text{ min} < t_r < 6\text{ h}$	$0.5 < a_r < 0.9$	High	Second	DS	[44,45]
Generation	PV Unit	Unidirectional (Upward)	Curtailable	$0.25 < a_r < 0.4$	Good a few hours ahead	Minute	DS	[46]
	Micro-CHP unit (kW)	Unidirectional (production mode)	Energy type	$a_r \approx 1$	Perfect	Rather slow (5%/min)	DS	[37]

[a] Where DS stands for distribution grid and TS for transmission grid.

[38,40], since changing their power consumption would have serious impact on their luminous capability. LED lighting systems can maintain this power variation for a significant period of time and therefore can be considered as *energy type* flexibility resources. However, their potential power modulation is relatively low in absolute values – LED lighting bulbs consume 75% less energy than conventional bulbs [47]. Their predictability is relatively good (for instance public lighting has very precise operating hours), while their availability highly depends on the usage considered. Typical lightings would be turned on from a few hours a day during peak hours to 12 h a day, thus we find $0.2 < a_r < 0.5$. It should be noted that this criterion is highly seasonal dependent.

Residential appliances, such as water heaters, washing machines, electrical heaters and air conditioners have rather low *max power temporal ratios* t_r; changing the power consumption of most of these units impacts their primary usage. The latter can range from a few seconds (e.g. for cookers) to about a dozen of minutes (electric space heaters) [40], thus providing a *maximum temporal ratio* of $5\text{ s} < t_r < 15\text{ min}$. Their availability depends a lot on the appliance considered: whereas electric space heaters have a good availability ($0.4 < a_r < 1$) due to the fact that they are turned on for long periods of time, washing machines have a very limited one ($a_r < 0.1$) as they are typically turned on once every two days for two hours [48,49]. Similar rationale applies for their predictability [41,50]. Heat pumps coupled with thermal energy storage stand out in this category; their *max power temporal ratio* can reach up to 3 h without any inconvenience for end-users [51], making those units suited for longer grid services such as peak shaving.

3.2. Bi-directional DER: electrochemical storage and EVs

Storage units are potentially beneficial for electric energy time-shift, power supply capacity and transmission congestion relief [33]. Electrochemical Energy Storage (EES) units have a perfect availability and predictability ($a_r \approx 1$). Whether they should be considered as *energy type* or *power type* resources depend on their power density and energy density characteristics, both parameters being much related to the type of battery technology, e.g., Li-ion, Ni-MH and Ni-Cd [42]. Thus, it is possible to find EES units for all kind of applications, from very-fast high-power responding units (such as supercapacitors, $t_r \approx 4\text{ s}$) to energy type chemical batteries (such as Li-ion batteries, $t_r \approx 10\text{ h}$) [42].

Most Electric Vehicles[1] on the roads today have a battery capacity of around 20 kWh[2]. Their *max power temporal ratio* depends on the power of the charging station they are plugged in. Typical charging station powers range from 3 kW to 50 kW, leading to approximately $30\text{ min} < t_r < 6\text{ h}$. Because EVs are primarily used for transportation, capacity type services that would not empty the battery would be most suited. Privately owned EVs are mainly available during nighttime and weekends ($a_r \approx 0.5$), but the availability could rise up to $a_r > 0.9$ if charging points are installed at working places. Company fleets could also be available in the afternoons ($a_r \approx 0.8$). EVs predictability patterns are easily fore-seeable [45], especially when considering a fleet of EVs and not a single vehicle.

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[1] EV market share is today rather low everywhere (except in Norway): this is mainly due to their limited driving range, their high prices and the lack of charging infrastructure. However, these three barriers could be overcome in the near future, with the joint action of technology improvements and public policies

[2] Nissan Leaf: 24 kW h; Renault Zoe: 22 kW h; BMW i3: 19 kW h. In the future, battery characteristics are expected to increase significantly, what could change the value of EVs as DER

3.3. *Producing DER: micro CHP and PV units*

Micro-CHP units are small heat and electricity generating units. They have a large availability and predictability since they are dedicated to heat and electricity production ($a_r \approx 1$). It is more difficult to define a *max power temporal ratio* for micro-CHP units because they could produce electricity at maximum power continuously, as far as they are being supplied by the primary energy source (mainly gas). Rather, their availability to maintain a change in their electricity production will be based on economics considerations. The control strategies of micro-CHP units are likely to take into account energy costs [37] in their economic balance. Therefore, micro-CHP units would fit in the *energy type* category.

PV units are different from the others, in the sense that their production output cannot be controlled – however, with smart inverters, PV production can be curtailable and, considering aggregation across multiple sites, PV aggregations could even provide downward and upward reserves. The units produce electricity between 6 and 10 h a day depending on their location. Generally production forecasts can be achieved a few hours ahead [46] for single units. However, the predictability improves with the aggregation of many solar units rather than individual units (similar to EV fleets as discussed above).

4. Markets for electric flexibility trading

Traditional electricity systems are managed in a top-down manner, meaning that generally large generation units connected at high voltage levels feed in electricity for electricity consumers that are located at all other voltage levels. Flexible generation units (mostly hydro units, gas and coal fired power plants) are besides providers of bulk electricity supply, also providers of electric flexibility by means of upward and downwards adjustments. Those adjustments could be incentivized by for example capacity contracts with the System Operator (SO) for automatic adjustments.

Besides generation, also consuming units might be suppliers of electric flexibility. In the United States demand response is largely applied in many markets, for example with the Regional Transmission Operator (RTO) of Pennsylvania-New Jersey and Maryland, shortly named PJM [52]. France and the United Kingdom (UK) are important frontrunners in Europe regarding developments with demand response [53]. In France, already before sector liberalization, demand response activity was triggered by the electricity utility EDF for industrial electricity customers. These units received dynamic tariffs that incentivized consumption shifting. Table 2 provides an overview of the most common traditional markets for electricity trading in the short and long term, based on the French trading time periods. The next sections describe in further detail examples of demand side flexibility applications worldwide. Please note that the examples presented here are not meant as an exhaustive review, rather as representative examples. There are more existing examples than those presented markets for DER participation in system flexibility.

4.1. *DER trading for ancillary services*

Ancillary service markets are in place in order to manage transactions for upward or downward adjustments in the short to very short term. These markets are organized very close to real-time and require automated load adjustment. In France ancillary service markets are organized shorter than 30 s before real-time for Frequency Containment Reserves (FCR, also named primary reserve), below 15 min for Frequency Restoration Reserves (FRR, also named secondary reserve) and lastly Replacement Reserves (RR, tertiary reserve) for system balancing between 13 min-2 h before real time (see Table 2). In the United States (US) and UK numerous projects present examples of DER flexibility provision within ancillary service markets [44,54]. Due to the fact that individual DER do not provide sufficient reliable electric flexibility to be tradable in markets, aggregation is required in order to trade in organized markets. In the US, the REG-D (Dynamic Regulation) signal is used for activating fast responding resources like flywheels and stationary batteries [55,56]. Furthermore, within the Delaware EV project this signal is used for activation flexibility from aggregated EVs. In this project an EV aggregator acts as an intermediary firm between PJM (the regional transmission operator) and flexibility service providing EVs. This aggregator sells a certain amount of capacity to the grid operator and bids this in the hourly auction for frequency regulation and for the available power capacity ($/MWh) [44,57]. When participating in the frequency regulation market, EVs receive the REG-D dispatch signal from PJM and are remunerated accordingly. If the regulation service offered by the Delaware EV aggregator has not met with the performance thresholds over a specified time period in terms of correlation (delay) and precision, PJM is allowed to penalize and disqualify the aggregator [58, 84].

4.2. *DER trading for system balancing and network congestion management*

Markets for balancing services are arranged longer before real-time than ancillary services and do allow aggregated flexibility resources to participate in places in the United States and Europe. In the US, for example, through the Boston based aggregator EnerNOC, demand response suppliers can trade their flexibility in balancing markets [58]. In Germany, many industrial loads are directly participating in the balancing mechanism; however, for aggregated loads still many barriers exist to participate within the balancing markets [59]. In the French system such barriers have been lowered by the reduction of the minimum bidding capacities for balancing services from 50 to 10 MW in order to motivate the entrance of smaller entities like aggregators to participate in balancing mechanisms [53].

Differently, for network congestion management a French example of small load aggregation is the aggregator named Voltalis.[3] Customers contracted with Voltalis receive a free box installed in their home named Bluepod, which reduces their electric heating device operation in short time intervals when Voltalis receives a signal from the TSO. The dispatch signal is mostly related to endangered electricity supply sufficiency in Brittany (a poorly interconnected French region) and network limitations. Customers who have the box installed are automatically enrolled, but can opt-out at any time by pushing a button on the device and use their electric heater as usually. Voltalis as an aggregator is able to trade the aggregated flexibility in different markets like balancing markets and demand response mechanisms of the TSO. The customers observe a reduction of their normal electricity bill due to those interruptions in electricity consumption for heating, however do not receive extra payment for their provided flexibility.

In Sweden the DSO can incentivize load shifts by the provision of Time of Use (TOU) prices in order to defer network investments or decrease congestion by incentivizing the customer to shift the load away from peak moments [60,61]. Different from the previous examples, the DSO does not trade this flexibility within a market for congestion management or deferred network investments, but this is a direct incentive arrangement between the DSO and electricity users.

4.3. *DER trading in spot markets and generation capacity markets*

In the United States, demand resources can also participate in

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[3] Information on Voltalis via: www.voltalis.fr

Table 2
Markets for electric flexibility trading related to DER possibilities.

Time frame	Technical system flex need	Trading mechanism	Capacity or Energy trade?	Notification[a] before real time	Suited DER type	Location[b] DER connection	Examples of DER trading/incentive in traditional centralized markets
Long Term ← ← ← Medium Term ← ← ← Short Term	Ancillary Services	Primary Reserves (FCR)	Capacity	$<$ 30 s (automatic)	EV's, residential loads, continuous loads, EES	Transmission and Distribution	UK: Demand Response with dynamically- controlled refrigerators [54]
		Secondary Reserves (FRR)	Capacity	$<$ 15 minutes (automatic)	EV's, residential continuous loads, electrical heating, EES	Transmission and Distribution	USA: EVs and stationary batteries for frequency regulation in PJM [44,56]
	System balancing	Balancing mechanism (Tertiary reserves, RR)	Energy and/ or Capacity	13 min – 2 h	EV's, EES, CHP units	Transmission and Distribution	Germany: industrial loads participate in balancing mechanism [59] USA: aggregators can trade flexibility in balancing markets [43]
	Network constraints/ Network capacity planning	Transmission congestion management	Energy	13 min – 2 h with balancing mechanism or separate	large EV coalitions, EES, CHP units	Transmission and Distribution	France: congestion management is traded in balancing market [66] And the Voltalis load management of residential heating devices [36]
		Distribution congestion management	Energy or Capacity	No dedicated market found	EV's, residential loads, electrical heating, EES	Distribution	Sweden: distribution Time-of-Use pricing for residential users. [60]
	Spot market energy trading	Intraday market	Energy	1 – 24 h	Aggregated loads	Transmission and Distribution	Elbas intra-day market (Nordic region) opened to DR [67]
		Day ahead market	Energy	24 – 48 h	Aggregated loads	Transmission and Distribution	France: The NEBEF mechanism allows trading of DR in spot market [68] USA: Some wholesale markets allow DR trading, such as in PJM [69]
	Generation Capacity planning	Capacity Market	Capacity	Year ahead	Aggregated loads	Transmission and Distribution	USA: DR is participating in capacity markets in PJM, ISO-NE, NY-ISO [63,70] France: DR trading in capacity markets is foreseen in 2017. [65]
		Capacity Payments	Capacity	Year ahead	Aggregated loads	Transmission and Distribution	No evidence found.

[a] Note that these time values relate to the French system and can be different elsewhere.

[b] This paper focused mainly on flexibility provision from DER connected at distribution level. However if no example of DER flexibility provision at the distribution level was found for specific markets, the table presents examples of large industrial units for this purpose.

wholesale and capacity markets. A Curtailment Service Provider (CSP) is the entity responsible for DR activity for electricity consumers in the PJM wholesale markets [62]. Demand response was growing relatively quickly due to supportive Order 745 which settled prices for demand response equal to that for generation in wholesale electricity markets [49]. DR is a major supplier of capacity in most U. S. capacity markets like PJM, ISO-NE, NY-ISO [52,63,64].

As the first one in Europe, the French system provides a possibility for demand response trading within spot markets. This is possible since 2014 wherein demand response can be traded in the day-ahead market through the NEBEF mechanism.[4] In 2017 it is foreseen that DR will also be tradable in capacity markets in France [65]. Furthermore, the French TSO organizes an annual tender dedicated specifically to DR providers.

5. Incentives for efficient operation of Distributed Energy Resources

Price signals can play an important role in incentivizing efficient interactions from network users [1]. The literature of tariff design shows the complexity of incentivizing efficient interactions however, due to the many different principles that should be taken into account. Those principles include efficiency, equity, simplicity, consistency, transparency, stability and additivity [71–73]. Possibilities with smart metering and real-time pricing allow for the increase of cost causality with tariff design, meaning that the electricity prices reflect the actual costs that are being occurred when delivering the service. A number of approaches have dealt with this topic during the last years, considering the impact of an increasing deployment of DER [1,19,24,74–76]. However, dynamic prices could result in trade-offs for the stability and transparency principles of the tariffs for residential users. Therefore, for frequently changing prices, it could be preferred to use direct control or automation in order to increase reliability of the demand responsiveness. Furthermore, due to the fact that each DER has its own technical requirements and abilities to provide flexibility services, a non-singular approach is suggested; rather, a combination of for example tariffs, contracts and direct control should be considered.

Broadly speaking, a distinction is made between **price based** and **controllable** methods for demand response, also referred to as price based and interruptible demand response [77] or as direct and indirect methods of load modification. Next to tariffs therefore, direct control and other contract arrangements are methods by which efficient operation of DER could be incentivized.

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[4] See https://clients.rte-france.com/lang/fr/clients_distributeurs/services_clients/effacements.jsp

5.1. Price based methods for DER management

Price-based demand response is incentivized by exposing the DER owner to a time-varying electricity rate, also called a dynamic rate. The theory of dynamic tariffs for demand response has already been discussed in 1989 by David and Lee for large industrial electricity users [78]. Table 3 presents an overview of those tariff options with definitions. In this table, a distinction is made between basic dynamic pricing options and those that specifically incentivize adjustments of users' normal consumption patterns (also called baseline consumption adjustments). The basic pricing options leave more freedom to the user, without requiring extra information on baseline consumption levels. Options for such pricing methods are 1) Time-of-Use pricing (TOU), 2) Real-Time Pricing (RTP) and 3) Critical Peak Pricing (CPP). An extreme and one-sided economic approach on settlement of incentives for DER management would be the application of real-time nodal pricing that would incorporate both grid and supply constraints at each moment in time, incentivizing upward or downward adjustments for all DER [79].

Furthermore, the more specific incentives for baseline adjustments are 4) Peak Time Rebates (PTR), 5) Interruptible capacity programs (ICAP) and 6) Emergency demand response [80]. Those options require baseline consumption information penalizing or remunerating for specific load adjustments. With RTP, the user receives a changing price per time step (for example 15 minutes) and the customer will shift electricity consumption accordingly. With critical peak pricing, only in specific hours per day a higher price is presented to the customer. Electricity customers receive an ex-ante notification of these moments in time and can therefore plan their consumption [81]. Critical peak pricing together with the options for baseline adjustments are specifically incentivizing the shift of electricity consumption away from a specific moment in time. A driver for such incentives could relate to, for example, high wholesale market prices or jeopardized system reliability [81].

5.2. Direct load control for DER management

Different from the price based approaches in Section 5.1 where the customer is free to decide in real-time regarding the supply of flexibility, direct control methods are more contractual and introduce obligations for the flexibility supply [47]. With controllable or incentive-based DR, the system operator, aggregator or even retailer could make the end user agree to automatically control (upward or downward) the operation of the DER appliance. This control could be price driven, like in wholesale or balancing market trading of flexibility. Differently, this could be directly to avoid reliability problems like network congestions [30]. In the PJM market, direct control is managed by the curtailment service provider [50]. This means that a central actor has direct access to the load and is able to reduce or increase this as required for the system and/or for portfolio management purposes. Load shedding refers to the “switching off” of entire network zones from electricity supply in order to sustain total system operation [80]. With brown outs, the system operator slightly reduces frequency in order to reduce the needed electricity transport capacity and generation capacity but to maintain electricity supply quality within limitations [85]. Consequently, direct control methods are probably more suited for short-term provision of flexibility services and services which require a very precise location of activation like voltage control and congestion management. Table 4 provides an overview of different incentives presented in Section 5 and relates them to their suitability to DER types and markets for flexibility.

5.3. Techno-economic alignment of incentives

Depending on the type of DER, certain incentive or control might be appropriate to support interactions that take into account the technical attributes of the DER flexibility. Taking into account the technical activation time of DER and possible incentives, Table 4 provides an overview of appropriate incentives or control methods within existing trading platforms for trading DER flexibility. For grid interactions which require response between 1 to 30 min before real-time, direct load control would be suited in order to secure response of this DER. Appropriate DER for such short notification time periods would be most DER except for CHP units due to their longer ramp-up times, although *capacity-type* DERs would be more efficient than *energy-type* DERs. Furthermore, PV units would not be dispatchable due to their generation dependence on weather conditions; however, in combination with storage flexibility trading could be enabled. For longer notification times of 30 min to 1 h, all other pricing methods could be suited and decisions should be further dependent on socio-economic factors like user characteristics of price elasticity and the availability of home automation. All DER types would be appropriate for supplying flexibility for longer than 1 h of activation time, except for short-term duration batteries or other short-term energy storage. For the very long term, critical peak pricing and time of use pricing are appropriate due to the possibility to settle those prices on a yearly basis, as this is the case in France with the tempo tariff.[5] Similarly, contractual arrangements are also appropriate for long-term capacity products, as done under PJM regulation [69].

6. Discussion

This paper has provided an overview of DER and their technical abilities to provide flexibility services for system needs. The effective use of flexibility from DER requires taking their technical characteristics into account and those of the existing trading platforms. However, the practical usefulness of incentive design is strongly dependent on socio-economic factors. Examples of such aspects are normal consumption/production patterns, perspectives on sustainability, investment costs for enabling technologies like smart metering and in-home automation, and the price elasticity of the end user or DER from whom flexibility is being demanded [86]. When designing effective incentives for flexibility from for example EVs or privately owned CHP units, socio-economic factors are of crucial importance.

6.1. The transition towards decentralized system operation

Besides the socio-economic context, also the regulatory environment of the electricity system at stake will affect the decisions for appropriate signals for flexibility. Flexibility trading options shown in this paper are all presented in the framework of centralized system management, generally under responsibility of the system operator. However, decentralized management approach could open up possibilities for locational pricing, local balancing and optimization at the distribution level [2,8,87]. Consequently, DER penetration could call for alternative trading models that focus on efficient flexibility trading for electricity flows at the lower distribution levels. Attempts have already been made with for example a local aggregator [26]. Besides the fact that decentralized management would yield benefits from more cost-causality based incentives, it could also encourage a new

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[5] See http://residential.edf.com/energy-at-home/offers/electricity/tarif-bleu-56121.html

Table 3
Possible dynamic pricing options for DER management [78,82,83].

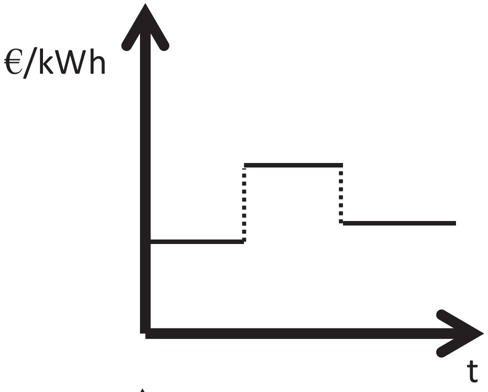
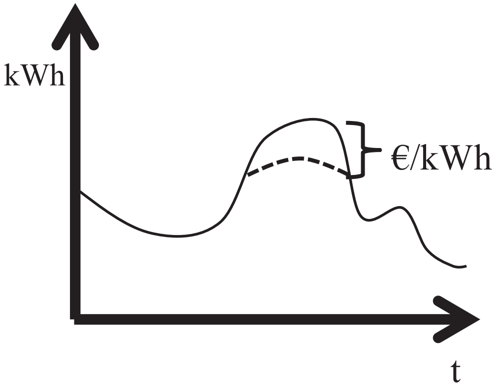
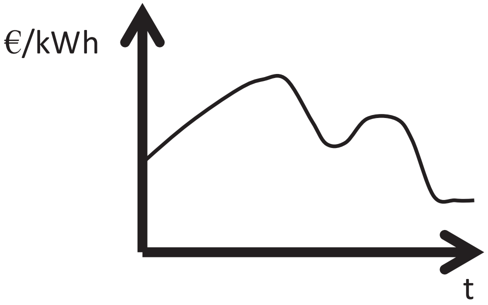
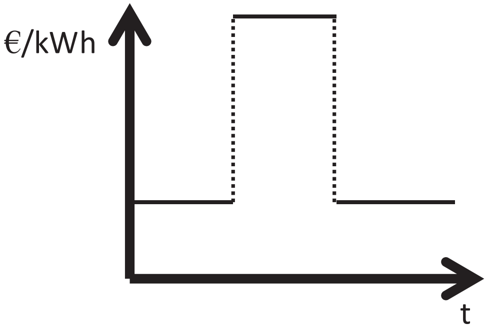
Basic Dynamic Pricing Options			**Specific incentives for baseline adjustment**		
Time-Of-Use (TOU)	Fixed electricity prices for different time blocks within a time period		**Peak time rebates (PTR)**	A rebate when electricity is reduced compared to baseline consumption, within certain hours in a year.	
Real-Time-Pricing (RTP)	An hourly rate depending on the day ahead real-time price of electricity		**Interruptible Capacity Program (ICAP), Interruptible load**	A rebate when electricity is reduced below a baseline value.	
Critical Peak Pricing (CPP)	High electricity price periods for certain (fixed) days of time within a year		**Emergency Demand Response**	Mandatory commitment to reduce load, with penalties if not supplied.	

Table 4.
Relationship between notification times, appropriate incentives and markets for DER flexibility trading.

Notification time before real-time	Appropriate incentives or control method for DER management	Related markets for electric flexibility trading[a]	Appropriate DER
< One minute	Direct control	Frequency control (primary, secondary, tertiary reserves), voltage control	*EV, Continuous loads (heating/cooling, lightning), EES*
1–15 minutes	Direct control	Network restoration, voltage control	*EV, Continuous loads (heating/cooling), EES*
15–30 min	Direct control	Network restoration (HV/LV), Balancing market, Portfolio balancing	*EV, EES, CHP units Continuous loads (heating/cooling), dispatchable loads*
1 hour	Direct control, ICAP, Emergency demand response, Real time pricing, Peak time rebates, Critical Peak Pricing	Balancing market, Network Congestion Management	*EV, EES, CHP units Continuous loads (heating/cooling), dispatchable loads*
1 – 48 hour	Direct control, ICAP, Emergency demand response, Real time pricing, Peak time rebates, Critical Peak Pricing	Spot Market (Day ahead and Intraday market)	*EV, EES, CHP units Continuous loads (heating/cooling), dispatchable loads, PV units with storage*
Year ahead	Critical peak pricing, Time of use pricing	Deferring network investments (HV/LV), generation investment peak reduction	*EV, EES, CHP units Continuous loads (heating/cooling), dispatchable loads, PV units with storage*

[a] Composed with insight from report [92].

approach on consumption, moving from "*passive energy consumer*" towards an "*active energy citizen*" [86]. Therefore, the use of centralized markets for DER management might be seen as a transition phase towards possibly a decentralized techno-economic management approach of the electricity system [88,89]. Fig. 2 presents a conceptual presentation of the arrangement of such a decentralized system based on possible system challenges and opportunities with DER integration.

6.2. Settlement of incentives and control: which roles for different actors?

Depending on the electricity market design and the level of sector liberalization, one or more of the actors in the sector could decide on (dynamic) tariffs, direct control and other flexibility enabling methods. Insights in the role(s) of the DSO, electricity retailer, supplier, (independent) aggregator and third parties are crucial to effective incentive design. Some challenges that arise have never been dealt with before, as for example the ones related to load aggregation. Due to the fact that there are minimum bidding values for the balancing and other markets, DER should be bundled to simultaneously provide significant tradable amounts of flexibility in those other markets. However, when aggregation is being conducted by independent aggregators, this could compete with balance responsibility programs of electricity suppliers from whom the initial electricity was procured [90]. Furthermore, it should be taken into account that multiple actors could want to procure flexibility at the same time for a different direction. This for example is the case when the network is congested, however the electricity prices are low. Thus, cooperation between TSOs and DSOs, and DSOs with retailers or other market parties should be improved, so that simultaneous procurements of flexibility services would not happen to be counterproductive. Therefore, enabling flexibility from distributed energy resources requires an holistic perspective of roles and responsibility. An approach for this has been presented with the Universal Smart Energy Framework (USEF) [90].[6]

7. Conclusions

This paper presented a review of existing Distributed Energy Resources' (DER) abilities to provide flexibility services and reviewed options to incentivize this service provision. With a central management approach on electricity systems, flexibility services from DER could be traded within traditional markets for securing reliability of supply. Due to the fact that each flexibility source has its own technical abilities to provide flexibility services, the authors of this paper argue that utilization of DER flexibility services require a non-singular approach. Depending on the type of DER, therefore also a difference should be made between the appropriate signals, which could be a combination of tariffs, contracts and direct control. Next to the central utilization of DER flexibility services in traditional markets (like for ancillary services, balancing, and spot markets), also decentralized management of DER could be possible through for example local markets or local aggregation and optimization (see Fig. 2). The interest for this type of management is arising, especially due to upcoming risks for overvoltage and congestions with the penetration of distributed generation (DG) [9,10]. Such alternative management methods can be supported with the roll-out of smart meters, distributed automation and control [27].

In this paper we focused on the provision of electric flexibility through already existing electricity markets. Even though aggregated flexibility trading is possible, in many places this is still happening due to the fact that flexibility markets were historically designed for large power producers or large industrial consumers leaving still many regulatory barriers. In order to allow aggregation of DER, policy should assist to lower those barriers and arrange compensation mechanisms between aggregators and electricity suppliers [90]. Further developments could allow for flexibility trading not only at central markets, but also at local levels in which locational needs for flexibility could reduce network capacity problems [91]. Questions that remain are weather there should be one central aggregator or multiple aggregators for providing such services [26]. A very ambitious techno-economic approach on settlement of signals for DER management could be based on a nodal pricing mechanisms that would incorporate both grid and supply constraints at local levels [79]. However differently from transmission levels, this approach currently does not seem viable due to the passive management of distribution grids [19].

Therefore, future work should be done to include socio-economic factors within developments of new models for flexibility management at local network levels. Socio-economic factors include consumption or production patterns, the consumer perspectives on sustainability, investment costs for enabling technologies like smart metering and in-home automation and the price elasticity of the end user or DER from whom flexibility is being demanded. Furthermore, from a technical perspective of

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[6] For the complete documentation of this framework, see www.usef.org

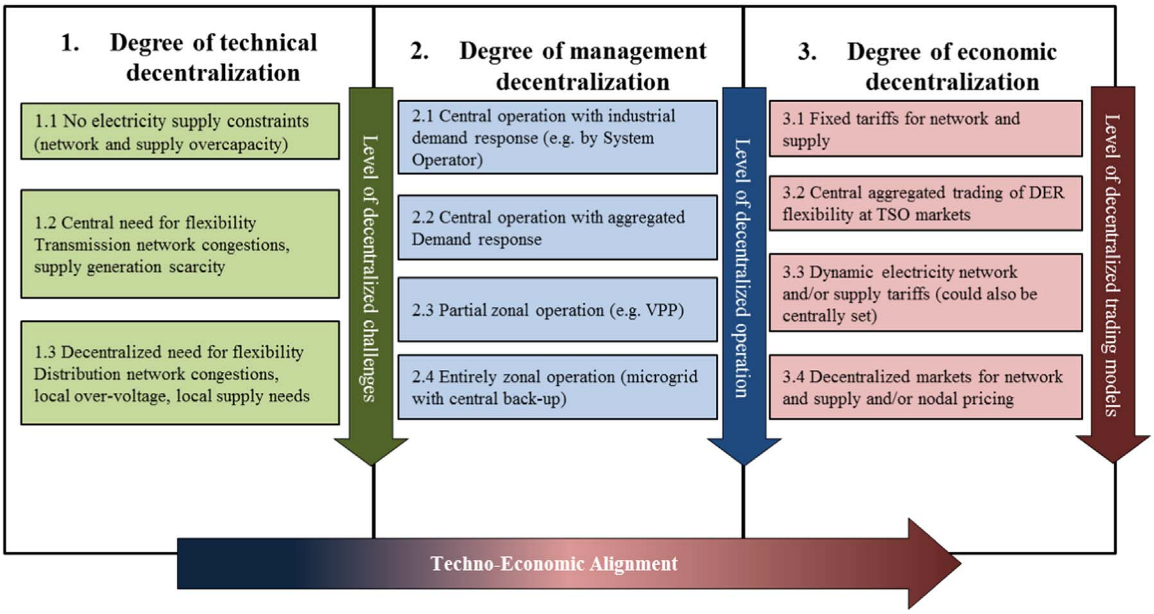

Fig. 2. Techno-economic alignment of decentralization in electricity markets.

flexibility management, research should provide insight in cost-efficient DER combinations to supply flexibility for specific technical system needs. Not unimportant are furthermore the roles of traditional and new actors in the development of flexibility management; especially when current regulation discourages the use of flexibility from local network users. Depending on the current and expected challenges in electricity systems, policy should anticipate the required DER transactions and incentivize arrangements and market models that will benefit the system from an economic, sustainability and reliability perspective.

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References

[1] I Pérez-Arriaga, A. Bharatkumar A Framework for Redesigning Distribution Network Use of System Charges Under High Penetration of Distributed Energy Resources New principles for New problems. 2014.
[2] Pudjianto D, Ramsay C, Strbac G. Virtual power plant and system integration of distributed energy resources. Renew Power Gen 2007;1:10–6. http://dx.doi.org/10.1049/iet-rpg.
[3] von Appen J, Braun M, Stetz T, Diwold K, Geibel D. Time in the Sun. IEEE Power Energy Mag 2013:55–64. http://dx.doi.org/10.1109/MPE.2012.2234407.
[4] Greentech Media, Solar Energy Industries Association. U.S. Solar Market Insight. 2013.
[5] International Energy Agency. CHP/DHC Country Scorecard: Denmark Energy Overview 2005:1–12.
[6] ABB. Electric vehicle market share in 19 countries 2014. 〈http://www.abb-conversations.com/2014/03/electric-vehicle-market-share-in-19-countries/〉.
[7] Lund H, Münster E. Integrated energy systems and local energy markets. Energy Policy 2006;34:1152–60. http://dx.doi.org/10.1016/j.enpol.2004.10.004.
[8] Alanne K, Saari A. Distributed energy generation and sustainable development. Renew Sustain Energy Rev 2006;10:539–58.
[9] Eftekharnejad S, Vittal V, Heydt GT, Keel B, Loehr J. Impact of increased penetration of photovoltaic generation on power systems. IEEE Trans Power Syst 2012. http://dx.doi.org/10.1109/TPWRS.2012.2216294.
[10] Walling RARA, Saint R, Dugan RCRC, Burke J, Kojovic LALA. Summary of distributed resources impact on power delivery systems. IEEE Trans Power Deliv 2008;23:1636–44. http://dx.doi.org/10.1109/TPWRD.2007.909115.
[11] EPIA. Global Market Outlook for Photovoltaics 2014 – 2018. Brussels: 2014.
[12] EPRI. The Intergrated Grid: Realizing the Full value of Central and Distributed Energy Resources. California: 2014.
[13] W Yan, M Braun, J Von Appen. Operation strategies in dISTRIBUTION SYSTEMS WITH hIGH LEVEL pv Penetration. 2011.
[14] RTE. Bilan previsionnel de l'equilibre offre-demande d'electricite en France). 2014.
[15] Dang X, Petit M, Codani P. Transformer Operating conditions under introduction of PV and EVs in an Eco-district. IEEE PES Gen. Meet., Denver: 2015.
[16] Ottesen SO. How demand side can provide operational flexibility to power system through a holistic aggregator concept. Int J Technical Phys Probl Eng 2012;4:144–8.
[17] Tan KM, Ramachandaramurthy VK, Yong JY. Integration of electric vehicles in smart grid: a review on vehicle to grid technologies and optimization techniques. Renew Sustain Energy Rev 2016;53:720–32. http://dx.doi.org/10.1016/j.rser.2015.09.012.
[18] Hota AR, Juvvanapudi M, Bajpai P. Issues and solution approaches in PHEV integration to smart grid. Renew Sustain Energy Rev 2014;30:217–29. http://dx.doi.org/10.1016/j.rser.2013.10.008.
[19] Ruester S, Schwenen S, Batlle C, Pérez-Arriaga I. From distribution networks to smart distribution systems: rethinking the regulation of European electricity DSOs. Util Policy 2014;31:1–9. http://dx.doi.org/10.1016/j.jup.2014.03.007.
[20] EvolvDSO. Development of methodologies and tools for new and evolving dso roles for efficient dres integration in distribution networks. 2014.
[21] EDSO. Response to CEER public consultation on the future role of the DSO. Brussels: 2015.
[22] Cossent R. Economic Regulation of Distribution System Operators and its Adaptation to the Penetration of Distributed Energy Resources and Smart Grid Technologies. Universidad Pontificia Comillas, 2013.
[23] JD Jenkins, IJ. Pérez-Arriaga The Remuneration Challenge: New Solutions for the Regulation of Electricity Distribution Utilities Under High Penetrations of Distributed Energy Resources and Smart Grid Technologies. 2014.
[24] Picciariello A, Reneses J, Frias P, Söder L. Distributed generation and distribution pricing : why do we need new tariff design methodologies ? Electr Power Syst Res 2015;119:370–6. http://dx.doi.org/10.1016/j.epsr.2014.10.021.
[25] Li BF, Wanderley Marangon-Lima J, Rudnick H, Medeiros Maragon-Lima L, Prasad Padhy N, Brunekreeft G, et al. Distribution pricing: are we ready for the smart grid? IEEE Power Energy Mag 2015:76–86. http://dx.doi.org/10.1109/MPE.2015.2416112.
[26] Niesten E, Alkemade F. How is value created and captured in smart grids? A review of the literature and an analysis of pilot projects Renew Sustain Energy Rev 2016;53:629–38. http://dx.doi.org/10.1016/j.rser.2015.08.069.
[27] Faruqui A, Harris D, Hledik R. Unlocking the €53 billion savings from smart meters in the EU: how increasing the adoption of dynamic tariffs could make or break the EU's smart grid investment. Energy Policy 2010;38:6222–31.

[28] Lin C-C, Yang C-H, Shyua JZ. A comparison of innovation policy in the smart grid industry across the pacific: China and the USA. Energy Policy 2013:1–14. http://dx.doi.org/10.1016/j.enpol.2012.12.028.

[29] Haidar AMA, Muttaqi K, Sutanto D. Smart Grid and its future perspectives in Australia. Renew Sustain Energy Rev 2015;51:1375–89. http://dx.doi.org/10.1016/j.rser.2015.07.040.

[30] Di Santo KG, Kanashiro E, Di Santo SG, Saidel MA. A review on smart grids and experiences in Brazil. Renew Sustain Energy Rev 2015;52:1072–82. http://dx.doi.org/10.1016/j.rser.2015.07.182.

[31] Aghaei J, Alizadeh M-I. Demand response in smart electricity grids equipped with renewable energy sources: a review. Renew Sustain Energy Rev 2013;18:64–72.

[32] Geelen D, Reinders A, Keyson D. Empowering the end-user in smart grids: Recommendations for the design of products and services. Energy Policy 2013;61:151–61. http://dx.doi.org/10.1016/j.enpol.2013.05.107.

[33] Eyer J, Corey G. Energy Storage for the Electricity Grid : Benefits and Market Potential Assessment Guide. vol. 321. Californ: 2010. doi:SAND2010-0815.

[34] Clement-Nyns K, Haesen E, Driesen J. The impact of vehicle-to-grid on the distribution grid. Electr Power Syst Res 2011;81:185–92. http://dx.doi.org/10.1016/j.epsr.2010.08.007.

[35] Green eMotion. D4.3 - B2: Grid Impact studies of eLECTRIC VEHICLES ; Reinforcement CoSTs IN Low-VOLTAGE GrIDS 2013.

[36] Eid C, Codani P, Chen Y, Perez Y, Hakvoort R. Aggregation of Demand Side flexibility in a Smart Grid : A review for European Market Design. In: Proceedings of the 12th Int. Conf. Eur. Energy Mark., Lisboa: 2015, p. 1–5.

[37] Houwing M, Negenborn RR, De Schutter B. Demand response with micro-CHP systems. Proc IEEE 2010;99:200–13. http://dx.doi.org/10.1109/JPROC.2010.2053831.

[38] Lee CK, Li S, Hui SY. A design methodology for smart LED lighting systems powered by weakly regulated renewable power grids. IEEE Trans Smart Grid 2011;2:548–54. http://dx.doi.org/10.1109/TSG.2011.2159631.

[39] Lu N, Xie Y, Huang Z, Puyleart F, Yang S. Load component database of household appliances and small office equipment. IEEE Power Energy Soc. 2008:1–5. http://dx.doi.org/10.1109/PES.2008.4596224.

[40] Samarakoon K, Ekanayake J, Jenkins N. Investigation of domestic load control to provide primary frequency response using smart meters. IEEE Trans Smart Grid 2012;3:282–92. http://dx.doi.org/10.1109/TSG.2011.2173219.

[41] Tomiyama K, Daniel JP, Ihara S. Modeling air conditioner load for power system studies. IEEE Trans Power Syst 1998;13:414–21. http://dx.doi.org/10.1109/59.667361.

[42] Yang Z, Zhang J, Kintner-Meyer MCW, Lu X, Choi D, Lemmon JP, et al. Electrochemical energy storage for green grid. Chem Rev 2011;111:3577–613. http://dx.doi.org/10.1021/cr100290v.

[43] Divya KC, Østergaard J. Battery energy storage technology for power systems-An overview. Electr Power Syst Res 2009;79:511–20. http://dx.doi.org/10.1016/j.epsr.2008.09.017.

[44] W Kempton, V Udo, K Huber, K Komara, S Letendre, S Baker, et al. A Test of Vehicle-to-Grid (V2G) for Energy Storage and Frequency Regulation in the PJM System. 2009.

[45] Pearre NS, Kempton W, Guensler RL, Elango VV. Electric vehicles: How much range is required for a day's driving? Transp Res Part C Emerg Technol 2011;19:1171–84. http://dx.doi.org/10.1016/j.trc.2010.12.010.

[46] International Energy Agency. Photovoltaic and Solar Forecasting: State of the Art 2013.

[47] DOE. Benefits of Demand Response in Electricity Markets and Recommendations for Achieving them. Washington DC: 2006.

[48] Roscoe AJ, Ault G. Supporting high penetrations of renewable generation via implementation of real-time electricity pricing and demand response. IET Renew Power Gen 2010;4:369. http://dx.doi.org/10.1049/iet-rpg.2009.0212.

[49] Hamidi V, Li F, Robinson F. Demand response in the UK's domestic sector. Electr Power Syst Res 2009;79:1722–6. http://dx.doi.org/10.1016/j.epsr.2009.07.013.

[50] Wong S, Pelland S. Demand response potential of water heaters to mitigate minimum generation conditions. In: Proceedings of the 2013 IEEE Power Energy Soc. Gen. Meet., 2013, p. 1–5. doi:10.1109/PESMG.2013.6672552.

[51] Arteconi A, Hewitt NJ, Polonara F. Domestic demand-side management (DSM): role of heat pumps and thermal energy storage (TES) systems. Appl Therm Eng 2013;51:155–65. http://dx.doi.org/10.1016/j.applthermaleng.2012.09.023.

[52] PJM). The Evolution of Demand Response in the PJM Wholesale Market. 2014.

[53] SEDC. Mapping Demand Response in Europe Today 2014.

[54] dynamicDemand. A dynamically-controlled refrigerator 2005):1–4. ⟨http://www.dynamicdemand.co.uk/pdf_fridge_test.pdf⟩ [accessed 01.02.15].

[55] PJM. Description of Regulation Signals 2013.

[56] PJM. M-11: Energy & Ancillary Services Market Operations 2015.

[57] Kempton W. Public Policy toward GIVs for TSO Services: State of the Art and Future Trends, 2014, p. 18–19.

[58] P. Chris PJM Manual 12: Balancing Operations. 2013.

[59] Koliou E, Eid C, Chaves-Ávila JP, Hakvoort Ra. Demand response in liberalized electricity markets: analysis of aggregated load participation in the German balancing mechanism. Energy 2014;71:245–54.

[60] Bartusch C, Wallin F, Odlare M, Vassileva I, Wester L. Introducing a demand-based electricity distribution tariff in the residential sector: demand response and customer perception. Energy Policy 2011;39:5008–25. http://dx.doi.org/10.1016/j.enpol.2011.06.013.

[61] Bartusch C, Alvehag K. Further exploring the potential of residential demand response programs in electricity distribution. Appl Energy 2014;125:39–59. http://dx.doi.org/10.1016/j.apenergy.2014.03.054.

[62] PJM. Retail Electricity Consumer Opportunities for Demand Response in PJM's Wholesale Markets. 2013.

[63] PJM. PJM Manual 18: PJM Capacity Market. 2015.

[64] FERC. Order Accepting Tariff Revisions. United States: 2015. doi:10.4324/9781410610348.

[65] RTE. Mecanisme de capacite 2013.

[66] CRE. Services systeme et mécanisme d'ajustement 2015. ⟨http://www.cre.fr/reseaux/reseaux-publics-d-electricite/services-systeme-et-mecanisme-d-ajustement⟩ [accessed 23.04.15].

[67] Andersen FM, Jensen SG, Larsen H V, Meibom P, Ravn H, Skytte K, et al. Analyses of Demand Response in Denmark. vol. 1565. 2006.

[68] RTE. The Block Exchange Notification of Demand Response mechanism (NE-BEF) 2013. ⟨https://clients.rte-france.com/lang/an/clients_producteurs/services_clients/dispositif_nebef.jsp⟩ [accessed 20.01.15].

[69] J. Mcanany 2014 Demand Response Operations Markets Activity Report : December 2014. 2014.

[70] FERC. Order Accepting Tariff Revisions. United States: 2015. doi:10.4324/9781410610348.

[71] Leveque F. Transport pricing of electricity networks.Boston: Kluwer Academic Publishers; 2003.

[72] R Green, MR. Pardina Resetting Price (Control) (for Private Utilities: A Manual for Regulators). 1999.

[73] Reneses J, Rodríguez Ortega MP. Distribution pricing: theoretical principles and practical approaches. IET Gen Transm Distrib 2014;8:1–11. http://dx.doi.org/10.1049/iet-gtd.2013.0817.

[74] Li F, Tolley DL. Long-run incremental cost pricing based on unused capacity. IEEE Trans Power Syst 2007;22:1683–9.

[75] Mutale J, Strbac G, Pudjianto D. Methodology for cost reflective pricing of distribution networks with distributed generation. In: Proceedings of the 2007 IEEE Power Eng Soc Gen Meet PES 2007:1–5. doi:10.1109/PES.2007.386080.

[76] Sotkiewicz PM, Vignolo JM. Towards a cost causation-based tariff for distribution networks with DG. IEEE Trans Power Syst 2007;22:1051–60.

[77] Muratori M, Schuelke-Leech B-A, Rizzoni G. Role of residential demand response in modern electricity markets. Renew Sustain Energy Rev 2014;33:546–53. http://dx.doi.org/10.1016/j.rser.2014.02.027.

[78] David A, Lee Y. Dynamic tariffs: theory of utility-consumer interaction. Power Syst IEEE Trans 1989:4.

[79] Sotkiewicz PM, Vignolo JM. Nodal pricing for distribution networks : efficient pricing for efficiency enhancing DG. IEEE Trans Power Syst 2006;21:1013–4.

[80] Newsham GR, Bowker BG. The effect of utility time-varying pricing and load control strategies on residential summer peak electricity use: a review. Energy Policy 2010;38:3289–96.

[81] Koliou E, Eid C, Hakvoort RA. Development of Demand Side Response in Liberalized Electricity Markets : Policies for Effective Market Design in Europe. In: Proceedings of the 10th Int. Conf. Eur. Energy Mark., Stockholm: IEEE; 2013.

[82] Faruqui A, Sergici S. Household response to dynamic pricing: a survey of the experimental evidence. Brattle Gr 2009:1–53. http://dx.doi.org/10.1016/j.energy.2009.07.042.

[83] Hakvoort R, Koliou E. Energy Management and Demand Side Response. Energy Sci. Technol.. Studium Press LLC; 2014.

[84] PJM. Description of Regulation Signals 2013.

[85] Blume SW. Electric power system basics: for the nonelectrical professional. Hoboken, New Jersey: John Wiley & Sons; 2007.

[86] Goulden M, Bedwell B, Rennick-egglestone S, Rodden T, Spence A. Smart grids, smart users ? The role of the user in demand side management Energy Res Soc Sci 2014;2:21–9. http://dx.doi.org/10.1016/j.erss.2014.04.008.

[87] Kamat R, Oren SS, Hall E, Oren K. Multi-settlement Systems for Electricity Markets : Zonal Aggregation under Network Uncertainty and Market Power 1 2002;00:1–10.

[88] Orehounig K, Evins R, Dorer V. Integration of decentralized energy systems in neighbourhoods using the energy hub approach. Appl Energy 2015;154:277–89. http://dx.doi.org/10.1016/j.apenergy.2015.04.114.

[89] Schmid E, Knopf B, Pechan A. Putting an energy system transformation into practice: The case of the German Energiewende. Energy Res Soc Sci 2016;11:263–75. http://dx.doi.org/10.1016/j.erss.2015.11.002.

[90] Eurelectric. Designing fair and equitable market rules for demand response aggregation. Brussels: 2015.

[91] Burger S, Chaves-Ávila JP, Batlle C, Pérez-Arriaga JI. The Value of Aggregators in Electricity Systems 2001. http://dx.doi.org/10.1002/pssb.201300062.

[92] International Energy. Integration of Demand Side Management, Distributed Generation, Renewable Energy Sources and Energy Storages Participants - Final Synthesis Report Vol. 1. vol. 1. Finland: 2008.