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Abstract:

This document reports the work performed in the context of WP10 WiseGRID Consumer-Centric Demand Response Framework and Infrastructure and focuses on the analysis of DR technologies and their potential for the distribution grid. In this respect, it first aims to provide information and a description of existing DR technologies. Additionally, it gives an overview of European as well as International projects dealing with DR. Then, the document analyzes other energy carriers, such as power-to-heat and power-to-gas. Last but not least, there is an extensive description of DR operations and applications provided to the grid.

Keywords:

Demand Response, Balance, Ancillary Services, Renewable Energy Sources, Frequency regulation.

Revision History

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V1.0	31.10.2017	Version including partners comments and final changes	Georgia Asimakopoulou (ICCS), Aris Dimeas (ICCS), George Messinis (ICCS)

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EXECUTIVE SUMMARY

Power systems are facing major changes related to both technological and market advances. Changes in the structure of power systems (moving from unidirectional to bidirectional networks) and the increased DER penetration create new problems and opportunities. One of the most important needs (apart from security, firmness, adequacy and strategic energy policies) is power system flexibility, either seen as the ability of the system to provide sufficient levels of reserves, the ability of generation units to follow consumption or ramping reserves. RES penetration is one of the most important drivers for power system flexibility due to their high volatility, uncertaintly and stochasticity. The effects of increased RES penetration in transmission have been reported by various organizations (for example ENTSO-E) highlighting the important role of flexibility for accommodating such a paradigm shift. Increased RES penetration has an immediate impact on the power system energy balance which is first reflected on system frequency. Given the unpredictability of demand and high stochasticity of RES, frequency deviations are expected if schemes for controlling demand are not applied. Load frequency control has been well documented in literature but the role of Demand Response (DR) has not yet been explicitly defined. The current regulatory framework includes the Network Code on Load-Frequency Control and Reserves, however, following the European Guidelines for the Capacity Allocation & Congestion Management (CACM 2015/1222) and Forward Capacity Allocation (FCA 2016/1719), the new Electricity Balancing Guideline is expected to enter into force in December 2017. This new Guideline defines the roles of the actors in DR, such as Balance Responsible Parties (BRPs), Balance Service Providers (BSPs), DR aggregators, etc., thus trying to define the whole ecosystem of DR both in a technical and market perspective. In addition, the EU Winter Package sets a priority to Energy Efficiency and the active management of demand in order to optimize energy consumption, reduce costs for consumers and import dependency, while reducing the use of fossil fuels. The emerging role of DR is thus obvious and consumers will have to embrace it either by directly participating or through aggregators. Finally, the foreseen participation of DR in the Market will require Distribution System Operator (DSO) - TSO cooperation and the installation of suitable equipment, such as smart meters, control and communication infrastructure. This document will first provide an overview of existing DR technologies, their relative costs and involved actors. Communication technologies and several European and international projects/initiatives related to DR will be presented. Next, the importance of other energy carriers such as power to heat (P2H) and power to gas (P2G) will be documented. Finally, the most important DR services provided to the grid will be analysed, namely voltage control, frequency support, congestion management and RES curtailment avoidance.

Existing DR technologies

DR programs can be classified according to three main criteria: control information, decision variables and motivation, the last one receiving increased attention lately. In this case, DR programs are divided into price-based and incentive based, a more detailed classification of which is presented next.

Incentive-based DR aims to trigger demand profile modification at specific times and, potentially, at specific grid connections/lines with the main goal to support the grid and/or to provide real-time services to parties that must maintain portfolio energy balance. Such programs are usually managed by third-party demand-side aggregators that build up a portfolio of controllable demand assets.

The main purpose of price-based DR is to modulate the demand profile of a retailer customer portfolio according to the wholesale price of electricity. It is a valuable tool for retailers who want to manage their portfolio to minimize or avoid energy imbalances. The careful design of tariffs and rates has the potential to shift peak demand and help the retailer lower its cost structures by reducing hedging costs.

- Explicit DR (incentive-based DR)
    - Classical
        - Direct control
        - Interruptible / Curtailable loads
    - Market-based
        - Demand bidding
        - Emergency DR
        - Capacity market
        - Ancillary Services (AS) market
- Implicit DR (price-based DR)
    - Time of Use (ToU)
    - Critical Peak Pricing (CPP)
    - Extreme Day Critical Peak Pricing
    - Extreme Day Pricing
    - Real-time Pricing (RTP)
    - Peak Time Rebates

Each one of these schemes is described later in the document providing specific application examples as well as any shortcomings and advantages. Apart from describing DR technologies though it is important to also present the benefits that stakeholders receive from such technologies. DR participants, aggregators, energy suppliers/utilities, market participants and the power system itself enjoy different benefits from the various schemes. These benefits are listed in the document for highlighting the value of DR, while relative costs are alos presented per stakeholder. For example, costs for setting up DR infrastructure and running the relative system both for DR program participants and DR program owners are documented. In addition, the major challenges for the successful roll out of any DR program are listed in order for the reader to acquire a complete view of DR real life applications. Such challenges include baselining (i.e. how to measure the impact of DR), democratizing the access to explicit DR, standardization, personal data security and more.

Apart from referring to strictly technical aspects of DR, the document also describes DR market participation by first describing relative markets and their status in Europe and the US. The current state of European energy markets, the design, development and operation of an Internal Energy Market based on the principles of the so-called "Target Model" as well as on the European Guidelines (CACM, FCA, EB), which cover also the cross-border exchanges is in focus.

Next, the main actors involved in DR (and their relative roles), are described, namely TSOs, DSOs, Suppliers, Prosumers and Aggregators while the impact of consumer classification on the success of DR programs is highlighted by describing DR program selection processes and consumer selection in DR events. The first one refers to the appropriate selection of DR programs by the aggregator in order to increase consumer participation in these programs, while the second refers to how to select consumers whose loads are to be curtailed, interrupted or shifted.

The document thus manages to present in a concrete and coherent way the most important aspects of DR ranging from market operation to actors and DR schemes tailored to specific consumer characteristics and network needs. In order to make the analysis more realistic though, existing communicaton technologies used in DR schemes are described and various European and international projects and initiatives relative to DR are presented.

Communcation technologies include different domains from the HAN (Home Area Network) to smart meters/AMI, concentration points and utility data centers. The technologies and protocols analused in this document include well known communication solutions such as ZigBee, Z-Wave, Wi-Fi, HomePlug, THREAD, IEC62056, OSGP and TCP/IP.

Finally, in order to better evaluate the current status of DR for real life applications as well as the current status of DR from an applied research perspective, several European and international projects are referenced. The document highlights the most important characteristics and results of these projects and initiatives from Europe, USA, Japan, China, New Zealand, South Africa, Australia etc.

Analysis of other energy carriers

Apart from the traditional DR resources, alternative energy carriers can play an important role as flexibility providers in the new energy market and smart grid paradigm. The document makes specific mention to two carriers: electrical power to heat (P2H) conversion and electrical power to natural gas (P2G) conversion.

P2H conversion links the electricity and heat networks and thus provides an alternative solution for managing electricity oversupply as it provides flexibility to the energy market participants to balance an existing power mismatch. In principle, P2H technologies convert the surplus of energy produced at times of lower electricity demand to heat, which is either fed directly into the heating network in order to cover the current thermal demands of the customers or stored in a buffer tank for later use. The main operation principles of such systems are described while the focus of the document is on how P2H can contribute to DR. In fact, P2H systems can be very useful in DR applications as they can convert excess electrical power into heat with very fast response (ramp up) and high precision. Especially in the distribution grid, where mainly small consumers are connected, DR programs can provide valuable services taking advantage of the fact that heating and cooling requirements are in high priority for this class of customers. In addition, DR programs can actively collaborate with CHP system operators for optimally managing the surplus of heat energy, which they unavoidably produce and waste by chilling it in power absorption chillers/refrigerators. The principle for exploiting wasted CHP systems's energy for satisfying thermal needs of consumers and thus reducing electrical demand and achieving more benefits like increased reliability, increased station capacity, reduced production costs and increased flexibility is described. In addition, the principles under which P2H is used for utilizing the excess production of RES are described and the importance of thermal storage is highlighted.

The Power-to-Gas (P2G) process can link the power grid with the gas grid by converting excess electricity into gaseous energy carriers. This concept can facilitate various roles in the energy system and become a useful tool as far as sustainability and alternative enrgy are concerned. It can contribute to solving grid congestion, as it enables stable renewable power supply, and the exploitation of renewable energy for long-distance transport. Finally it can also be used as a storage method. The main operation principles of such systems are again described as well as the ways they can contribute as DR resources. Various DR strategies are listed in this case for preventing RES curtailment, load following, providng Ancillary Services (AS) to the system, etc. The main actors and communication technologies/requirements for such systems are described together with a number of European and international projects implementing them. Finally, the document provides a concise presentation of DR regulatory framework referring to P2G systems.

DR operations provided to the grid

The most important DR operations provided to the grid are presented here. Load modification is the most usual objective of DR. Load modification includes applications like peak shaving, valley filling, load shifting, strategic conservation, strategic load growth and dynamic energy management. Each of these applications requires different DR schemes on different time scales and achieve various benefits for the grid. A lot of literature exists on these applications so the document focuses on applications strictly referring to grid operation, namely: voltage control, frequency support, congestion management and RES curtailment avoidance.

High RES penetration in the distribution network frequently results to various voltage disturbances such as overvoltages and undervoltages. These issues may cause a lot of problems to both consumers and electrical network infrastructure. The various voltage disturbances occurring in distribution networks as well as the impact of RES on the phenomenon are described in this report before presenting how DR can mitigate such issues. In fact, DR can be conceived as a voltage controller if operated under various strategies according to the specificities of the voltage problem. For example, undervoltages can be avoided by peak shaving, load shifting, dynamic energy management and strategic conservation while overvoltages can be avoided by valley filling, dynamic energy management and strategic load growth. The modification of local generation can also help to mitigate such problems. Volt/VAr control, coordinated voltage control and control of DERs such as PVs, wind turbines are also standard solutions to the problem, although a lot of barriers still exist for their wide adoption and implementation, including the absence of specialized equipment and telecommunication networks as well as incomplete regulatory framework.

The second service DR may provide to the grid is frequency support. A number of processes for frequency regulation are already in place since maintaining frequency levels is probably one of the most important power systems operations. This report describes these processes and moves forward in defining how DR may contribute to the solution. The types of DR resources capable to provide frequency support services are listed together with methods for estimating their flexibility. Althoug DR for frequency support has received a lot of attention lately, there is a number of barriers to overcome before applying them in real life. The absence of frequency measuring devices on controllable loads is such an example. ICT infrastructure, including reaction times, measurement equipment and accuracy must be upgraded in order for such services to be realized in the future.

Grid congestion refers to cases when the existing transmission and/or distribution lines cannot handle the required load during periods of time with high demand or during emergency load conditions. The main consequences of congestion is the reduction of the amount of low cost electricity that can flow through the network (increasing consumers' bills) and increased transmission and distribution losses. Congestion is mainly caused due to demand peaks, concentrated charging of EVs, and excessive power generation from RES. The document lists a number of solutions to this problem and focuses on DR strategies for congestion management. Such strategies include peak shaving, load shifting, dynamic energy management and strategic conservation. The various DR resources that can provide such services are listed together with the most important technical and regulatorty barriers.

Finaly, DR can be used in order to reduce RES curtailment. RES are intermittent in their production, becoming null during some periods of the day. Therefore, a correct modulation of the demand is important, transferring, as much as possible, the consumption to hours when renewable energy, of any kind, are at maximum production points. This action is carried out by the so-called DR mechanism. The aim is to achieve, through various methods, a change in the user consumption habits; focusing, in this case, on the increase of the consumption of renewable energy at the expense of energy generated by fossil fuule burning generators. The most common mechanisms under which DR can reduce RES curtailment are described together resources able to provide this service and relative barriers.

1 INTRODUCTION

1.1 PURPOSE OF THE DOCUMENT

Demand Response (DR) constitutes one of the key technical areas addressed within WiseGrid. In particular, the smooth integration of innovative and advanced DR mechanisms and its demonstration forms an inextricable part of the WiseGRID fourfold objectives. As such, sub-project SP5 DEMAND RESPONSE MECHANISMS AND TOOLS is dedicated to the specification of the technical aspects of the functionalities pertaining to DR and their implementation. Within SP5, Task 10.1, provides a general overview of the current DR technologies that is necessary for setting a realistic –albeit innovative and challenging– stepping stone for further SP5 activities (within WPs 10 & 11) which focus on the design and development of the WiseGRID Demand Response framework and the WiseHOME application.

1.2 SCOPE OF THE DOCUMENT

This document includes a detailed report of existing Demand Response developments in Europe and worldwide that serves to guide future activities in WP10 of the project. More specifically, existing DR technologies are analyzed in terms of their features, the implicated actors, the communication technologies, as well as their demonstration within European and international projects. Apart from the classical and established DR strategies, an analysis of other energy carriers, such as power to gas or power to heat, follows. Last but not least, the various operations implicating DR in order to offer services to the distribution network are described in detail.

1.3 STRUCTURE OF THE DOCUMENT

The rest of the document is organized as follows. Section 3 describes the current status of DR in Europe. Section 3 elaborates on the existing DR technologies and, more specifically, it focuses on the DR strategies, DR Actors and Communication technologies. In order to have a wide overview of the status of DR worldwide, Subsection 3.5 provides a list of European and International projects on the topic. Section 4 analyzes other energy carriers, such as Power-to-heat and Power-to-gas. Section 5 includes a very useful description of DR operations provided to the grid, such as voltage control, frequency support, congestion management and RES curtailment avoidance. Section 6 outlines the derived conclusions whereas, Section 7 has the References and Acronyms used in this document.

2 DEMAND RESPONSE: CURRENT STATUS

2.1 EVOLUTION OF POWER SYSTEMS: NEW EMERGING NEEDS

The changes in the structure and operation of power systems during the last years and, above all, the massive penetration of Renewable Energy Sources (RES), have modified the power system's needs. In particular, until today the main concern of system operators has been to ensure that there is sufficient capacity to cover the volume of the expected demand and peak load; therefore, it has mainly *been a capacity adequacy* problem. However, the massive installation of RES units has resulted in different, additional kind of power system needs: the needs for *flexible capacity*. The system flexibility needs focuses on:

- The ability of the system to provide sufficient levels of reserves;
- The ability of generation units to follow the demand at each moment, so that the system is balanced and
- The existence of different means and units that can provide fast ramping services (both upwards and downwards: ramp-up and ramp-down).

The reliable and continuous supply of electrical energy to consumers can be separated in the following categories, based on the time-horizon:

- **Security**: it expresses the readiness of the existing and operating network capacity to respond in real-time, when it is necessary to satisfy the actual demand. The time horizon of security is short-term.
- **Firmness**: it expresses the readiness to provide generation and grid services, when the latter are needed. It depends on the management, in short and medium-term, of the already installed resources: generating units and grid maintenance, reserves (stocks) management, contracts for fuel delivery, start-ups scheduling etc.
- **Adequacy**: it expresses the existence of sufficient available capacity (of the already installed units as well as the ones that are planned to be installed), so that peak demand can be met. The horizon here is long-term.
- **Strategic energy policy**: it relates to the long-term availability of energy resources and infrastructure: generation mix, fuel supply, geopolitical factors, environmental restrictions, expected developement, expansion of interconnections etc. The time horizon of strategic energy policy is very long-term.

Flexibility has been added in the above-mentioned list as a new reliability parameter. The most important factor that shapes the system flexibility needs is the *net load/residual load*[1] variation. The massive penetration of RES results in high volatility, uncertaintly and stochasticity of the generated energy. Figure 1 shows the residual load curves from 2012 to 2020 (to demonstrate the effect of RES penetration) on March 31 in California. This graph is also known as the "duck curve". It shows how the Californial Independent System Operator (CAISO) assesses the flexibility needs. Simular curves characterize the European system.

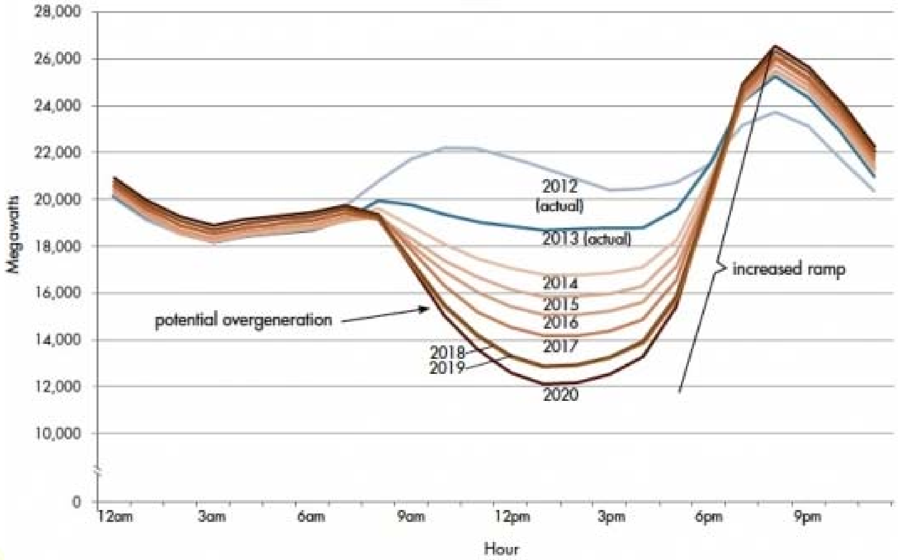


Figure 1 – Residual load curves from 2012 to 2020 on March 31 in California [1].

ENTSO-E has produced an extensive report on the RES penetration in European countries in the Scenario Outlook & Adequacy Forecast (SO & AF) of 2015 and in the Mid-term Adequacy Forecasts (MAF) of 2016 and 2017[2] [2], [3], [4]. Figure 2 shows the variation of the installed RES capacity from 2016 to 2025 per European

[1] Residual load is defined as the total demand minus the production of RES, minus must-run generation (e.g. Combined Heat and Power - CHP, biomass etc.). It corresponds to the part of the total load that must be satisfied by conventional generating units, interconnections and DR.

[2] The MAF of 2017 is currently under Public Consultation.

country for Scenario B of [2]. On the opposite side, Figure 3 shows the respective variation of the installed capacity of fossil fuel units for the same years.

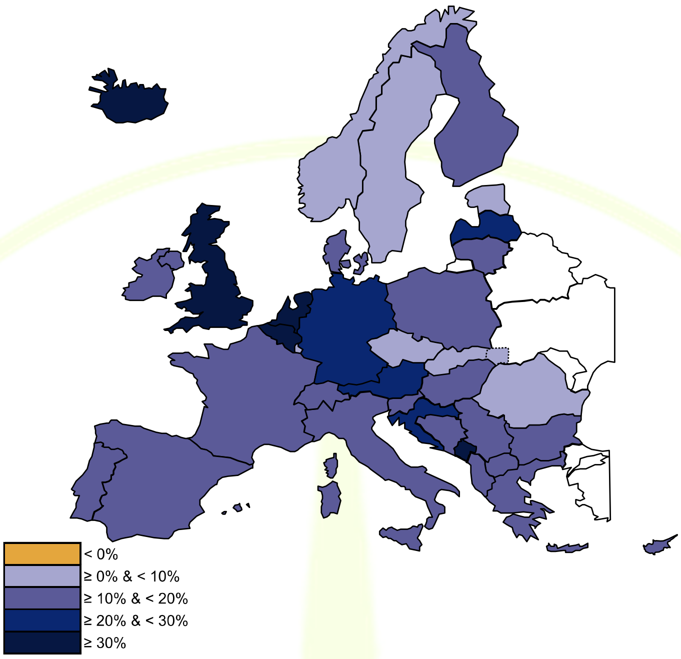


Figure 2 – Variation of the installed capacity of RES from 2016 to 2025 as a percentage of the total Net Generation Capacity, per country, in 2016, Scenario B [2].

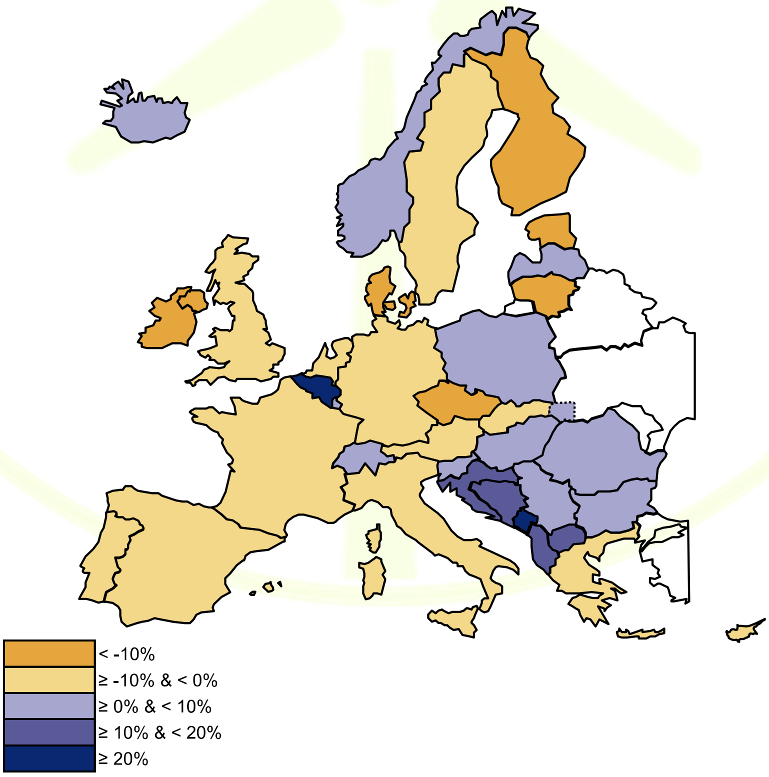


Figure 3 – Variation of the installed capacity of fossil fuel units from 2016 to 2025 as a percentage of the total Net Generation Capacity, per country, in 2016, Scenario B [2].

The increased needs for operational flexibility can easily be derived fro the above. With high RES shares, the system may even need to operate under significant oversupply events (negative net load). In these cases the excess generation/supply can be absorbed with one of the following ways:

- The demand should increase;
- The excess of energy should be transported to adjacent areas (interconnections) or
- The excess of energy should be stored.

2.2 BALANCE OF GENERATION AND DEMAND: IMPACT ON FREQUENCY REGULATION

The system frequency is an indicator of the total Active Power balance in the whole Synchronous Area. In particular:

- If the Active Power generation exceeds the Active Power consumption, the System Frequency will rise and
- If the Active Power consumption exceeds the Active Power generation, the System Frequency will fall [5], [6].

The unpredictability of the demand and the fact that it is currently not easy to control the demand side makes it tricky and challenging to avoid imbalances and therefore frequency deviations.

The Load-frequency control processes are performed in specific areas, according to the hierarchy shown in Figure 4 [6]. TSOs in a Synchronous Area should agree on topics related to the Frequency Containment Process (FCP), whereas TSOs of the same Load-frequency control Block should agree on topics related to the Frequency Restoration Process (FRP).

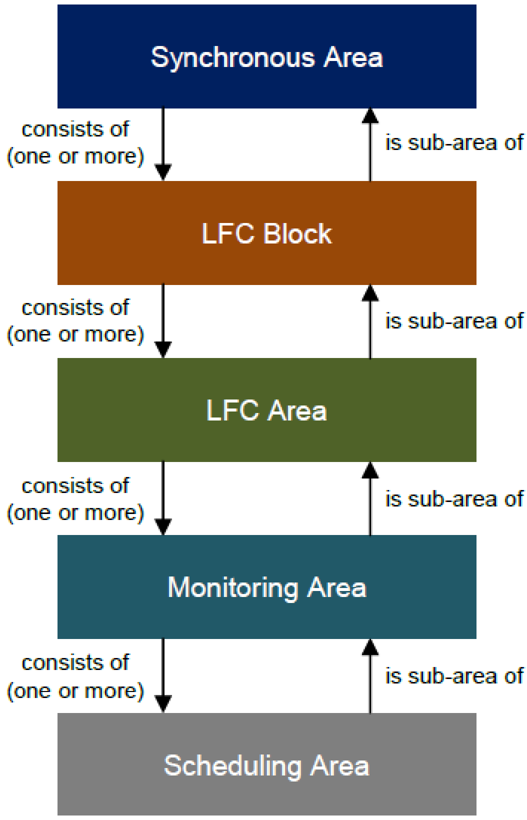


Figure 4 – Types and hierarchy of geographical areas for the operation of which are responsible the TSOs [6].

Figure 5 shows the hierarchy of the Load-frequency control processes.

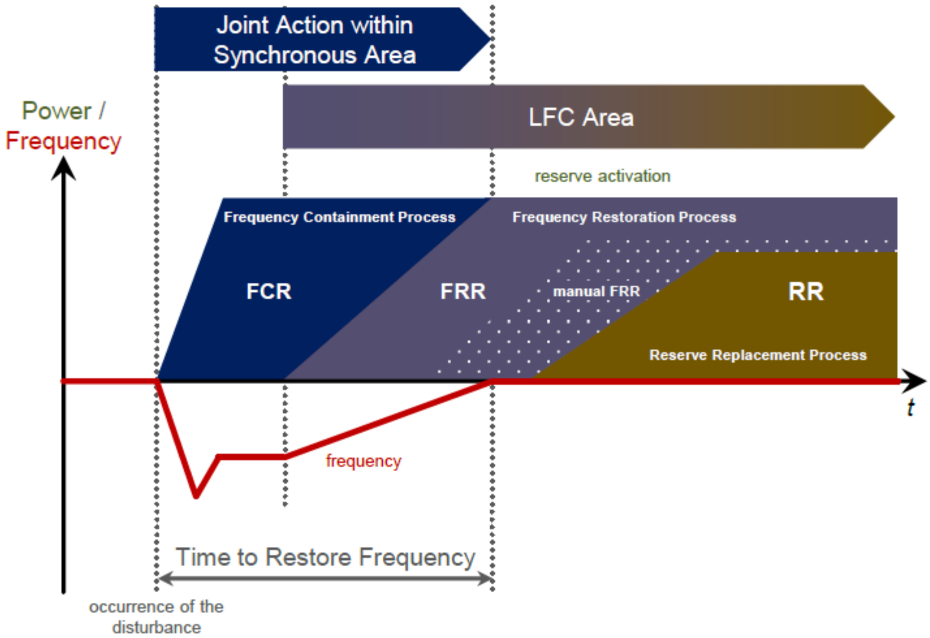


Figure 5 – Dynamic hierarchy of Load-Frequency Control processes (under assumption that FCR is fully replaced by FRR) [6].

It is noted that the Frequency Containment Process is also known as Primary Regulation, the Frequency Restoration Process as Secondary Regulation and the Reserve Replacement Process (RRP) is known as tertiary reserve.

Hence, it becomes evident that in modern power systems it is of utmost importance to develop suitable DR schemes, since DR is expected to play a significant role in the balance of the system and its safe and reliable operation.

2.3 REGULATORY FRAMEWORK AND ACTIONS

The existing regulatory framework includes the Network Code on Load-Frequency Control and Reserves, issued on 28 June 2013 [5]. However, following the European Guidelines for the Capacity Allocation & Congestion Management (CACM 2015/1222) and Forward Capacity Allocation (FCA 2016/1719), the new **Electricity Balancing Guideline** is expected to enter into force in December 2017 [7]. This Guideline will treat, among other things, the cross-border exchanges to move towards an integrated electricity market and to ensure operational security and efficient balancing rules.

This Guideline defines the roles of the actors in DR, such as Balance Responsible Parties (BRPs), Balance Service Providers (BSPs), DR aggregators etc. It also inserts the so-called "**standard products**" in order to enhance competition between BSPs. This means that the majority of BSPs will have to be able to participate in the Electricity Market. The BSPs can be conventional generating units, RES or DR units (controllable electricity loads). A standard product is defined as a "harmonized balancing product defined by all TSOs for the exchange of balancing services".

There are currently the following projects and corresponding platforms:

- Manual Activation Reserve Initiative (MARI): related to the manual Frequency Restoration Reserve (mFRR) product (see Figure 6);

- Platform for the International Coordination of the Automatic frequency restoration process and Stable System Operation (PICASSO): related to the automatic Frequency Restoration Reserve (aFRR) product (see Figure 7) and
- Trans European Replacement Reserves Exchange (TERRE): aims at setting up and operating a platform capable of gathering all the offers for Replacement Reserves (RR) and to optimise the allocation of RR across the systems of the different Transmission System Operators (TSOs) involved.
- Imbalance Netting: International Grid Control Cooperation (IGCC) and Imbalance Netting Cooperation. The former is a project aiming at maintaining the balance between electricity generation and consumption at all times in the respective Load-frequency control areas of the TSOs, avoiding the simultaneous aFRR activation in opposite directions.

The TSOs that are currently involved in the MARI and the PICASSO platforms/projects, either as members or as observers, are shown in Figure 6 and Figure 7, respectively. Croatia, Romania and Poland are in the process of becoming observers (and later on, after a certain time, they can become full members). Instead, Ireland and Bulgaria have refused to participate, even as observers. Figure 8 shows the TSOs participating in the TERRE project[3]. Last but not least, Figure 9 shows the TSOs participating in the IGCC project.

In the above-mentioned projects there is a close collaboration between National Regulatory Authorities, TSOs, the Agency for the Cooperation of Energy Regulators (ACER), the EU and General Stakeholders.

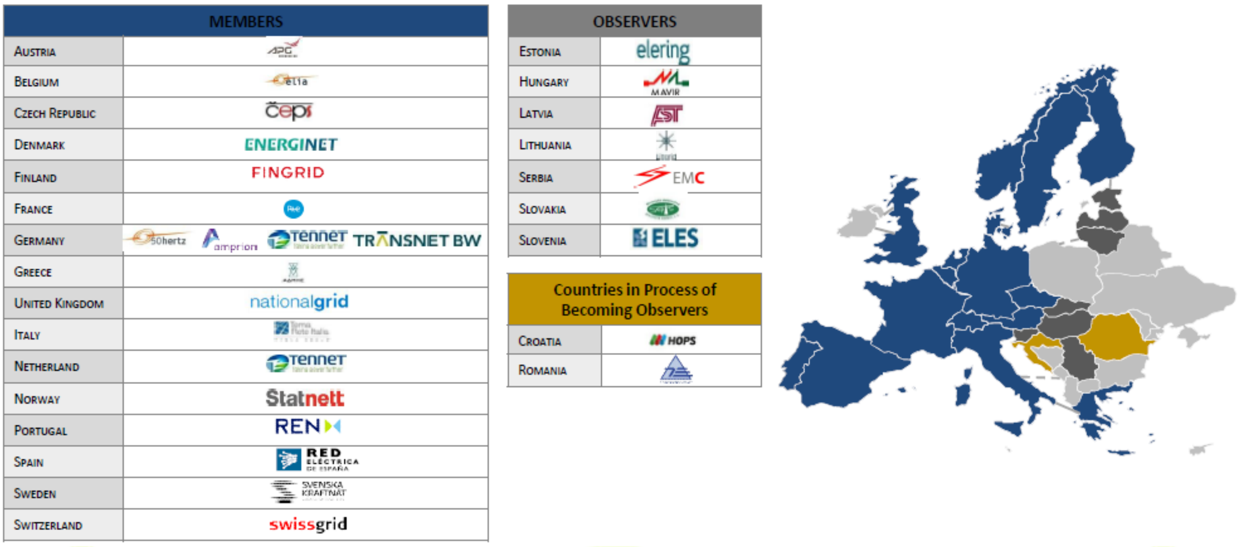


Figure 6 – TSOs participating in the MARI initiative [8].

[3] The Greek TSO (ADMIE) has recently changes its status from "member" to "observer".

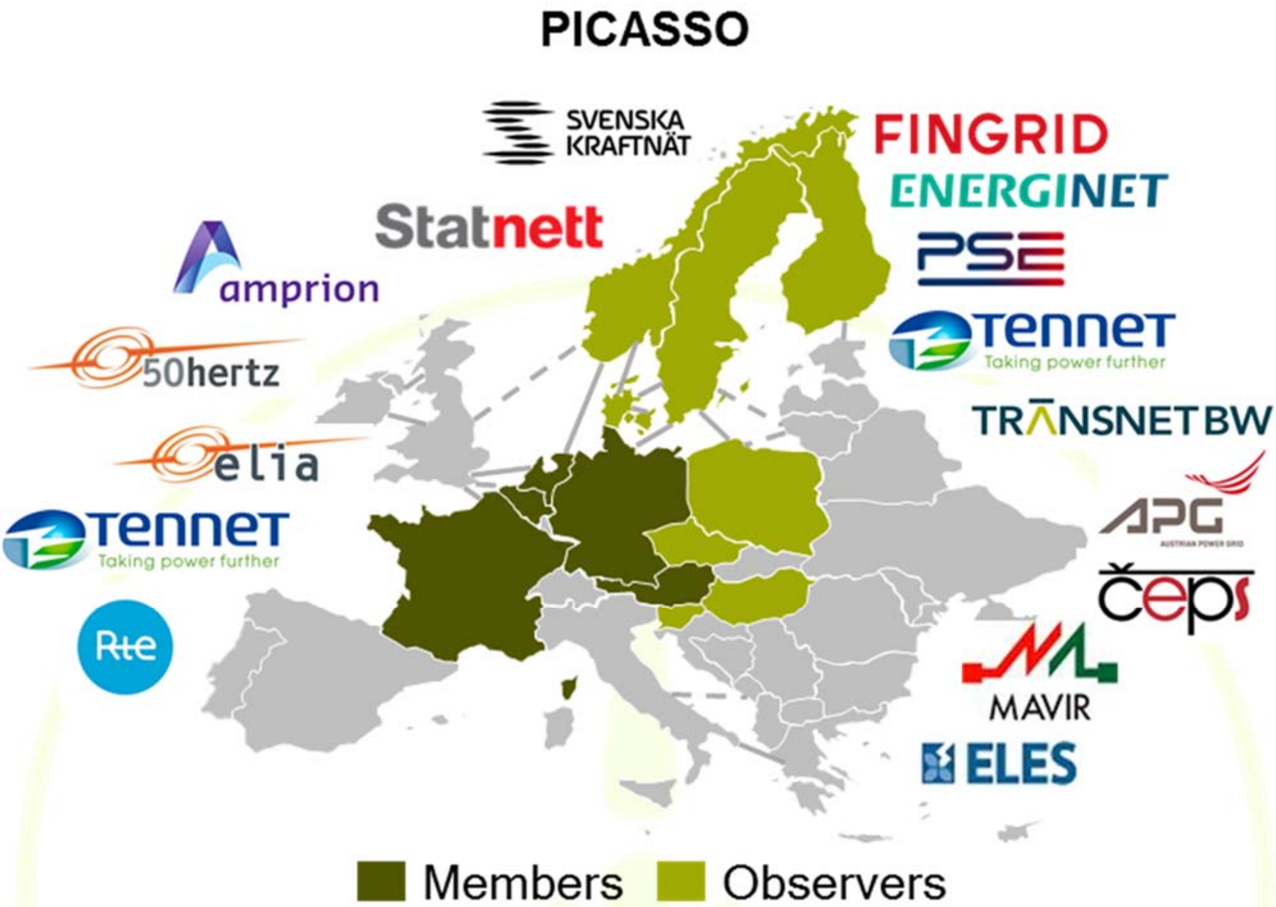


Figure 7 – TSOs participating in the PICASSO initiative [9].

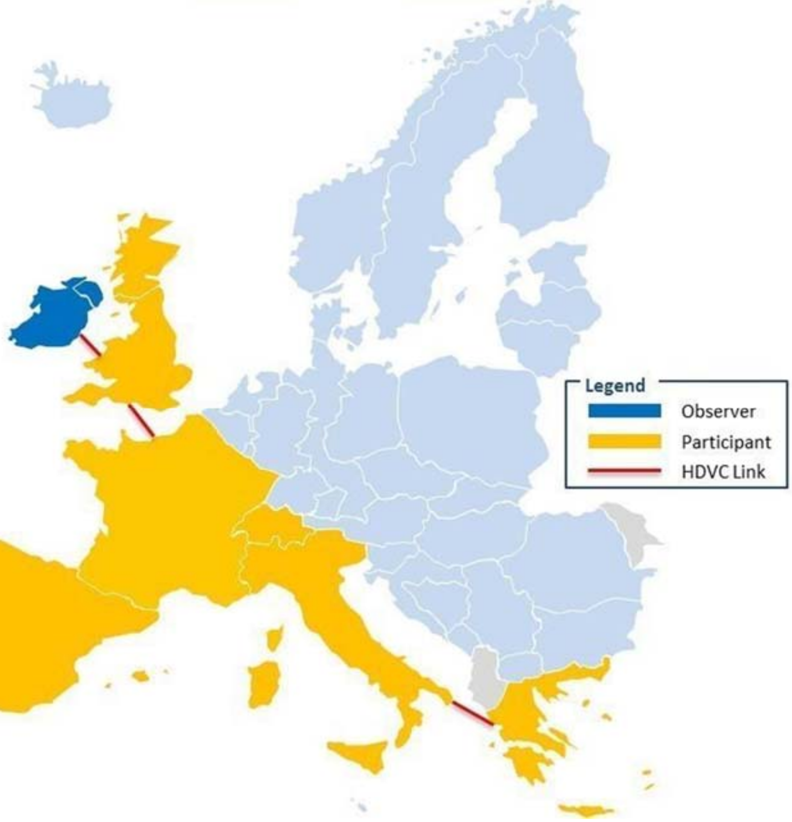


Figure 8 – TSOs participating in the TERRE initiative [10].

Figure 9 – TSOs participating in the IGCC project [11].

2.4 EU WINTER PACKAGE: CLEAN ENERGY FOR ALL EUROPEANS

The EU Winter Package sets a priority to Energy Efficiency and the active management of demand in order to optimize energy consumption, reduce costs for consumers and import dependency, while enabling - in parallel - the progressive retiring of the generation from fossil fuels. Figure 10 and Figure 11 show the directions set by the EU Winter Package at a glance.

Figure 10 – The EU Winter Package at a glance (1/2) [12].

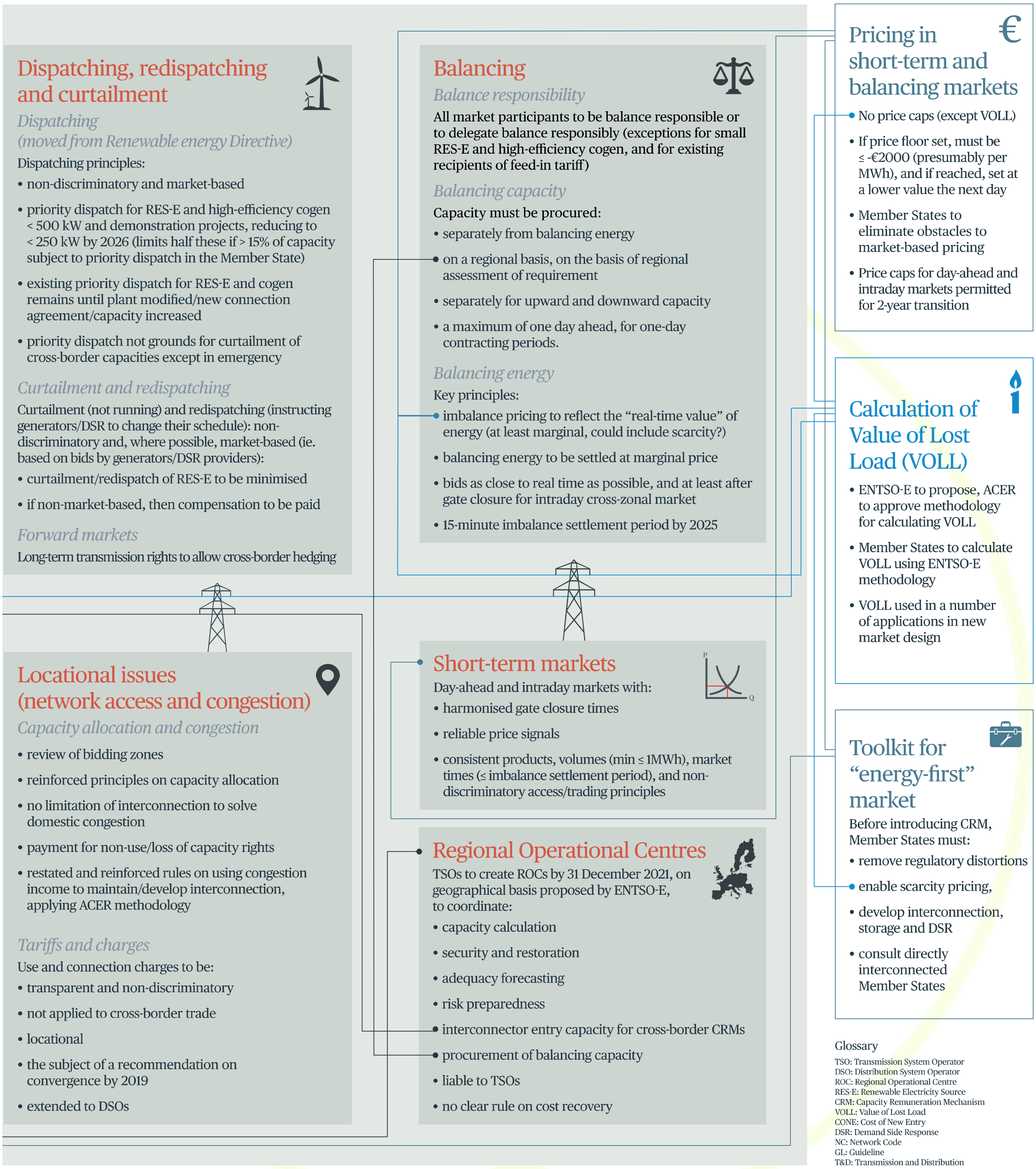


Figure 11 – The EU Winter Package at a glance (2/2) [12].

In this new reality, the DR participation will be an important asset of the Electricity Market. At the same time, by allowing the trading closer to the time of delivery (real-time markets), operational flexibility will have to be ensured through DR and storage. Consumers will be able to participate in DR schemes directly or through aggregators.

In case of shortages of electricity, there will be suitable capacity mechanisms to remunerate electricity generators and DR providers. These mechanisms often fall to be assessed under Article 107(1) of the TFEU and the Energy and Environmental Aid Guidelines (EEAG) of 2014. Regional Operational Centres will play a significant role in this direction, integrating prosumers and DR into the national as well as the regional wholesale markets. The participation of DR in the Market will be definitely facilitated by the Distribution System Operator (DSO) - TSO cooperation and the installation of suitable equipment, such as smart meters.

According to the EU Winter Package, DR embraces more than just efficient use of energy; it is rather an important source of flexibility in the power system, as analyzed above. Active consumers will be able to shift their consumption in real-time and reduce peak load. The third package of 2009 did not anticipate the importance of the demand side or contemplate the need to encourage flexible demand-side management or electricity storage.

3 EXISTING DEMAND RESPONSE (DR) TECHNOLOGIES

3.1 DR STRATEGIES

3.1.1 Classification of DR strategies

A broad classification of DR programs is provided in Table 1 according to three main classification criteria, i.e. control information, decision variable and motivation.

Table 1 – Classification of DR programs according to three main classification criteria.

Classification Criteria	DR Categories
Control information	Centralized
	Distributed
Decision variable	Event scheduling
	Energy management
Motivation	Price-based
	Incentive based

The motivation criterion has recently become the most dominant one, when distinguishing between the various DR programs. This is especially true regarding their marketing and how they are communicated to potential customers. A further – more detailed classification – breakdown of price and incentive-based DR techniques is presented below:

- Explicit DR (incentive-based DR)
    - Classical
        - Direct control
        - Interruptible / Curtailable loads
    - Market-based
        - Demand bidding
        - Emergency DR
        - Capacity market
        - Ancillary Services (AS) market
- Implicit DR (price-based DR)

- Time of Use (ToU)
- Critical Peak Pricing (CPP)
- Extreme Day Critical Peak Pricing
- Extreme Day Pricing
- Real-time Pricing (RTP)
- Peak Time Rebates

These two main categories of DR programs are typically managed by different roles in the Smart Grid ecosystem.

Incentive-based DR aims to trigger demand profile modification at specific times and, potentially, at specific grid connections/lines with the main goal to support the grid and/or to provide real-time services to parties that must maintain portfolio energy balance. Such programs are usually managed by third-party demand-side aggregators that build up a portfolio of controllable demand assets.

The main purpose of price-based DR is to modulate the demand profile of a retailer customer portfolio according to the wholesale price of electricity. It is a valuable tool for retailers who want to manage their portfolio to minimize or avoid energy imbalances. The careful design of tariffs and rates has the potential to shift peak demand and help the retailer lower its cost structures by reducing hedging costs.

More detailed descriptions of each of these DR alternative strategies are provided in the following paragraphs. The strategy descriptions will be mostly based on information from respective programs that have run in the United States (US); the DR market there has been active for a much longer time than in the European one. Member States are or are expected to start opening balancing and ancillary service markets to demand in line with one or more of these strategies.

3.1.1.1 Explicit DR - Direct Load Control

Direct-load-control (DLC) programs are typically mass-market programs directed at small commercial (less than 100 kW peak demand, although actual magnitude depends heavily on country and service type) and residential customers. Customers sign up for the program to allow the utility to control specific end electricity uses at the customer site. The most frequently controlled end-use is heating, ventilation and air conditioning (HVAC) loads, but lighting is also gaining acceptance within commercial DLC programs. Where available, electric water heating and pool pumps are targeted in residential DLC programs, since they represent a significant fraction of consumption and their control causes rather limited annoyance to residents. Such programs are already present in the US, which has a longer track record in DR compared to Europe [13] [14].

Incentive structures for DLC programs typically include fixed monthly payments credited to the customer's utility bill, plus a one-time participation payment. Some utilities provide tiered payments based either on the size of the load committed (in terms of kW) or on the control cycling strategy (15%, 25%, 50%, or 100% of the hour). Some utilities provide an additional payment when a load reduction event is called. As part of the DLC program, the utility establishes agreements with customers that specify the maximum number of events per year (e.g. up to 30) and the maximum duration of any given event (between 2 and 8 hours, but typically 4). Because the utility controls the customer loads directly, very little advance notification is given prior to initiating an event (3 minutes or less).

DLC programs are relatively simple and inexpensive to implement. Generally, they employ load control switches or "smart" thermostats linked to the utility to reduce loads. Load switches cycle the compressor or completely shut off other loads such as lighting, water heating, and/or swimming pool pumps. Smart thermostats are programmable, communicating thermostats (PCTs) used to raise temperature set points and reduce customer load automatically during peak reduction events. Because these technologies have become mature consumer goods and are relatively inexpensive, utilities typically pay upfront for the technologies and offer them to customers free of charge. These technologies are quite reliable, and capable of achieving up to 60 percent load reduction per site for small customers.

This DR program is best suited for the demonstration of the WiseGRID concept and tools, since it can leverage and aggregate multiple small loads in a reliable and coordinated fashion in order to offer grid support or balancing services. It represents – if properly implemented and rolled out – the most viable explicit DR alternative in order to actively engage citizens in the energy transition and energy markets.

3.1.1.2 Explicit DR - Curtailable/Interruptible Loads

Curtailable-load programs target medium (100-500 kW peak demand, although actual magnitude depends on country/legislative framework and aggregator) to large customers and, like DLC programs, are relatively simple to implement. Participants agree to reduce or turn off specific loads for specified periods of time when notified by the aggregator. Only a handful of the largest customers have the loads and capability to participate in interruptible load (IL) programs. In this scenario, the most common customer strategy is to use the facility's backup generators during an interruptible event. Some large commercial and industrial facilities install backup generation to supply power to critical loads in case of unexpected interruptions in power supplied from the electrical grid. Because backup generators are meant to be used only a limited number of hours per year (e.g., less than 50), customers install equipment such as diesel engines that have low capital costs but high operating costs [13].

It is important to note that early DR offerings in Europe have been based on this option. The utilization of backup generation has been a popular option, especially in the early stages of market acceptance of demand side assets for AS. The prices offered during the transitional periods of demand acceptance, the United Kingdom (UK) being a notable example, were high enough to overcome the operational costs of diesel generators. This was mainly attributed to the incentives that aimed to stimulate the creation of a liquid market of demand-side resources. As incentives/subsidies slowly disappear, the business case of several market participants should be revised toward more cost-efficient consumption profile modulation options.

Customers can switch off loads or adjust settings manually or automatically, depending on the agreement and availability of control technologies. Aggregators must notify customers before a curtailable load event. Advance notice is typically given minutes to hours ahead, but some programs notify participants up to a day ahead. Like direct-load-control programs, the aggregator must inform customers well in advance the maximum number of events and durations per year, which may be stipulated in legislation or market/network codes/

The range of incentive structures varies widely among curtailable-load-response programs. These incentive structures can include a monthly payment or capacity credit (depending on the availability of other commercial engagements between the parties - €/kW), a monthly payment or capacity credit plus a rate reduction (€/kWh), an option payment with variable strike, or a per event credit based on market pricing. Aggregators may also choose to tier the monthly payment or capacity credit based on the amount of advanced notification a customer signs up to receive.

Because only the largest customers qualify, the program is implemented via bilateral agreements between a utility (for balancing purposes) or a third-party aggregator (for grid support services) and a customer. These are binding contracts and severe penalties can be enforced for non-performance. As such, facilities are called upon only in dire emergencies, though contracts can obligate availability at any time. The main DR paradigms that have been exercised in Europe are based on this option, whereby large loads are controlled by third-party aggregators (automatically or via notification of the facility/load manager) in the ancillary service markets of the UK, France and Switzerland or directly (e.g. in Greece) [15].

3.1.1.3 Explicit DR - Demand Bidding

Demand bidding gives facility managers – or the aggregator as a proxy for multiple facility managers in order to aggregate the required power magnitudes - the opportunity to actively participate in market trading by offering to reduce loads for a price. In one type of bidding structure, participants name the price at which they are willing to sell their load reductions on the market. In other types of structures such as over-the-counter transactions, the utility or independent system operator (ISO) determines the price they are willing to pay, and customers determine how much load reduction they are willing to provide. The utility or ISO then reviews the DR bids, along with those submitted by independent generators, and accepts bids in order of lowest price first (merit order) until the demand is met [13].

In liberalized markets where demand bidding is used, the customers are most commonly large commercial and industrial customers with experience interacting directly with real-time power markets. They also have sophisticated load management tools and strategies. Smaller customers can participate via intermediaries such as aggregators or energy service providers, who aggregate small loads and package the total bid for submission.

3.1.1.4 Explicit DR - Emergency DR

Emergency DR is a commitment that a customer makes to reduce its load or only consume a certain amount of electricity when the system operator requires emergency assistance to maintain the grid. Examples of emergency conditions include capacity shortages, hot weather, or a power plant failure [16].

There are three specific types of emergency DR programs in a representative real-life deployment of such a service in PJM, the TSO of the Eastern United States:

- Limited DR, where a customer agrees to be available for several weekdays from June through September (up to six hours for a given day);
- Extended Summer DR, which requires customers to be available for an unlimited number of days between May through October for up to several hours at a time; and
- Annual DR, where a customer is available for every day of the year.

Emergency DR programs of other system operators may vary in the exact terms compared to the aforementioned, but the structure of the programs is similar.

These emergency resources are treated just like power plants; the system operator completely relies upon their DR performance when the grid most needs it. Customers who make themselves available through these emergency markets are paid by the system operator simply to be available during any expected emergency conditions. But if a customer fails to reduce its load when called upon, that customer can face a significant penalty.

Another way customers can participate in emergency DR is on a voluntary basis, where the customer chooses to reduce its load when an emergency event is called. If the customer can successfully reduce its load and measure its reduction, the system operator will pay the customer for its voluntary participation.

3.1.1.5 Explicit DR - AS Market

AS (AS) DR consists of a number of special services that are needed to ensure the secure operation of the transmission and distribution grid and which have traditionally been provided by generators. Load participation in AS increases the available pool of flexible resources, supports reliability, and reduces costs for all power system users. The increased use of load-side resources for AS can improve overall system efficiency and may, thereby, reduce emissions from the electricity sector. By allowing load to provide AS, generators may run at more efficient operating points; and further emission savings are possible. Several different AS exist; the types, names, definitions, and technical requirements differ by country, region and by market. Typically the most valuable ASs – with the highest remuneration from the system operator – are the ones that require very fast response given the inherent ramp up times of most conventional generators and the promise of immediate response from loads. Such services are called frequency regulation and spinning reserve in the USA or Firm Frequency Response and Fast Reserve in the UK or by other names in each country/market jurisdiction [17].

DR programs using automated control of energy assets are promising for fast services, especially in the case of aggregating (electrochemical) storage elements that have very fast response time for both energy flow directions. Grid support through the aggregation of stationary batteries and Electric Vehicles (EVs) is one of the key objectives of the project and will be demonstrated in the pilot tests.

3.1.1.6 Implicit DR – Time of Use

TOU pricing programs are based on a stepped rate structure that includes a peak rate, an off-peak rate, and sometimes a shoulder-peak rate for pre-determined blocks of time set by the utility. A TOU tariff might charge customers 5.5 cents per kilowatt-hour (kWh) consumed on weekends and weekdays from 9:30 PM to 8:30 AM, 8 cents/kWh on weekdays from 8:30 AM to noon, and 6:00 PM to 9:30 PM, and 12 cents/kWh on weekdays from noon to 6:00 PM. TOU rates do not recognize day-to-day volatility of supply costs, and are designed to reflect prices under expected, average market conditions. These conditions, however, typically account for – variable – renewable production, which has a predictable supply-side impact and hence comprises a systemic factor in wholesale energy prices [13].

3.1.1.7 Implicit DR – Critical Peak Pricing

CPP is a variation of TOU tariffs that tries to reflect the uncertainty and volatility of electricity supply costs. The CPP tariff adds a time-dependent rate several times higher than normal rate to either standard, or TOU rates, during peak periods. The utility can call a critical peak event anywhere from 24 hours to just minutes before when they are applied. Since the days when critical peak events will be called are unknown, the utility usually agrees to limit both the duration and number of events per year. For example, an agreement might specify that a critical peak rate of 24 cents per kWh can be imposed for 4 hours up to 30 days each year. Utilities then can base notification decisions on their forward-looking criteria related to the balance between supply and demand (e.g., weather or declining reserves). The CPP rate can be added to either standard or TOU rates, and needs to be high enough to induce participant response (a minimum ratio of 2.5 to 1 between critical peak and peak price level is recommended) [13].

CPP programs are suitable for both small and large customers. Automated load control technologies are not required, but are desirable in CPP in order to maximize performance because customers may not be on-site when critical peak events are called.

This is exactly one of the scenarios that the WiseGRID consortium desires to test in a real-life context. Price peaks due to increased wholesale prices – or even due to lack of green generation in the case of renewables cooperatives – are a realistic prospect for incentivizing consumers to modulate their demand profile. This has been already shown to work in limited tests in past efforts and will be replicated and used in a large scale during WiseGRID to showcase the performance of critical peak prices as an effective price signal for demand modulation.

3.1.1.8 Implicit DR – Extreme Day CPP

This rate design is a variation of CPP in which the critical peak price applies to the critical peak hours on extreme days but there is no TOU pricing on other days.

3.1.1.9 Implicit DR – Extreme Day Pricing

This rate design is similar to CPP, except that the higher price is in effect for all 24 h for a maximum number of critical days, the timing of which is unknown until a day ahead.

3.1.1.10 Implicit DR – Real-Time Pricing

RTP programs fully expose customers to the variability and volatility of costs in the wholesale electricity market. Rates charged for electricity reflect the actual supply costs to the utility for each hour of the day. The prices are provided to customers anywhere from an hour, to as much as 24 hours ahead of time. Facility managers are free to maintain operations as planned, or to adjust operations in response to higher or lower rates. Implementing an RTP program requires significant technology investments, including automated interval metering, along with more complex price forecasting, communications and billing systems. Currently, only a small subset of the largest industrial and commercial customers has a demand elasticity high enough to justify participation. These customers typically have backup generation or discrete production processes that can be rescheduled—the same strategies employed by customers who participate in curtailable or IL response programs. Automated control technologies for customers are recommended to maximize performance and savings [13].

RTP programs provide customers with market-based information on which to base their energy use decisions and— combined with customer education programs— remain a strong tool for managing both load growth and peak demand. Their downside is the necessity for commitment, planning and effective execution of energy management strategies on behalf of the end user in order to benefit from the potential for cheaper energy. Unfortunately these aspects are atypical for residential consumers, so the only viable way for RTP to penetrate the residential electricity market is through automation. Some solutions already exist in this space, Switzerland being the most successful [18] in Europe in terms of market penetration.

3.1.1.11 Implicit DR – Peak Time Rebates

PTR is a program that rewards members who conserve energy during certain hours when a “Peak Event” is called. On days with high electric usage, more power is needed to support our system; this additional power typically comes from resources that are inefficient and have higher costs. PTR helps utilities to avoid buying power from higher cost resources, by having members voluntarily reduce usage during Peak Events. A Peak Event is a block of time (usually only a few hours) when we expect the system electric load to be at a very high level. This can occur on very hot summer afternoons, when air conditioners are on at full blast. In the winter, Peak Events often occur on very cold mornings or evenings. In the spring and fall, Peak Events can occur at various times [19].

Customers who reduce electricity consumption during peak events are rewarded with monetary rebates. Those who do not reduce usage during peak events are simply charged the normal rate. For this reason, PTR programs typically see much higher participation rates than many other DR programs. In addition, PTR programs generally have high customer satisfaction ratings.

And on the utility side, PTR programs do not require any changes in rate design. Assuming PTR rebate levels are set correctly, PTR programs can benefit both customers and utilities, resulting in a win-win outcome. PTR programs typically have very low upfront costs. Although they do require Advanced Metering Infrastructure (AMI) interval reads for the participants, if AMI is already in place, upfront costs are minimal. Costs to the utility are mainly incurred in the form of rebates to the customers in exchange for demand reductions; therefore, ongoing costs will be a function of how many peak events are called each year. If the utility’s event call strategy is managed properly, ongoing costs should be lower than the savings attributable to the peak reduction.

3.1.2 Benefits of DR for stakeholders

DR offers a wide range of benefits for all stakeholders involved:

DR program/campaign participant

- Incentive payments: the most obvious benefit for participants in explicit DR campaigns (and Peak Time Rebate implicit DR campaigns) is the remuneration they receive for successful response to DR signals.

- Energy cost savings: implicit DR campaigns offer the possibility to electricity consumers to significantly reduce their energy costs.
- Increased market power: participation of small electricity consumers –especially through any kind of federation schemes – gives them market power, i.e. the capability to affect prices according to their needs. This can be achieved via direct negotiations with utilities/aggregators or even through the establishment of cooperatives that act as electricity producers and retailers under the complete control of their members.

Aggregators (explicit DR)

- Financial benefits from capacity and ancillary service markets or Over-The-Counter (OTC) transactions with BRPs and/or Distribution/Transmission System Operators (DSOs and TSOs, respectively). This is the main revenue stream for the aggregator business model.

Energy suppliers/utilities (implicit DR)

- Portfolio imbalance risk hedging: the capability of suppliers to affect the aggregated demand profile of their clientele allows them to hedge against imbalances of demand versus electricity purchased in the wholesale market, which could lead to imbalance penalties.
- More predictable demand profile yields better forecasts and purchase strategies from the wholesale energy market: demand shaping also allows the supplier to improve their forecasting and wholesale purchasing strategies and – in an extreme case – lower their costs by shifting significant demand to times of cheaper electricity (i.e. by lowering night tariffs).
- Compliance to EU directives on energy efficiency: the EU Winter Package published at the end of 2016 foresees specific energy efficiency targets that must be met by suppliers. As a result, implicit DR provides them the necessary tools to comply with policy and regulatory requirements.
- Differentiated energy tariff programs, offering diversity: the capability to customize and personalize energy tariff schemes to the requirements of individual customers gives retailers an important tool to diversify and increase the attractiveness of their offerings.

Market

- Reduced energy prices: DR can lead to avoidance of electricity generation from costly generators that are low in the merit order and push the wholesale price upwards. This leads to an average reduction of energy prices, especially at times of peak demand.
- Increased capacity: capacity of the energy system refers to available reserves that can support the system in times of need. DR can become an important, since it is a cheap and practically already available source of capacity for the energy system.
- Participation of many consumers – especially federations of consumers - in energy markets increases market liquidity, reduces the market power of large buyers/sellers and yields lower and more stable electricity prices.

Energy system

- Increased reliability of the system as whole due to diversified sources of ancillary/balancing services that lead to reduced outages.

Avoided/deferred infrastructure investment costs due to the decreased need for further network capacity to counter increased demand.

3.1.3 DR costs

DR can offer significant benefits to participants and the energy system as a whole, but also brings some costs for setting up and operation. These costs per stakeholder are indicated below:

DR program participant (residential, business or industrial)

- Set up
  - Purchase and installation of required enabling technology – in some cases the cost of this equipment can be borne by the program owner, but this depends on the respective commercial arrangement.
  - Definition of response plan and processes. This is an important cost element, since a detailed execution plan needs to be put in place in order to reap the benefits of participation in DR campaigns with minimal disruption to the normal activities of the load owner/manager.
  - Transaction costs in the process of identifying, screening and selecting the most beneficial offer for program owners for participation in DR programs.
- Running
  - Lost business: modification of the electricity demand profile may result in degradation in business operations. This has to be carefully evaluated so that it never outweighs the expected benefits from DR participation.
  - Inconvenience or degradation of operational performance: any electricity demand profile modification is bound to cause some inconvenience or disruption. If an adequate response plan is in place, this disruption can be minimized or alleviated.
  - Costs due to rescheduling energy-intensive processes: ramp-up/down of electricity hungry industrial processes can have significant overheads. The cost-benefit assessment performed prior to the enrolment in the DR program should take into account all these issues and verify a positive impact on the participant bottom line.
  - Costs for onsite generation: local generation has been used as a backup power solution to avoid disrupting the load operations while actually complying with the DR signals and hence fulfilling the obligations to the aggregator or supplier. This solution is clearly costly, but still may be cost effective depending on the potential DR incentives or non-compliance penalties.

DR program owner (aggregator/ supplier)

- Set up
  - Installation of metering and communication infrastructure, and control infrastructure for explicit DR campaigns (direct load control): the cost of equipment for the facilitation of participation in DR program may fall on the program owner depending on the arrangements made with the DR participant. This cost can be significant.
  - Availability of metering, reconciliation and billing capabilities: in the simple case price-based DR the program owner must be able to measure the actual demand profile of the client, calculate the energy cost and perform the necessary billing and financial transactions. In the case of explicit DR, things become more complicated. The baseline demand must be estimated in order to verify compliance to DR signals. This requires additional Information and Communications Technology (ICT) tools for the accurate estimation of a baseline.
  - Participant recruitment, including costs for education/awareness-raising, etc.: building, maintaining and extending a portfolio of clients is a costly activity. Especially the intended participation of residential consumers in the energy markets will lead to huge increase in the

necessary client numbers in order to reach the energy volumes required for market participation for aggregators. Given that DR is a very innovative concept and exposure of citizens to it is extremely limited, the necessary awareness raising and sales activities will be very challenging.

- Running
  - Administration, DR program management: significant effort is required for the successful implementation of DR programs, starting from program design all the way up to day-to-day management and assessment.
  - Marketing & advertisement: maintaining and extending a healthy market share requires expenditures for advertisement and marketing, especially for services that target the public at large.
  - Incentive payments to participants: this is the most obvious cost for the program owner, the incentive payments to their customers for the successful participation in DR campaigns. This mainly applies to explicit DR campaigns (and Peak Time Rebate implicit-DR programs to be exact), since in other cases the participant benefits from reduce energy costs rather than payments.

Evaluation & monitoring: continuous monitoring and assessment of DR program/campaign performance as well as identification of possible improvements should be a permanent activity in order to improve the program for all stakeholders involved.

3.1.4 Major challenges for the successful roll out of DR programs

3.1.4.1 Explicit DR

Baselining

Explicit DR programs – or more generally any DR program that directly remunerates the modification of electricity consumption profiles – faces a major challenge: how to accurately estimate the magnitude of the modification. The necessary prerequisite is that the original consumption pattern would be somehow known. This is however impossible and the best alternative is an estimation of this pattern: the baseline. The actual consumption pattern is then compared to the baseline to calculate the profile modifications (e.g. load shedding or shifting, generation) and establish the necessary remuneration.

In most realistic cases electricity consumption depends on a number of factors. Seasonal factors, such as the weather or daylight patterns, can have a very important impact. The impact of these factors on electricity consumption, however, can be estimated to a reasonable degree. Other factors have much higher volatility and much less predictability. Consumption patterns depending on human occupancy and activity – in the built environment for example - can be very unpredictable. A good example is household behaviors, which are seldom fully predictable even though the main activities of the residents are more or less similar on a day per day basis. The exact timing and combination of activities is very seldom the same, leading to electricity consumption patterns that cannot be accurately predicted.

Furthermore, baselining for DR cannot leverage the averaging effects that govern the grid-level demand predictions performed by the system operator. The baseline consumption of each individual electricity user (metering point) needs to be estimated in order to decide whether the user has responded to DR signals in an appropriate manner according to existing arrangements.

Democratizing access to explicit DR

DR programs are mainly targeted to large electricity consumers, i.e. industrial plants or large businesses/tertiary buildings and currently the low hanging fruits for participation in DR programs. The scale of their consumption means that a demand side aggregator can build the necessary portfolio volume for participation in the applicable markets with a limited number of customers. This is very important because customer acquisition and recruitment costs are quite high for aggregators. The whole process is still far from standardized and most arrangements are bespoke to suit the needs of individual arrangements. Furthermore and depending on the target market, the respective loads that will participate in the DR program may need to be qualified which adds additional costs and overheads to the process. The immediate implication is that it is currently prohibitive for aggregators to pursue small-scale customers and aggregate the small loads of many customers in order to reach the required volume for market participation.

Two ongoing developments that will alleviate this challenge include: a) the alteration of the legislative frameworks around Europe, which slowly reduce the minimum power volume that must be bid in markets, and b) the emergence of ICT tools and processes to manage DR campaigns.

This challenge also applies to explicit DR programs, since price-based DR benefits can be directly reaped by the electricity users as long as they modify their consumption patterns according to the price evolution.

Minimum requirements for participation in ancillary service markets

Current regulations typically impose minimum requirements on services in order for them to qualify for participation in wholesale markets. Examples include fixed trading charges (e.g. membership fees, entrance fees, etc.), minimum trading volume and minimum available capacity. These trading conditions may hinder the ability of smaller players (e.g. emerging aggregators) to participate.

The need for an appropriate definition of market structures and roles in all other Member States is emerging towards enabling the clear and direct access of consumers to aggregation service providers and ensuring free market competition around DR services. Any delay in this process would increase risks for all parties and enable abuse.

New balance of roles and responsibilities of market actors

Perhaps the greatest factor that needs to be considered concerns the roles and responsibilities of new and existing players on the electricity market. Current competences need to be reviewed and expanded where necessary, and DSOs, for instance, will likely need to play a more active role in the future. On top of this, a more thorough demarcation of the competences of aggregators is crucial given the importance of intermediaries when dealing with a large number of small consumers. Besides the need to establish new roles in energy market designs, the question arises as to how to deal with their interaction.

DR activations may have a significant impact on suppliers (e.g. their sales volume and costs) and the balancing exercise of balance responsible parties. The development of adequate compensation mechanisms is critical in this respect. Furthermore, accounting for the technical properties of the grid and the creation of priority rules between market and technical flexibility seem inevitable. For example, simultaneity of market signals in a local area could lead to network problems such as congestion, thereby requiring the DSO to define certain limits.

Standardization

Finally, standardization has an important impact on interest in investments and market competitiveness. With an increasing number of technologies being connected to the grid, interoperability is becoming a true challenge. However, there currently exist very few (inter)national smart grid standards. Fortunately, a number of European standardization organizations (CEN, CENELEC and ETSI) are developing smart grid standards. Besides standards, there is a need for clear legal definitions of new smart grid concepts, and for streamlining these definitions across different policy levels.

3.1.4.2 Implicit DR

Consumer acceptance

Electricity consumers around Europe – especially small consumers on the Low Voltage (LV) network – are used to fixed energy tariffs and pay-per-use programs. Dynamic prices bring a radical shift that requires significant awareness raising and training so that consumers enjoy the potential benefits. In general, most consumers are very reluctant to become exposed to volatile prices due to the inherent risk of energy cost increases if they fail to shape their electricity consumption profile accordingly. This reluctance seems to be part of human nature, they prefer to avoid downside risks rather than strive for a better situation with reduced energy costs.

Recent deployments of dynamic tariffs on a commercial scale in Finland and Sweden, however, show that consumers are able to leverage the dynamic prices to reduce their energy costs. Real electricity customers achieved reductions of 15% to 30% compared to their energy costs under flat tariffs [20] [21]. Research studies report similar results. A study [22] on 67 households in Germany reported consistent energy savings between 20% and 30% between households using a dynamic ToU tariff and smart appliances with limited intelligence (delay start until a price threshold is reached). Similar results are reported in the US [23]. All these results have been achieved without the use of intelligent automation at the building/home level.

Price regulation

Another aspect that comes into play is the distribution grid tariff. Nowadays, this tariff makes up a significant part of the final retail rate, and its design can therefore have an effect on the effectiveness of DR products based on dynamic pricing. For instance, the tariff structure can lead to the neutralization of market signals when there are conflicting interests between suppliers/aggregators and grid operators. More generally, a poorly designed tariff can lead to technical problems when it encourages sub-optimal grid usage (e.g. local overinvestment in Distributed Generation - DG). On the other hand, socio-economic problems ensue when the tariff leads to unacceptable cross-subsidization.

Moreover, active DR inevitably requires some form of signal to the consumer and/or (financial) compensation. Dynamic pricing (ToU) therefore plays an important role in its implementation, but at the moment it is substantially limited by national legal provisions around the EU. Having a pricing structure consisting of several time blocks with different prices during the day provided that adequate metering equipment is available, but continuous revision of these prices on a daily basis, for instance, is prohibited by regulations regarding variable contract types.

Personal data security and privacy

On the consumer side, although there already exists a broad legal framework on privacy and data security at several policy levels (EU, national), there is a lack of sector-specific rules regarding confidentiality and data handling and security in the context of DR for consumers. This factor may hamper consumer involvement and support. Current regulations are generally designed to support data processing for billing purposes, which typically takes place once a year. Active demand, however, will require a significant increase in processing frequency and data granularity.

3.1.5 Markets for DR services

In the US – where DR services and markets are much more mature than in Europe – the following classification of DR related markets is made. This specific breakdown corresponds directly to the markets operating in the PJM area (North-eastern USA).

In terms of explicit DR programs, the system operator offers voluntary programs that allow customers to reduce their load and realize new revenue streams through several markets. These include the Energy Market, Synchronized Reserve Market, Day-Ahead Scheduling Reserve Market, and the Regulation Market. Customers are paid for their responses based on the specific market [16].

- ***Energy Market*** is the most basic form of DR. It allows customer to voluntarily respond to prices by reducing their consumption when it makes sense economicaly (i.e., when the net benefits of the reduction exceed the costs of the reduction itself). Customers who reduce their usage sufficiently and measurably will receive a payment for their reduction. This is a balancing market managed by the TSO in order to maintain balance of energy flows on the grid. Aggregators can participate in this market by aggregating controllable loads – either automated or not – in order to modulate consumption of electricity according to the needs of the grid.

- ***Synchronized Reserve Market*** is designed to supply electricity to the grid if there is an unexpected need for more power on a short notice. Customers submit specific offers to reduce their energy notice quickly—the system operator requires customers to reduce their consumption in the Synchronized Reserve Market within 10 minutes of a signal dispatch. Customers who wish to supply synchronized reserve through DR must have the appropriate metering infrastructure in place to verify their response down to one-minute intervals and comply with the system operator rules and requirements.
- ***Day-Ahead Scheduling Reserves Market*** is a market-based mechanism designed to supply 30-minute "reserves" to the system. The operator requires this to be done within a half-hour of a signal dispatch. The market provides a pricing method and price signals that encourage customers to schedule additional capacity that will not be used the following day.
- ***Regulation Market*** corrects for short-term changes in electricity use that may affect the stability of the power grid. The Regulation Market, essentially, helps match the power that is being generated with the power that is being consumed, so it is a constant response effort from the customer. DR customers utilizing regulation service adjust their consumption to help maintain the grid's ideal frequency. This is an AS market for frequency support of the grid and in some countries it is further subdivided into primary and secondary regulation (according to the response time and the magnitude of service needed).

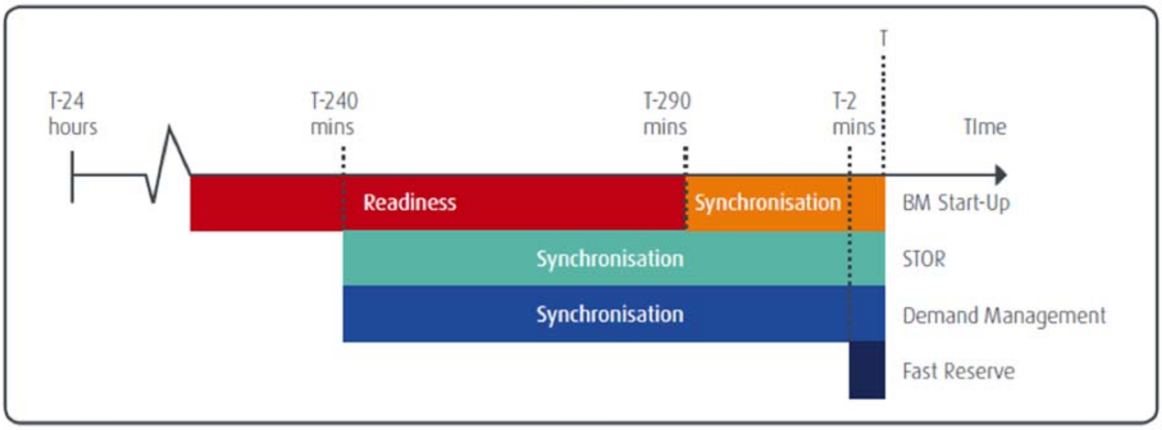


Figure 12 – Overview of balancing and AS in the UK markets [24].

In the UK – one of the most developed balancing and ancillary service markets in Europe – the market structure is similar, albeit with significant differences in terminology. Figure 12 illustrates the four main market types.

- BM refers to balancing services that are necessary for balancing the energy flows on the grid and corresponds to the "Energy Market" mentioned above.
- STOR and Demand Management are both used as slow reserve services for the restoration of frequency deviation. They correspond to the two aforementioned "Reserve Markets", which mainly vary in the notice they provide for service invocation and procurement schedule.
- Finally, Fast Reserve directly corresponds to the "Regulation Market"and refers to services for services for primary and secondary frequency support.

The participation of DR in all the aforementioned markets lies, in principle, in the discretion of the respective market codes. Given sufficient magnitude and ramp up/down speed, DR assets do possess the necessary technical capabilities to participate in the markets.

3.1.5.1 Current state of European energy markets

The situation in the European Union is much more complicated and fragmented due to the heterogeneity of national regulatory frameworks and market structures. However, it has to be pointed out that, during the last years, many important steps have been done towards the design, development and operation of an Internal Energy Market based on the principles of the so-called "Target Model" as well as on the European Guidelines (CACM, FCA, EB), which cover also the cross-border exchanges**.** The Joint Research Center of the European Commission provided in 2016 the following overview of the current situation of DR markets in the Member States [25].

The wholesale markets are by far the largest and (theoretically) most liquid markets in any given Member State. Here Retailers look to buy sufficient energy either from their own generators or from the market, to supply their customers. In order to maintain balance they should buy the same amount of energy for any given time period, as their customer's will consume.

This is part of their balance responsibility and each retailer will therefore have such a BRP, who will be responsible for the imbalances settlement of the BSPs, such as DR aggregators. Wholesale markets include futures markets but also intra-day and spot markets, where energy is bought and sold 15-60 minutes prior to the time of consumption. After this point there is 'gate closure'. The wholesale market activity is at an end and the TSO is responsible to maintain balance from the time of gate closure to the microsecond prior to consumption. This is done through balancing markets and AS. BRPs with an uninstructed shortage pay money to the TSO, whereas BRPs with an uninstructed surplus receive money from the TSO. This is done through the BRP-TSO Imbalance Settlement process, where the calculation of charges/remuneration of BRPs for their imbalances can be conducted by using f.e. Single Pricing, Dual Pricing, Based on total costs, Alternative payment direction, Two-price settlement and Additive Component. The EB Guideline with expected entry into force in the beginning of December 2017, there is a clear preference for dual pricing and the harmonization of the Imbalance Settlement period to 15 minutes.

Retailers may be required to pay the TSO for these services according to the amount that they were off in their balancing calculations. However the company's generators may also earn from providing balancing and AS to the TSO. This mechanism is different in different Member States, but the principle remains the same.

ENTSO-E writes: 'Balancing refers to the situation after markets have closed (gate closure) in which a TSO acts to ensure that demand is equal to supply, in and near real time. '

Efficient balancing markets ensure the security of supply at the least cost. An important aspect of balancing is the approach to procuring AS. AS markets provide a range of capabilities, which TSOs contract so that they can guarantee system security. These include black-start capability (the ability to restart a grid following a blackout); frequency response (to maintain system frequency with automatic and very fast responses); fast reserve (which can provide additional energy when needed); the provision of reactive power and various other services."

Explicit DR is first established within the balancing and AS markets. These provide the best investment security and prices. The types of services required by the TSO also fit a consumer's capabilities well.

At national level, few Member States clearly engaged in the process of a wide integration of DR in the electricity markets. Some markets were fully open, in others some DR products were allowed to participate. To enhance this situation, the following recommendations were formulated in the report:

1. As it appears from the UK experience, an open and competitive market is a prerequisite to more integration of DR. Therefore enforcing the full implementation of the Third Energy Package is seen as a precondition.
2. As of 2014, *none of the Member States had fully integrated DR in all national electricity markets, including wholesale, balancing and AS*: either the regulation did not allow for it, or the regulation allowed DR to participate, but the roles and rules were not clearly defined, or the business case for DR was not sufficiently attractive. Recommendations for improvement included:
    a. adapting market products to DR: this could be carried out in two phases. In a first phase, specific DR products are developed, with requirements on size, duration and availability that are adapted to DR; in a second phase, products could be neutral and adapted to the generation as well as the demand side. Leverage on DR products that were used in past DR programs also appears to be a valid option.
    b. adapting the regulation to DR products: this implies removing barriers, and eventually introducing quotas to (artificially) increase DR participation in a first phase.
    c. enabling and empowering the demand side: in order to enhance the active participation of final customers, the roll out of smart meters will be key for a diffuse participation of all sectors; additionally, clear and simple modalities for participation and a positive business case for end users are needed. Empowering intermediaries such as aggregators and service providers will also be a powerful means for reaching out a maximum number of customers. Finally, regulatory measures should be complemented with pilot project or information campaigns for the targeted groups.
3. While progressing toward the integration of DR in the national electricity markets, the European dimension and the Internal Energy Market should be taken into account. This implies referring to ENTSO-E Network Guidelines when defining specific products (e.g. the standard products defined in EB Guideline for products in the balancing market). Furthermore, research into convergence trend of national regulations and network tariffs could benefit the DR integration process at EU level. Similarly, investigating common definitions for electricity market products, including DR products, could bring benefits toward integrating DR at European level.

The market (re)design that allows for accommodating all the flexibility potential of DR, needs to be planned with attention. Parties involved shall include National Regulatory Authorities, the DR community and it might also involve as suggested "an ad hoc technical entity". The whole process shall:

1. ensure a wide participation of parties involved and stakeholders, include consultations and be transparent;
2. be based on a far-reaching forward-looking planning guaranteeing a regulatory stability that attracts financial partners and allows for long term planning of resources;
3. adopt a pragmatic and gradual approach, based for example on pilot projects followed by a wider deployment. The selected approach should be adaptive and ready to change with the fast evolving economic, regulatory and technological environment. European energy systems are undergoing substantial adjustments, with for example ageing or nuclear plants being phased out, increased renewable energy plants, more distributed energy sources, self-producers, new actors like prosumers, EVs or storage systems. A two-phase approach could firstly encourage the participation of DR in all the markets, with dedicated products or quotas and secondly reach a product-neutral market, fully compatible with DR;
4. shall be coordinated with other programs in order to reveal synergies (especially durin the design phase), e.g. with energy infrastructure or RES support programs, EE in all sectors.

A smooth integration of all resources, on the demand side as well as on the generation side, and at national as well as at European level should be the long-term aim.

3.1.6 Outlook for DR in the EU

Research [15] shows that there has been an overall increase of interest in enabling DR in many Member States. Regulatory changes have been implemented or are planned in many of the analyzed countries. Notably, in the countries where DR has traditionally been almost non-existent, such as Estonia, Spain, Italy, there has been at least some regulatory interest in exploring its potential. The European countries that currently provide the most conducive framework for the development of DR are Switzerland, France, Belgium, Finland, Great Britain, and Ireland. Nevertheless, there are still market design and regulatory issues that exist in these well-performing countries. Switzerland and France have detailed frameworks in place for independent aggregation, including standardized roles and responsibilities of market participants. In France, a new draft decree being reviewed by the Conseil d'Etat in early 2017 could provide for a new financial settlement framework whereby a significant of the payment to retailers with curtailed customers would be charged to retailers rather than to DR providers. However, issues persist around a standardized baseline methodology.

In both Belgium and Ireland upcoming legislation should help to increase the participation of DR. New legislation addressing the role of the aggregator and independent aggregation will soon be put in place in Belgium, which will help to provide an equal footing for all market actors; a strong sign for the uptake of DR. However, there are still some issues regarding measurement and verification that inhibit the growth of DR. In Ireland, the new "Integrated Single Electricity Market" to be implemented in 2018, together with the DS3 program, will open a range of markets for demand side response, specifically the balancing market, and the wholesale market, as well as a newly designed Capacity Mechanism.

Great Britain continues to have a range of markets open to demand-side participation. Independent aggregators can directly access consumers for AS and capacity products, and the country recently has started considering a framework for independent aggregator access to the Balancing Mechanism. Yet, with relatively burdensome measurement and verification procedures in place for DR, it still has room to improve.

Finland stands out amongst the Nordic countries primarily as it allows independent aggregation in at least one of the programs in the AS, and due to its advanced provisions for measurement and verification. It will also be experimenting through pilot projects with independent aggregation in other parts of the balancing market starting in 2017.

Austria, Denmark, Germany, Netherlands, Norway, and Sweden performance falls behind that of the aforementioned Member States as regulatory barriers remain an issue and hinder market growth. Although several markets in these countries are open to DR in principle, program requirements continue to exist which are not adjusted to enable demand-side participation. Furthermore, a lack of clarity remains around roles and responsibilities of the different actors and their ability to participate in the markets. However, Germany, the Nordic countries and Austria have started processes to find a standard solution for the role of independent aggregation. One of the notable differences lately is that Germany is making significant efforts through product definitions have been updated or are about to be updated, and balancing reserve markets that are about to be opened for independent aggregation.

Slovenia, Italy, and Poland performance lies in the third tier with respect to DR facilitation efforts. In Slovenia and Poland, no major regulatory changes have been made within the past couple of years that would have allowed for further DR participation. Italy has slowly started to take the regulatory steps needed for a solid framework for DR. However, despite the gradual opening of markets, significant barriers still hinder customer participation. For example, major sections of the market are still closed off and they lack a viable regulatory framework for DR overall.

Spain, Portugal, and Estonia are laggards because aggregated demand-side flexibility is either not accepted as a resource in any of the markets or it is not yet viable due to regulation. Here, we see a critical disconnect between political promises and regulatory reality. Estonia may be an important country to watch in the future given that markets could open once they have disconnected from the IPS/UPS synchronous area.

Greece is currently in the process of a major re-structuring of its internal Market. The transition from the current model of the Day-Ahead Market and the mandatory pool to the new Market design that involves the balancing market is expected to be completed at the end of 2018. There is currently an interruptibility scheme, which is expected to be prolonged. However, this refers only to large customers. DR will be an important part of the new Balancing Market and consumers will be able to adjust their electricity through their aggregators. Until the end of April 2017 and for a period of 1 year there was a flexibility mechanism (Transitional Flexibility Remuneration Mechanism - TFRM), which helped to remunerate generating units (gas and hydro plants) for the services they provided (mainly referring to ramping), in the view of the absence of a balancing market. The goal of this remuneration was to respond to the flexibility needs of the power system, avoid generation units mothballing and reward them for providing this necessary service. The Greek Regulator has recently done a Public Consultation on a new transitory flexibility mechanism, until Target Model is fully implemented.

3.2 ACTORS

In this section, we briefly describe the actors involved and their roles in each DR strategy.

3.2.1 TSOs

According to [26], [27], TSOs are responsible for a stable power system operation (including the organization of physical balance) through a transmission grid in a geographical area. The System Operator will also determine and be responsible for cross border capacity and exchanges. If necessary, he may reduce allocated capacity to ensure operational stability.

Traditionally, TSOs played the role of system operators and were responsible for system stability.

Under the Third Energy Package Directives 2009/72/EC and 2009/73/EC1, system operators (i.e., TSOs and DSOs) are subject to unbundling requirements, precluding generation and supply, due to their natural monopoly status. Instead, they should focus on transmission and/or distribution, operational security, maintaining system balance and offering other AS.

3.2.2 DSOs

According to CEER 2015, a DSO is an entity responsible for the distribution network planning and development; the safe and secure operation and management of the distribution system; for data management associated with the use of the distribution system; for procurement of flexibility services.

In general, their roles vary in different countries/markets.

The increased number of connected Distributed Generators (DG), RES, Electric Vehicle Supply Equipment (EVSE) to DSOs, has created the need for local balancing by the DSO –not to be confused with frequency balancing by the TSO. DSOs are responsible for procuring flexibility services from aggregators (see below).

DSOs are subject to unbundling requirements, similar to TSOs, and can engage in non-regulated and/or market-related activities only under specific circumstances. Instead, they should normally act as market facilitators [27], [28].

- Data ownership and openness requirements (Data Provider actor and their facilitation);
- Ownership of meters.

3.2.3 Suppliers (Retailers)

The traditional role of retailers / load representatives has been the supply of energy and invoicing to consumers. With the advent of DR programs, they can also play the role of aggregators of flexibility, which is then sold to DSOs and TSOs.

3.2.4 Prosumers

A consumption-side entity, which is producing power in addition to consuming. These can be large or medium-sized commercial or industrial customers, but more recently, also small & medium enterprises, community and residential users.

A prosumer is an active participant in balancing the grid through the use of DG technologies, energy storage units, and smart meter equipment: the locally produced and/or stored energy can feed local consumption, if the need to offload the grid arises in response to DR signals. Similarly, excess power produced or stored can be fed into the grid, whenever the prosumer finds it profitable to do so. This can be realized through an aggregating party (see below).

3.2.5 Aggregators

The aggregators are entities, which accumulate flexibility from prosumers and sell it to supplier, the DSO or the TSO; therefore they serves as BSPs from the supply side. Aggregators accumulate the flexibility of many residential and SME consumers to curtail, interrupt, or shift their load on short notice in the event of DR. This aggregated flexibility is then treated as a single resource and is sold to suppliers, the DSO or TSO.

Aggregators perform the following functions:

- Consumption and flexibility forecasting;
- Market and consumer portfolio management;
- Settlement and billing;
- Operational optimization and
- Short-term market price forecasting.

Somethimes the role of aggregator is taken by entities that also supply electricity in the retail market, predominantly for implicit DR campaigns. In this case, aggregation services should be unbundled from energy provision. Aggregators managing explicit-DR campaigns are usually independent entities.

The aggregate flexibility offered by aggregators is profoundly based on smart meter equipment, which monitor consumer loads in real time.

3.2.6 Other actors

- The *Market Operator*, as defined in [28], is a centralized institution being responsible for operation of an organized market for the (commercial) exchange of energy or other products on behalf of market participants. Its functions are:
    - Implementation of market rules;
    - Registration of market participants;
    - Receiving bids/offers from market participants;
    - Market clearing and
    - Delivery, settlement and invoicing.
- *BRPs* [29]: their role is described in ENTSO-E Supporting Document for the Network Code on Electricity Balancing of 23 December 2013 [26] and involves the responsibility of market players to balance the system. As described in ENTSO-E, the BRPs are financially responsible for keeping their own Position (sum of their injections, withdrawals and trades) balanced over a given timeframe – the Imbalance Settlement Period. The remaining short and long energy Positions in real-time are described as the BRPs' negative and positive Imbalances respectively. Depending on the state of the system, an Imbalance charge is imposed per Imbalance Settlement Period on the BRPs that are not in balance, as explained also in Section 3.1.5.1. This defines the Imbalance Settlement, which is a core element

of Balancing Markets. It typically aims at recovering the costs of Balancing the system and may include incentives for the market to reduce Imbalances – e.g. with references to the wholesale market design – while transferring the financial risk of Imbalances to BRPs.

- *EVSE Operators*: the entity responsible for managing and operating the electronic vehicle charging infrastructure.
- *Energy Service Companies (ESCOs)* provide energy services (e.g. RES-E installation, energy cost management, heating/ lighting management) instead of energy itself. ESCOs are most commonly involved in development projects lasting for 5 to 10 years, where they often design, develop, manage and finance the energy-related aspects of the project. Since they focus on end-user service goals, i.e., heating, lighting capability, it is in their interest to offer increased levels of energy efficiency. The three main features which identify the function of an ESCO, according to [30] is:
    - *Performance guarantee:* assurance of energy savings and/or same level of energy service at lower cost.
    - *Remuneration*: part of ESCO remuneration depends on energy savings provided to customer.
    - *Finance services*: an ESCO can finance or assist in arranging financing for the proposed services, thus sharing risks with costumers.

3.3 CONSUMER CLASSIFICATION

A characterization of consumers is necessary for performing:

- *DR program selection*, i.e., the appropriate selection of DR programs by the aggregator in order to increase consumer participation in these programs, and
- *Consumer selection in DR events* of whose loads are to be curtailed, interrupted or shifted. The latter applies to incentive-based programs only.

Each of them is discussed separately in the following paragraphs.

3.3.1 DR program selection

A key issue for the success of any DR strategy is the active engagement of consumers. In incentive-based programs, adequate remunerations should be offered by aggregators, otherwise customers will not find it worthwhile to participate. In addition to financial compensation, consumers consider a wide range of additional criteria, such as price and volume risk, prosocial behavior, and also have different flexibility characteristics as they employ diverse set of load mixes. Thus, it is important to consider the different types of consumers.

[31] employs a two-dimensional categorization based on A) consumer load mix, and B) consumer preferences. As regards to (A), the following categories and subcategories are proposed:

1. Storable load (e.g. storage unit, EV, heating)
2. Non-storable load
    a. Shiftable load (e.g. laundry, dish-washer)
    b. Non-shiftable load
        i. Curtailable load (e.g. lighting, TV, stove)
        ii. Non-curtailable load
            1. Base load (e.g. TV, automation, alarm system)

In the case of prosumers, the above categories refer to net load. Notice that flexibility increases as one moves upwards this list.

Certain load mixes, e.g., curtailable load, can response fast to DR signals and so are more appropriate for programs requiring fast response such as Real-Time and Critical-Peak-time pricing.

As regards to (B) consumer preferences, [31] notes the fact that different customers will react differently to shifting their loads and the financial compensation, e.g., due to their socio-economic status, pro-social motivation, program complexity, price and volume risk. Socio-economic factors affecting energy consumption are also discussed in [29], [32]. A fact that points to the intricacy of consumer preferences, is the observation that economic considerations are by no means the most important in DR program selection. Contrary to naive economic intuition, the complex Real-Time-Pricing programs have been noticed to place a high information burden on consumers leading to high abandonment rates. As noted in [33] in opt-out dynamic-pricing schemes of Rocky Mountain Power in US, up to 98% of consumers chose to leave the program after the mandatory period had been completed. This is also corroborated with research on consumer price elasticity price (see [34] and references therein) which shows that the residential and SME users have low participation even when retail price varies significantly through ToU tariffs. Thus, DR programs need to account for such factors in addition to the type of load. As shown in Figure 13, different DR programs are more appropriate to certain type of consumer preferences.

Contract	Price risk	Volume risk	Complexity	Autonomy/ Privacy loss	Financial compensation
Time of use pricing	Limited	None	Limited	None	Limited
Dynamic pricing	High	None	High	None	High potential
Fixed load capping	None	Limited	High	Limited	Limited
Dynamic load capping	None	High	High	Limited	High potential
Direct load control	None	None	None	High	Limited/ High potential

Figure 13 – Relation of consumer preferences (column labels) to DR programs (row labels) [31].

[31] and [34] argue that aggregators should offer multiple contracts in order to match better the diverse range of consumer characteristics.

3.3.2 Consumer selection in DR events

On a DR event, specific amounts of power need to be curtailed, interrupted or shifted; the precise response depends on the DR program details. The amount of DR as well as its relative characteristics are selected by the DSO, in coordination with the aggregators in that market area. An aggregator, when forming his bid, chooses which consumer loads to bundle together, based on the energy decrease each user is projected to make, and economic considerations such as size of financial compensations in the event of DR.
This decision can be made in an efficient manner, if sufficiently fine-grained information on consumer behavior is available. This is possible through AMI installations to residential customers which allow the collection of vast consumer data.
In the literature, two different definitions of efficiency have been employed:

- *Minimization of financial compensation*: the aggregator minimizes the compensation to be offered to consumers in a DR event. As consumers are here considered to curtail their loads, this case is suited to DLC. In [35] the Authors have formulated an optimization problem of this type, where they select of the subset of users –out of a given set-, for which the total decrease in utility (due to load curtailment) is the minimum possible. This is justified, by the observation that a competitive aggregator will compensate a consumer according to the latter's decrease in utility for foregoing consumption. Subsequently, this problem is solved by sorting users in the order of increasing utility loss, such that the least affected consumers are first selected. In [33] they have considered a similar model, but where the aggregator coincides with the supplier. Thus, the supplier selects the consumers to curtail such that his costs are minimized. The model, also incorporates shiftable loads and uncertainty. They demonstrate that through their algorithm only a small number of consumers is affected.

- *Volume risk minimizat*ion: the aggregator minimizes the probability the promised load volume will not be curtailed during DR, due to consumers not dropping their demand to the agreed levels. In contrast to the minimization of financial compensation, this case is more suited to consumer loads not controlled by the DSO. In [36] they formulate a problem of this type, where they select the subset of consumers –out of a given set-, which minimizes the probability that the aggregate dropped demand by the participating consumers exceeds a target. A key feature of this approach is that for each consumer a detailed profile is maintained regarding his adherence to shedding demand as agreed. This is possible through historical data gathered for each consumer using Smart Meters. The optimization is scalable for a large number of consumers. In [37] they consider a similar problem, where using machine learning algorithms, they build models for the capability of load reduction for each individual consumer, based on usage, load curtailment, and temperature historical data. By analyzing real data, they observe that users with more variable consumption patterns are more likely to reduce their consumption compared to users with a more regular consumption behavior.

3.4 COMMUNICATION TECHNOLOGIES

Recent developments in smart DR schemes are supported and enabled by the implementation of the smart grid as an automated way to deliver electricity and control the system, where different devices located along the power system can interact with each other. By means of these interactions and the involved devices different actions are possible, e.g. to check status, to connect, to disconnect, to turn on, to turn off and to read data [38]. In this context, communication technologies are relevant for managing information among the different actors involved.

The use of innovative communication technologies is enabling the involvement of energy users in DR programs providing, thus, additional support to TSOs and DSOs.

DR programs have been around for decades, in particular in the US, where they have proven to be an effective means for utilities to manage system peaks by controlling customer loads.

For residential consumers, these programs traditionally were characterized by the DLC of large appliances at the user premises, such as air conditioning systems, hot water heaters, and pool pumps, as described in Section 3.1. These were mostly one-way systems based on signals sent in different ways for instance via power line communications, energy management system (EMS), or telephone to the controlling devices to temporarily turn off or cycle the desired appliance during peak conditions.

This approach proved to be an effective demand control solution and continues to work well today, but with the support of new technologies, new functionalities and ways for implementing DR mechanisms are coming to light.

For instance, AMI systems provide significant foundational platforms for engaging consumer response to extraordinary DR events. By supplementing this technology with Internet usage, utilities can enable energy consumers to actively manage system capacity.

AMI implementations are becoming one of the main ways to engage the consumer.

Thus, enabling technologies for DR include:

- Smart meters with two-way communications capability, which allow customer utility bills to reflect their actual usage pattern and provide customers with continuous access to their energy use data.
- Multiple, user-friendly, communication pathways to notify customers of real-time pricing conditions, potential generation shortages, as well as emergency load curtailment events, etc.
- Energy information tools that enable real-time or near-real-time access to interval load data, analyze load performance relative to baseline usage, and provide diagnostics to facility operators on potential loads to target for curtailment.
- Demand management strategies that are optimized to meet differing high-price or electric system emergency scenarios.
- Load controllers and building energy management control systems (EMCS) that are optimized for DR, and facilitate automation of load control strategies at the end-use level.
- On-site generation equipment used either for emergency backup or to meet primary power needs of a facility.

The main tiers for providing advanced DR services are: Home Area Network (HAN), the AMI, Concentration Point and Utility Data Center. They are described briefly below:

3.4.1 Home Area Network (HAN)

A HAN connects in-home digital devices, such as PCs, mobile phones, entertainment devices, thermostats, home security systems and smart appliances, into a common network. In the context of energy utilities, HAN is a means for utility companies and Energy operators to extend their reach beyond the meter, and to incorporate the "smart thermostat," DLC appliances, smart appliances and in-home energy display into utility systems, as well as to enable DR and energy efficiency programs.

HAN is the backbone of the communication between smart meter and home appliances.

In a home area network, multiple components interact to provide a wide range of capabilities. The basic components of a home area network are:

- The network portal or gateway that connects one or more outside information services to the home area network;
- The access point or network infrastructure that form the wired or wireless network itself;
- The network operating system and network management software; and
- The end points such as thermostats, meters, load control switches, display devices, and intelligent end-use devices equipped with embedded features allowing for two-way communications and automated control.

The amount of data transfer at a given point will likely consist only of a number representing the *n* instantaneous electricity use of each device, expressed in Watts. Hence, the bandwidth requirement usually falls between 10 kbps – 100 kbps per device. The required bandwidth could grow exponentially for large office buildings, so the chosen networking technology must scale. Low-power, short-distance and cost effective technologies are well-suited for on-premises communications [e.g.: 2.4 GHz Wi-Fi, 802.11 wireless networking protocol, ZigBee (based on wireless IEEE 802.15.4 standard), IEEE 802.15.4G wireless Smart Utility Networks (SUN) and HomePlug (a form of power line networking that carries data over the existing electrical wiring)]. Internet protocol (IP) based uniform standardization is widely shouted for communications on the premise.

A fully deployed HAN can include DLC devices connected directly to large appliances for actuation purposes, programmable communicating thermostats to manage the heating and cooling system, in-home displays and displaying through different devices to provide near or real-time energy usage information. These latter can also inform the consumer of different critical grid events or provide signals that are part of a utility's DR program.

3.4.2 Smart Meter and AMI

According to [39], the so-called smart meter is an electronic device that enables two-way communication between utilities and consumers. Such meter provides reliable measurements of electricity production and consumption in short intervals, and remote transmission of data to a system operator. Remote reading and data transmission enable more accurate information to consumers about their consumption and associated costs and the possibility to build and provide innovative functionalities and information in order to actively involve end customers.

Specifically, the goal of an AMI system/infrastructure is to provide real-time data about power consumption to the utility companies and allow customers to take choices about energy usage based on the price at the time of use. For this reason AMI is considered as a very important part of any smart grid initiative. These new meters allow further development of novel services in the energy market and they are at the basis of the provision of advanced DR programs.

Many utilities in particular in the US where DR programs are more diffused, base their system for deploying DR functionality, on connectivity into the home via the smart meter. In this direction, since the last decade, AMI vendors are following initiatives such as the ZigBee® Alliance in order to prepare their systems to support this functionality through industry. For instance, the ZigBee Alliance promotes the integration of low-power wireless sensor and control network technology into the meter to act as a communicating gateway to devices in the home. These devices are used to both inform the consumer of ongoing energy usage and to control the significant discretionary loads available in the home. These smart meters and two-way AMI networks then enable the measurement and verification capabilities that allow the utility to verify which controlling devices participated in a DR event and how much load was removed [40].

3.4.3 Concentration Point

The concentration point represents another part of the smart grid, which has to collect information from a home network inside a smart grid. A concentration point can be, for instance, a substation, a transformer, or a communications tower. It enables the bi-directional transmission of data and information. Usually, the volume of the communicated data from concentration point to a home device will be less compared to that one's gathered from consumer side and sent to the utility. Different technologies can be considered and their adoption depends on considerations related to costs and efficiency in specific context.

According to [38], initial solution installations relied on Power Line Carrier (PLC) but real time data and intensive AMI requires bandwidth up to 100 kbps per device. In a "wireless mesh network", connectivity between meters and collection endpoints is achieved by means of a dedicated network using unlicensed radio spectrum managed by the utility or a subcontractor. Other possible choices for assuring a more bandwidth supportive broadband communications are the IEEE 802.16e, mobile WiMAX, broadband PLC, and next-generation cellular technologies and satellite technologies.

3.4.4 Utility Data Center

Usually the information from concentration points to the utility companies flows along private networks. In this context, it is possible to identify a variety of technologies such as: fiber optic cable, T1 cable, microwave networks or star networks to conduit data from the hub to the utility. Specific smart grid applications that support two-way communication require a bandwidth range of at least 500 kbps to dispatch data from a concentration point to a utility. Currently many AMI networks support, according to [38], intermittent connectivity to the utility because data are aggregated at a neighborhood node and are sent to the utility only periodically. Consequently, more bandwidth may be needed to support more functionalities or more real time connectivity.

In conclusion, in Table 2 the main communication protocol used for each of the tier described above are shown:

Table 2 – Main communication protocol used for each of the DR tier categories.

DR tier	Communication Protocol
Home Area Network (HAN)	ZigBee, Z-Wave, Wi-Fi, HomePlug, IP, THREAD
Smart Meter and Advanced metering infrastructure (AMI)	ZigBee, IEC 62056, Open Smart Grid Protocol (OSGP), TCP/IP
Concentration Point	Broadband network e.g.: WiMAX, UMTS-TDD, LTE, PLC
Utility Data Center	Private network

In the next part, a brief description is available for some of the mostly used protocols mentioned above.

3.4.4.1 ZigBee

ZigBee represents a set of high-level communication protocols using low power digital antennas and is based on the IEEE 802.15.4 standard for WPAN (wireless personal area network).

ZigBee devices are ideal for a home computing network and are used for intelligent home security systems, automatic household appliances, wireless smoke and carbon monoxide detectors and environmental control. The ZigBee standard allows transmission at distances of up to 100 meters, depending on how much energy is available and whether any physical blockage of the signal is present. It data transmission rates can arrived at 250 Kbits per second.

3.4.4.2 Z-Wave

Z-Wave is one of the most widely used wireless standards currently used for home automation. It is a wireless protocol designed specifically for home automation, whose field of use includes automation in residential, commercial, receptive and care environments and whose applications range from home automation to remote surveillance and telemedicine, to continue with home entertainment, access control, efficiency and energy saving systems. The Z-wave standard is slower respect to the ZigBee considering that its data transmission rates are of up to 100 kilobits per second.

3.4.4.3 Wi-Fi

Wi-Fi is a technology that, through the connected devices, allows user terminals to connect to each other via a local area network in certain wireless modes (WLAN) based on the specifications of the IEEE 802.11 standard. In turn, the local area network can be connected to the Internet network via a router and take advantage of all the connectivity services offered by an Internet Service Provider (ISP). Any device or terminal (computer, mobile phone, handheld, tablet, etc.) can connect to networks of this type if integrated with the technical specifications of the Wi-Fi protocol.

3.4.4.4 HomePlug

The HomePlug is a set of standards on powerline networks that allow to create telecommunications networks through the power network cables. HomePlug 1.0 and HomePlug AV are the two versions of the standard for home networks. The HomePlug Powerline Alliance [41] has defined the following standards:

- HomePlug 1.0 - Specifications for connecting devices through the home electrical network. Theoretical maximum speed of 14 Mbit/s.
- HomePlug AV - Designed to transmit HDTV and VoIP signals over the home electrical network. Theoretical maximum speed of 200 Mbit/s.
- HomePlug Command & Control - Specifications for the transmission of data over the power grid for devices with very low bandwidth requirements, such as lighting or air conditioning control.

3.4.4.5 THREAD

THREAD is an IPv6-based mesh networking protocol designed as a secure, reliable, scalable and low-power, networking solution for connecting Things to the Internet of Things. THREAD has been developed by industry leading technology companies for connecting products around the home and in buildings to each other, to the Internet and to the cloud. It is a concurrent protocol of the ZigBee and Z-wave. THREAD uses the IEEE-compliant 802.15.4 compliant radio platform as ZigBee Pro but, unlike the latter, provides native IP address-ability. More details are available in the dedicated web site [42].

3.4.4.6 IEC 62056

IEC 62056 is a set of standards for Electricity metering data exchange. It is managed by the International Electrotechnical Commission. They are the International Standard versions of the DLMS/COSEM specification. IEC 61107, currently IEC 62056-21 [43], was an international standard for a computer protocol to read utility meters. It is designed to operate over any media, including the Internet. The protocol is usually half-duplex. The following exchange usually takes a second or two, and occurs when requested usually manually from the utility. IEC 62056-42 [44] is about physical layer services and procedures for connection-oriented asynchronous data exchange. The IEC 62056-53 cover the COSEM application layer [45], while the IEC 62056-47 is about COSEM transport layers for IPv4 networks [46].

3.4.4.7 Open Smart Grid Protocol (OSGP)

The OSGP [47] are a set of specifications published by the European Telecommunications. It is one of the most widely used smart meter and smart grid device networking standards. OSGP is optimized for providing reliable and efficient delivery of command and control information for smart meters, solar panels direct load control modules, gateways, and other smart grid devices.

3.4.4.8 TCP/IP

TCP/IP [48] is for "Transmission Control Protocol/Internet Protocol". It indicates a set of network protocols on which the logical functioning of the Internet network is based. IP is the InterNetworking protocol of the DOD/DARPA model (according to the OSI model it is classified in the network layer). It handles nodes addressing and routing. Each node is assigned an IP address that will unambiguously identify it on the network. The routing capabilities, on the other hand, allow selecting the best route to convey a message to a given recipient node, known to be its IP address. Currently two main version are used the IPv4 and IPv6.

3.5 EUROPEAN AND INTERNATIONAL PROJECTS

This section provides a literature review of what has already been proposed/done both in European projects and globally in the field of DR and relevant technologies.

3.5.1 European projects & Initiatives

- SmartNet [49]

SmartNet includes Smart TSO-DSO interaction schemes, market architectures and ICT Solutions for the integration of AS from distributed energy resources.

It aims at providing architectures for optimized interaction between TSOs and DSOs in managing the exchange of information for monitoring and for the acquisition of AS (reserve and balancing, voltage regulation, congestion management) both at national level and in a cross- border context. It considers the participation of DG, demand side and storage to system services.

SmartNet provides optimal solutions for analyzing the provision of AS involving actors located at the distribution level. Different TSO-DSO interaction architectures will be evaluated with their pros and cons, and costs will be analyzed thoroughly in order to develop a clear business model. SmartNet will provide a fully validated ICT application on a replica "lab" environment. This environment could be re-used after the end of the project by proposing fully customized products tailored to the different national markets.

The project involves 22 partners from 9 European countries, 3 national pilot projects in Italy, Denmark and Spain. It started in January 2016 with a duration of 3 years and a Budget of 12,65 M€.

- DeCAS [50]

DeCAS aims to investigate and analyze system services such as DR and coordination of individual Volt/VAr control concepts crossing traditional boundaries from high voltage (HV), medium voltage (MV) to LV, as well as the market integration. It will further include the integration of related monitoring and controls in process-control systems. The result will be an orchestration of the power system via hierarchical and integrated network control, taking into consideration the market integration of flexibility and stakeholder involvement focusing on consumers and networks operators.

The main objectives of the DeCAS project are:

- To research and analyze the coordination of AS such as, aggregated "prosumer" response control reserve, individual voltage control and reactive power management concepts over traditional boundaries from high voltage, medium voltage to low voltage.
- To develop approaches and concepts for a coordinated control considering the different objective functions of individual voltage levels. It will include the integration related to monitoring and controls in process control systems as well as to existing and future flexibility markets. LV grids are usually not automated yet and there are hardly any measurements available. Thus, the project will evaluate promising concepts for LV grid operation tools and processes, and how they can interface with MV/HV Supervisory Control and Data Acquisition (SCADA) Distribution Management System (DMS).

The project DeCAS is going to develop and investigate solutions for the coordinated activation of AS over traditional boundaries from HV, MV to LV considering the different objective functions of individual voltage levels. The project includes the integration of related monitoring and controls in process control systems as well as to flexibility markets. Through the field tests, it is possible to solve practical implementation issues e.g. due to the interconnection of installed and established products with new solutions from IoT world. Additionally, in course of the project existing grid codes are going to be analyzed and recommendations for a further development will be derived.

DeCAS is researching for solutions gaining flexibility from a large range of resources. A reasonable amount of possible flexibility is not owned by DSOs, but rather by prosumers or independent plant operators. DeCAS will analyze market-based solutions as part of network control to involve for instance prosumers, covering both generation and demand side management, in future flexibility markets.

Via demonstration activities and description of best practices the DeCAS project will reduce the barriers for engaging the prosumers in smart grid topics by investigating and evaluating how this unrealized potential of prosumers participation can be realized for the benefit of all stakeholders involved. Business models as well as future roles for prosumers and distribution network operators are important parts of this investigation.

- ERIGrid [51]

It aims at providing access to concentrated know-how and European research infrastructure to scientists and companies involved in the development of smart grid concepts and components.

A core activity in ERIGrid is the provision of a distributed and integrated research infrastructure, which is capable to support the validation and testing of smart grid configurations. Overall 19 installations provided by the consortium members are available for transnational access projects.

ERIGrid targets industrial and academic researchers active in the smart grid domain and provides them free transnational access (TA) to the integrated research infrastructure of the ERIGrid members. This access is funded by the project and is therefore offered free of charge to researchers planning to carry out research projects at a high level of excellence and innovation. The projects submitted by industrial and academic researchers will have to tackle challenging scientific and complex technical impacts. The consortium organizes two calls for proposals yearly.

- Leafs [52]

Leafs evaluates the effects of increased costumer and energy market driven utilization of energy storage systems and load flexibility on power distribution grids. Technologies and operation strategies are developed that enable optimal use of distribution grid infrastructure by activating flexibilities using direct or indirect control also by the local grid operator or even incentives. The consumer benefits from more flexible integration of distributed energy resources at minimum network reinforcement costs as well as achieving a higher self-consumption level for customers operating their own DG-unit.

The project Leafs proactively tackles the above-mentioned challenge by developing technologies and operation strategies that minimize network reinforcements required from the integration of RES and dynamics resulting from the market. Approaches in the project for activation and control of flexibility include both active control of home storage systems and flexible loads also by the grid operator (technical solution) and evaluation of monetary incentives and motivation (organizational solution). The end-costumer benefits in a long term from minimized network reinforcement costs and even higher self-consumption levels in case of operating their own DG-unit.

- morePV2grid [53]

The objective of the project morePV2grid is to develop and validate voltage control concepts with PV installations. The concepts allow numerous distributed PV systems to contribute to voltage control by autonomous adjustment of active and reactive power without any supervisory system and communication technology. Not only the performance of the concepts will be assessed, but the actual contribution and its potential impact on the energy production will also be considered. These concepts shall ultimately allow the cost-effective integration of many PV generators. Thus PV plants could change from “Troublemakers“ to ”Trouble-shooters“ and an increased penetration of DG would be possible.

- ISOLVES:PSSA-M [54]

It investigates technical conditions for the optimal integration of decentralized renewable energy plants in LV grids. Due to lack of accurate knowledge of the grid, high safety margins based on estimated peak demands in single line sections must be considered today. Therefore, the objective of the project ISOLVES:PSSA-M is to create real images of voltages in local networks. For this purpose, a method is developed to take an instantaneous image of the network, the so-called "Power Snap-Shot Analysis by Meters". Results from data analysis will contribute to model LV networks more precisely which leads to an essential improvement of network planning and network operation in distribution networks.

- HYBRID-VPP4DSO [55]

The HYBRID-VPP4DSO project combines network and market-driven approaches, in order to prepare electricity networks for future challenges caused by the energy transition. Identification of critical grid sections in the distribution grid, simulation of appropriate measure, experimental development of HYBRID-VPP algorithms, simulation of the distribution grid, tests in laboratory environment. The power generation from renewable sources must be better coordinated with the consumption of renewable electricity, for instance by activation and deactivation of loads and synchronization of demand & availability. The electricity system may be further optimized and stabilized. Development of new business and service models for hybrid virtual power grids will also offer benefits to the costumer.

- OpenNES [56]

Remote programmable device functions, an appropriate modeling method for distributed energy resources, and a generic and open communication infrastructure. One important result of the OpenNES project is the validation of the overall approach in the partner’s laboratory environments. With this proof-of-concept, an evaluation of the OpenNES approach can be performed, and the main benefits of this highly innovate approach can be shown.

The OpenNES demonstrator will make a flexible and adaptable automation system available that is able to fulfill future requirements of the Smart Grid.

- Parker Project [57]

The aim of the Parker project is to validate that series-produced EVs as part of an operational vehicle fleet can support the power grid by becoming a vertically integrated resource, providing seamless support to the power grid both locally and system-wide. They seek to ensure that barriers regarding market, technology and users are dealt with to pave the way for further commercialization and not least to provide an evaluation of specific EVs' capability to meet the needs of the grid.

Ultimately, Parker will contribute to ensuring the role of EVs as contributors to securing an economic and reliable power system based on a high share of renewable energy.

- EcoGrid EU

The key idea of EcoGrid EU is to introduce market-based mechanisms close to the operation phase that will release balancing capacity, particularly from flexible consumption. A real-time market concept will be developed to give small end-users of electricity and distributed RES new options (and potential economic benefits) for offering TSO's additional balancing and AS. To make the EcoGrid EU solutions more widely applicable, the market concept will be designed for existing power exchange(s).

EcoGrid EU is the winner of the prestigious EU Sustainable Energy Award 2016 (EUSEW16). The project received the prize for the most outstanding and innovative energy project in the category Consumers. Its successor is EcoGrid 2.0, still in development. The focus is different problem definitions for the future electricity system. The project is based on chosen partners and equipment from the original EcoGrid project.

- iPower [58]

iPower is a strategic platform where universities and industrial partners consolidates innovation and research activities for the purpose of developing intelligent control of decentralized power consumption. The iPower Platform develops and matures Smart Grid technologies for the electrical grid, industries and residential applications. The iPower platform links research, innovation and demonstration to actual product development by specifying technologies, requirements and methods for Smart Grid products. The society needs Smart Grid technology to ensure that the electrical grid can absorb all the energy generated by wind and solar renewables. It enables the industry partners to become first movers in a new and growing world market.

The iPower platform's full name is "Strategic Platform for Innovation and Research in Intelligent Power. iPower is organized into eight parallel work packages covering:

- Grid4EU [59]

Designed in response to a call for projects from the European Commission, GRID4EU is a Large-Scale Demonstration of Advanced Smart Grid Solutions with wide Replication and Scalability Potential for EUROPE. The project was led by six electricity DSOs from Germany, Sweden, Spain, Italy, Czech Republic and France, in close partnership with a set of major electricity retailers, manufacturers and research organizations. As a whole, the consortium gathers 27 partners.

- DR-BOB Project [60]

The "DR in blocks of buildings" project aims to demonstrate the economic and environmental benefits of DR in blocks of buildings for the actors required to bring it to market.

The key functionality of the DR-BOB DR energy management solution is based on the real-time optimisation of the local energy production, consumption and storage. The optimisation will be adjusted to either maximize economic profit or to minimize CO2 emissions according to user requirements.

The solution will be intelligent in the sense that it is automated and can adapt to fluctuations in the energy demand or production, subject to dynamic price tariffs and changing weather conditions.

The DR-BOB solution will be implemented by integrating the following tools and technologies to provide an innovative scalable cloud based central management system, supported by a local real-time energy management solution which communicates with individual building management systems and generation / storage solutions within a block-of-buildings.

The configuration of the DR-BOB energy management solution will allow energy management companies to provide varying levels of control from the centralized macro-view, through to localized complete control of the energy systems at the building level, the micro-view.

The solution will utilize existing standards such as IEC60870-5-104 and OpenADR, and an architecture that will enable new adaptors to be added to support new standards in the future. These standards allow access to most generation, storage and load assets. It is expected that any new interfaces between the platform and the ESCO could form the basis for new standards.

In combination, the DR-BOB solution will provide open connectivity to both SCADA/utility communications and customer side AMIs. The decentralized approach – allowing both supply side and DR to be hierarchically optimized between blocks of buildings and other infrastructures, with automatic distribution of results via building management systems – removes some of the burden and alleviates the complexities involved in individual customer or resident participation.

- SINTEG [61]

The funding program "Smart Energy Showcases - Digital Agenda for the Energy Transition" (SINTEG) aims to develop and demonstrate in large model regions exemplary solutions for a climate-friendly, secure and efficient energy supply with high proportions of intermittent power generation on the basis of wind and solar energy. The program focuses on smart grids, which should help to ensure stability and improve the interplay of power generation, consumption, storage and grids by means of modern information and communications technologies. The funding program thus addresses key challenges of the energy transition including the integration of renewables into the system, flexibility, security of supply, system stability, energy industry efficiency and the establishment of smart energy systems and market structures.

At least two large showcase regions are planned to be established in order to pool knowledge, experience and activities of different systems. A showcase might, for instance, use smart grids to connect centres where there is high population and industrial density - and thus high, flexible demand - with regions in which there are temporary surpluses of renewable energy. The solutions developed in the model regions should serve as a blueprint for broad use and implementation. The Federal Ministry for Economic Affairs and Energy will provide funding of up to 80 million euros for a period of four years.

The smart combination of power generation and consumption and the application of innovative grid technologies and operational concepts should help to achieve in particular the following objectives: guaranteeing secure and efficient grid operation with high shares of renewables, tapping efficiency and flexibility potentials (in terms of markets and grids), ensuring efficient and secure cooperation of all players in the smart energy system, making more efficient use of the existing grid structure and reducing the need for grid expansion at the level of distribution grids.

- ENQEIR506 - Residential Consumer DR

EIRGrid developed this competition in order to stimulate growth and innovation in residential consumer based DR.

- Enel Info+ [62]

Enel Info+ is a large-scale trial of the Enel Smart Info device that has been designed by Enel Distribution to allow end users to have certified information on electricity data managed by their electronic smart meter at their fingertips.

The Trial is part of the “Isernia Project”, a project financed by the AEEG (“Autorità per l’Energia Elettrica e il Gas”) that foresees the installation of a model of smart grid on the grid connected to the Primary substation of Carpinone (a little town in the Isernia district).

Enel Info+ will involve a representative sample of families served by the Carpinone primary sub- station in the area of Isernia, the potential universe of participants includes about 8000 LV households.

The consumers participating to the project thus receive an energy monitoring kit including Enel Smart Info and dedicated interfaces.

The Enel Info+ kit and the related monitoring solutions are modular and foresee three levels of analysis:

The first one is based on the use of Smart Info Display, a full color, touch screen in-house display, that lets the consumers keep an eye on their household energy consumption pattern easily. Smart Info Display provides both close to real time and historical information on energy consumption, which are shown in bar graphs and pie charts to highlight their mean value and how they split in tariff time bands for different periods of time (a single day, one week, one month, a bi-month, one year). The actual power and tariff time band are displayed, together with the date and time of tariff time band switching. Moreover, additional feedback contents are given such as alarms at pre-defined, modifiable thresholds and when the contractual power is exceeded, DSO’s announcements and contractual data.

The second monitoring solution is based on Smart Info Manager, a software application that allows the consumers to examine their consumption data in depth on their personal computers and the energy prosumers to compare production and consumption data.

The third monitoring solution is based on the smartphone App Smart Info Mobile that enables the consumers/prosumers remote access to their own energy data.

"Prosumers", consumers who are also producers of renewable energy (by PV or mini-wind plants), receive an additional Enel smart info in order to manage both production and consumption metering data.

Moreover, all participants receive a quarterly feedback report helping them to get awareness of their behavior, any changes they make and how their peers are behaving. The consumption patterns of the families living in municipalities included in the project have been observed by Enel Distribuzione since 2011.

The participants consumption is observed by Enel Distribuzione for the whole duration of the trial and compared with the pre-pilot ones as well as analyzed in relation to other factors (e.g. household size, number and type of appliances, etc..). Besides, a “control group” of consumers who do not take part to the trial are selected and monitored, to verify that the use of the Enel Info+ kit is actually responsible for any change in the load curves.

Additional information is gathered by means of interviews carried out among an appropriate representative sample of families participating to the trial and among the control group likewise.

- Smart Domo Grid [63]

Smart Domo Grid is a project integrating home appliances for enhanced energy efficiency and reduced cost of energy consumption. The project aims at integrating traditional’ electric grids, electronic meters, renewable energy in-house production system (PV energy), and smart appliances. In particular, energy consumption was measured and managed by the help of an application through Wi-Fi connection embodied in the new models of appliances (namely washing machine, dishwasher and the refrigerator) which is beneficial both for the energy providers and users.

The project has been carried out in collaboration with twenty Italian families. The in-field pilot test started in July 2014 in the city of Brescia. All the other smart grid components were provided by the companies involved. The energy management application helps monitoring energy consumption with providing insights on how to minimize the consumption. The Smart grid will enable users to actively save energy by scheduling the most convenient time slot for operations of the appliances via the insights of the application. In particular, the insight is exposed by the cost of energy in each time for users based on overloads and multi-tariff system (provided by the energy provider company according to the estimated production of the PV system). Therefore, the application is able to automatically identify the optimal point taking into account costs/benefits for users and leveraging consumptions for the energy provider. The final goal would be to avoid overloads of energy consumption leading to enhance the quality of the service offered.

The system will have obviously economic and environmental benefits both for users, energy and appliances providers. It will enable the energy providers to be able to manage overloads to avoid using inefficient resources of energy, enhance the energy quality, minimize energy dispersion where users exceed PV production, and avoid penalties and unneeded investments. It will enable appliance providers to understand how the market interacts with the possibilities offered by the new technology before the market launch. Moreover, the project has social benefits by stimulating users for more sustainable life style.

- FLEXICIENCY [64]

In the FLEXICIENCY project, , major DSOs having deployed smart metering infrastructure are working together with market players and other stakeholders on a technical model to concretize a vision for the provision of services based on meter data accessibility. Access to the data in an open way is addressed to foster the deployment of new services not in place or fully exploited in most of the EU countries, overcoming existing barriers. The development of an EU Market Place prototype, together with open interfaces providing access to data to any player, will catalyze the interactions between relevant stakeholders in a standard way and encourage a cross-country and cross-player access to innovative energy services at EU level.

The overall project architecture has been defined to be applicable to different regional and market contexts and four building blocks can be identified:

1. DSO Platforms: interoperable platforms for meter data accessibility in a non-discriminatory way, with customer consent, being enhanced in the project. Advanced capabilities are developed such as metering data provision at a given frequency and data processing and storage, facilitating service provision in the retail market.

2. Service platforms: platforms of different market players operating in diverse regional contexts, interested in having access to data, provided that they are accessible through open APIs and with interfaces compatible with the variety of Information Technology (IT) systems in use. Interested players can be e.g. energy retailers and ESCOs using data streams to design new retail business models, aggregators developing loads programs, or any other companies offering services.

3. Field components: devices for both measurement and control, acting as local interfaces and controllers at customer premises to deliver services.

4. EU Marketplace: a virtual ICT environment developed in the project, communicating with both the DSOs and Service platforms.

- Agder Energy/Demo Steinkjer/Smart Energy Hvaler

Pilot project targeting a grid substation ,which operates at 120 percent of its capacity a few hours each year.

- Smart Village Skarpnes [65]

The goal of the project "Electricity Use in the Smart Village Skarpnes" is to examine how the electrical distribution network can be designed and managed in an optimal way in the future, where new requirements in the building sector implies an increasing proportion of new "near- zero energy" houses. The introduction of low-energy housing with local energy production from PV systems are expected to provide changing consumption patterns. Although the total annual energy consumption is low, it is still unclear whether power consumption peaks will remain high.

The project will collect data from the Skarpnes housing development outside Arendal, where the developer Skanska has built 5 detached zero houses which have equipped with sensors for detailed measurement of how energy and power consumption is distributed across various loads in the residence, as well as measurement of indoor climate and weather data. The houses have solar panels (PV) on the roof and are equipped with sensors for solar radiation and PV temperature in order to analyze the performance of the solar installations.

The project collaborates with Scanmatic for the design and installation of the technical measurement equipment, and with Sintef through the projects ZEB (Research Centre on Zero Emission Buildings) and EBLE-Low Energy Programme (evaluation of housing with low power requirement). Data from the buildings will be collected over a timescale of 2 years to reflect the variation in consumption as a function of season.

Based on the collected data, this project will examine how the electricity production from the PV system coincides with power variations in the consumption profiles of the households, and how this affects the grid. If the resulting power peaks are equal to or larger in the zero energy houses at Skarpnes than in traditional homes, we want to identify what kind of equipment is causing this and how it may be controlled to reduce peaks in power demand.

The University of Agder and Teknova have in collaboration with Agder Energi Nett developed procedures for pattern recognition to identify power peaks in consumption profiles for electricity customers. The work has been published and presented at a Norwegian informatics conference and an international conference on artificial intelligence. A web-based visual data tool for automatic identification of consumption peaks has also been developed. The University of Agder has presented a poster on a German workshop for integration of solar power. Here the Skarpnes project was used as a basis for an assessment of the technical and economic aspects of grid-connected PV systems with different options for battery capacity.

Agder Energi Nett has worked with the specifications for the equipment and procedures for voltage quality and power variation measurements with high temporal resolution at Skarpnes. The equipment is now in place in the residences and in the local grid substation. Of particular interest are results that show the coincidence factor for the aggregated power consumption in the village, and how the residential area affects the substation during different time periods of the day and year. The project is of great value to Agder Energi Nett, who will use the results to evaluate the impact of new zero-energy homes with regard to future planning and efficient operation of the grid.

A database consisting of measurements from Skarpnes has been established during 2015. After quality assurance, the data series will be analyzed to build a foundation for the anticipated power variations in electricity consumption and the production from the PV rooftop systems. The growing database will contribute to a better fit between the model and the actual consumption patterns of the zero energy homes at Skarpnes.

The data collected from the Skarpnes residential area is unique. This is the first zero-energy housing development in the Nordic countries. The houses are equipped with instrumentation that detects real consumption data distributed across different electrical circuits and simultaneous production data from the PV system, with high time resolution allowing for the detection of rapid variations. This kind of data is not available from other known sources in Norway. All houses are of the same type, the same living space and are located within the same geographical area. This makes it easier to compare the residences and identify trends. The houses have different orientations in azimuth angle (East-West), which will result in somewhat different PV production and thus better insight in coincidence factor variations between PV production and consumption for otherwise identical conditions.

The high resolution Elspec data shows transients with very high current and rapid changes in power quality parameters. AMS is unlikely to register these short duration events.

- NEDO [66]

In collaboration with the Portuguese government, and with the participation of public buildings and households in Lisbon, the project will demonstrate an automated DR system, which can adjust electricity demand and supply without reducing customer comfort. The system will also be able to provide automatic operation management of air-conditioning equipment in response to the needs of individual customers.

Manual DR operation with the cooperation of utility customers involves an uncertainty of power adjustment. The project will increase certainty through automatic DR operation and also address the growing need for electricity demand and supply stability with the large-scale deployment of renewable energies.

The project also aims to establish a system to achieve economic efficiency by shifting electricity demand from periods of higher power costs to periods of lower power costs.

NEDO selected three companies, NTT DATA Corporation, Daikin Industries, Ltd., and the Japan Research Institute, Limited, to carry out a feasibility study to realize the demonstration project. They will carry out the feasibility study until January 2016, aiming to launch the demonstration project in FY2016.

- DOMINOES [67]

The DOMINOES project aims to enable the discovery and development of new DR, aggregation, grid management and peer-to-peer trading services by designing, developing and validating a transparent and scalable local energy market solution. The project will show how DSOs can dynamically and actively manage grid balance in the emerging future where microgrids, ultra-DG and energy independent communities will be prevalent.

The project will establish solutions for this challenge by addressing the following steps:

1. Design and develop a local energy market architecture;
2. Develop and demonstrate ICT components enabling the local market concept;
3. Develop and demonstrate balancing and DR services supporting the local markets;
4. Design and validate local market enabled business models;
5. Analyze and develop solutions for secure data handling related to local market enabled transactions.

The project will deliver:

1. New business models for DR and virtual power plant (VPP) operations;
2. Tools and technology validation for DR services;
3. Services based on smart metering;
4. Methods to utilize VPPs and microgrids as active balancing assets;
5. Secure data handling procedures in local markets.

These results will be validated in three validation sites in Portugal and Finland. A DSO environment in Évora (Portugal), a VPP site distributed across bank branches in Portugal and a microgrid site in Lappeenranta (Finland).

VPS will be the technology partner contributing with its expertise in the development of platforms for operating VPPs and microgrids, platforms for managing and forecasting DR resources mobile end-customer solutions for participation in DR and VPPs and ensuring secure customer transactions.

- inovgrid [68]

EDP Distribuição coordinates the Project InovGrid which entails a large-scale smart grid demonstration project in Évora (Portugal) and demonstrates Smart Grid concept by means of integrated management tools that:

- Improve service quality
- Promote distribution network remote management Reduce operating costs
- Promote a more active role for customers/producers Support new commercial services
- Increase energy efficiency
- Exploit the potential of DG;
- Enable the integration of EVs charging network
- Promote the environmental sustainability through the increase in energy efficiency Foster the proliferation of micro-generation
- Support the renewal of technologies and the improved exploitation of current capabilities.

Being a distinctive project in the European landscape, the InovGrid project was chosen by the Joint Research Center of the European Commission to be the support of the development of its “Guidelines for Conducting a Cost-Benefit Analysis of Smart Grid Projects” [Report EUR 25246 EN], a comprehensive assessment framework of smart grid projects centered on a cost- benefit analysis.

InovGrid is currently in a deployment stage, with more than 150 thousand customers in Portugal and sharing its main findings and benefits with Spain and Brazil, as well as in several European projects. The main goal is to reach at least 80% of the consumers in the Iberian Peninsula by 2020, in line with the European internal market of electricity Directive.

- Smart City Project Malaga [69]

The Smart City Malaga Project was launched by Endesa and covers 4 square km in the area of the Playa de la Misericordia and includes 11,000 domestic customers and 1,200 industrial and service customers.

The Smart City Malaga Project works on "Smart Grids". It was the first real smart grid pilot project aiming at searching the optimal integration of different renewable energies into the power grid while bringing the generation closer to the consumers. This is done through the establishment of a new energy resource management distribution for electrical microgeneration, as well as incorporating the end users as an essential element of the intelligent management system. Storage systems managed in batteries help the incorporation of the renewable energy.

It involves many interesting subjects, for example the use of new smart meters in the context of the remote management system enables a much more sustainable electricity consumption, as well as the installation of advanced telecommunications systems and remote controls.

The team, led by ENDESA, is formed by such important industry leaders as Enel, Acciona, IBM, Sadiel, Ormazábal, Neo Metrics, Isotrol, Telvent, Ingeteam and Greenpower. National and International Universities and Research Centers have also supported this project. We visited the experimental center of other international projects, such as the Green e-Motion or Zem2All e-mobility project.

3.5.2 International projects

3.5.2.1 Japan

- Energy Pool and TEPCO [70]

Energy Pool delivers to TEPCO a wide range of services and tools (including Energy Pool's DRMS (DR Management System) platform) to identify, contract and enable DR participation for thousands of TEPCO's clients. As of April 2017, Energy Pool will manage DR operations (load reduction/stimulation) from its NOC (Network Operations Centre) based in Tokyo.

Energy Pool started its DR activity in Japan in 2013, building a demonstrator for electricity modulation under the tender program *Next Generation Energy and Social System Demonstration Projects led by the government (METI).* Since then, Energy Pool managed several DR events enabling both the government and TEPCO to measure DR benefits for the Japanese electricity system.

The two partners designed DR programs meeting TEPCO and TEPCO customer needs from capacity programs dispatchable within 2 hours to fast response programs with response time below 30 minutes.

First DR programs were deployed across 50 industrial customers, monitored in real-time from Energy Pool Operating Center in Tokyo. This latter is equipped with Energy Pool world class IoT platform Distributed Energy Resources Management System (DERMS) and can activate flexible load in case of grid emergency or at times of high electricity demand.

This is the largest deployment of advanced DR technology in Japan, bringing Energy Pool and TEPCO Energy Partner at the forefront of innovation in demand management. The alliance was recognized as the Best Demand Side Management & Energy Efficiency project at Asian Utility Week in Bangkok on May 24th. "We are very proud of this Award, be a symbol for the rise of demand side management technology in Japan as well as a brand-new energy bond between France and Japan" said Takeshi ICHIMURA, Energy Pool Japan KK CEO.

Energy Pool and TEPCO Energy Partner will accelerate this deployment to reach 500 MW by 2020 and 1.5 GW in the future. The alliance is focusing not only on demand curtailment but also on demand stimulation, to allow demand-side resources to join the upcoming new market mechanisms that will likely be in place by 2020.

3.5.2.2 China

- Shanghai Project [71]

Apart from the four DSM pilot cities, a pilot program launches in Shanghai in the summer of 2014 is studying a new market mechanism for DR.

The kick-off meeting was held in Beijing in May 2014. Participants were from the NDRC price department, the Ministry of Housing, the Shanghai Municipal Commission, the SGCC Marketing Department, the Shanghai Municipal Electric Power Company, the US Energy Foundation, the NARI Group Corporation and other relevant units. Overall goal was to explore a new step within DSM activities with focus on general feasibility, improvements for energy service operation management, the impact on grid security, promotion of sustainable energy development, possibilities of large scalability and gap reduction towards advanced international experiences. The pilot is led by a team of well-known experts with leading roles in the NARI Group Corporation, Shanghai Electric power, Shanghai Electrical Apparatus Research Institute, Honeywell Corporation, Shanghai Tongji University Energy Foundation, NRDC and other industrial players. The project is funded by the local Shanghai government and the Energy Foundation. Participants with load reduction potential are monitored and controlled with the "Changing DR Management Platform", aggregating more than 100 MW in total load capacity across 64 voluntary pilot users. This comprises 33 commercial and public buildings and 31 industrial enterprises from the steel, chemical and automotive sectors. The first test event started in July with only four buildings and was extended to 34 users by the end of August, covering 55 MW and monitoring responses under different test scenarios to reach the target load reduction. Researchers are analyzing the impact on load reduction, with either (financial) compensation or on voluntary basis, over different time scales: one day before, the same day, whiting four hours, within two hours or 30 minutes before. For load reductions provided during the summer peak, customers can receive RMB 2 /kWh (EUR 0.25/kWh) from the local Shanghai government and additionally (EUR 0.25/kWh) from the central government. This compensation is roughly four times the local retail electricity price.

The objective of the Shanghai project is to test technology capability coordinate and control existing electricity load management systems, collect customer feedback and investigate a market incentive mechanism as a fundament of a potential trading scheme and future policy.

3.5.2.3 South Africa [72]

- DRAPP

It is a program owned by Eskom. Is focused in small industrial consumption or commercial building. The potential of reduction of consumption is around 10 MW (for the whole system).

- DMP

It is also an Eskom project focused on large industrial consumption. The potential of this program is over 20 MW and less than 80 MW.

3.5.2.4 New Zealand

- Transpower [73]

Transpower ran a commercial DR program between July and December 2013, using its new DR Management System.

The program went a long way to meeting its objectives. There were 8 participants with 134 MW of DR registered at the commencement – which for context is more than the winter peak load of New Plymouth. Over the program, there were 20 DR events successfully called, with the largest DR call of 175 MW during testing for the HVDC Pole 3 project. Natural price points were found for the types of DR provided, and importantly – non-generation DR was priced competitively compared to DR through generation.

Through the testing it was shown that participant fatigue – the point at which participants cease responding to DR events either through lack of ability or willingness – was not apparent. Indeed, participants' feedback at the end showed an overall positive attitude towards the program and an expectation that they would participate in future DR programs.

There are some learnings that Transpower will be taking away to improve the DR Management System and broaden the resources available. For example, this program was over-represented with hot water load from two participants, meaning that events tended to be over-delivered. This also impacted on the 'snap back' effect (where post-event demand increases greater than anticipated, once load that has turned off is put back on the system again).

3.5.2.5 Australia

- ARENA-AEMO [74]

The Australian Renewable Energy Agency (ARENA) and the Australian Energy Market Operator (AEMO) today jointly announced 10 pilot projects have been awarded funding under the DR initiative to manage electricity supply during extreme peaks.

In total, the $35.7 million initiative will deliver 200 megawatts (MW) of capacity by 2020, with at least 143 MW to be available for this upcoming summer.

Over three years, the pilot projects will be trialed in Victoria, South Australia and New South Wales to free up temporary supply during extreme weather - such as prolonged summer heat waves - and unplanned outages.

On behalf of the Australian Government, ARENA has committed $28.6 million in total to fund set-up and operational costs for the projects, with $7.2 million to be matched by the NSW Government for NSW-based projects.

Successful funding recipients include energy retailers, a Victorian energy distributor, a DR aggregator, a Victorian smart thermostat developer and a South Australian metal foundry.

DR involves paying an incentive for energy users to reduce their power consumption, switch to backup generation or dispatch their energy storage for short periods when electricity reserves reach critically low levels.

3.5.2.6 United States of America

- OpenADR [75]

DR programs encourage customers to change their electricity use, by reducing their usage during peak periods or shifting usage to off peak periods. DR is used to mitigate grid management problems including generation constraints, transmission constraints and or to reduce costs in utility programs with variable prices. DR programs and tariffs are designed to improve the reliability of the electric grid and reduce the use of electricity during peak times in order to drive down total system costs. This study examines the automated response of small and medium commercial sites to DR events communicated via the Internet using Open Automated DR (OpenADR). OpenADR is an information exchange model that provides utility price, reliability, or other DR event signals to initiate pre- programmed customer demand management strategies. Essentially, OpenADR facilitates automated DR (AutoDR) through continuous, secure, standardized and open communication signals.

Pacific Gas and Electric Company (PG&E) offers AutoDR programs to its large commercial and industrial (C&I) customers. With the future roll out of default dynamic pricing tariffs for small and medium commercial customers, PG&E wanted to assess the applicability of the same infrastructure to this customer group. The tests reported in this paper aim to provide insights about the readiness of available technology to provide DR response capability for small and medium commercial buildings.

The goal of this DR emerging technology assessment was to determine how well small and medium commercial buildings could respond to OpenADR signals using available technologies that are able to receive and interpret these signals. Specifically, this study looked at the capability of existing technologies to automatically shed demand to determine the extent to which these technologies, as applied, provided significant DR from non-aggregated small to medium commercial sites. In general, the work reported here was intended to help equipment manufacturers modify or improve their products so that their products can be more appropriately responsive to the needs of this customer group.
OpenADR signals used in this project modeled the Peak Day Pricing (PDP) tariff that is planned to be the default for small and medium commercial buildings in November 2011. AutoDR test events were published by the DR automation server on warmer days during the summer of 2010. All events lasted four hours, except for one event that was called for six hours. Most DR events were called with a day-ahead notification in most cases, but some events in this study were called with notifications only on the day of the DR event to verify the ability of systems to respond in the case of grid emergencies.

4 ANALYSIS OF OTHER ENERGY CARRIERS

The goal of this task is to identify the high-level flexibility capabilities offered (i) by the application of novel power-to-heat (P2H) systems for water heating and space heating/cooling and (ii) by the conversion of electricity to synthetic natural gas.

4.1 ELECTRICAL P2H CONVERSION

Power network imbalance, due to the power mismatch between generation and consumption, causes a lot of problems to the energy market participants and the System Operators (i.e. TSO and DSO). Instantaneously matching electricity generation with consumer demand is a difficult task due to the highly fluctuating nature of renewable power generation sources such as wind, solar, etc. As a result, there is often a surplus in electricity generation, which, if not possible to be absorbed, has to be curtailed and numerous RES generators have to be disconnected from the grid. In addition, mismatch between generation and consumption leads to total/partial black-outs. This means, at least, loss of customer convenience as well as other important services. From a financial point of view, the aforementioned mismatch leads to extreme energy prices in the energy market, to the detriment of consumers when prices are very high or producers when they are very low or even negative.

P2H conversion can link the electricity and heat networks and thus provide an alternative solution for managing electricity oversupply as it provides flexibility to the energy market participants to balance an existing power mismatch. In principle, P2H technologies convert the surplus of energy produced at times of lower electricity demand to heat, which is either fed directly into the heating network in order to cover the current thermal demands of the customers or stored in a buffer tank for later use.

P2H systems are based on the following principles for converting into/producing thermal energy:

- Exploitation of the heat generation of the CHP systems;
- Exploitation of the surplus electricity generation of RES-E.

The coupling components in such multi-energy systems include CHP units, heat pumps, electric boilers and circulation pumps. CHP units are used to generate electricity and heat in one single process. Heat pumps and electric boilers are used for the conversion of electricity to heat, while circulation pumps use the excess electricity for the circulation of the heated water in the heating network. Electric boilers are a state of the art technology, very commonly used in district heating network applications [76].

4.1.1 Basic/Possible DR strategies

DR programs can potentially exploit the capabilities that P2H conversion systems provide in order to facilitate the integration of RES in a larger scale and increase the reliability and efficiency of the whole system. The P2H systems can be very useful in DR applications as they can convert excess electrical power into heat with very fast response (ramp up) and high precision. Especially in the distribution grid, where mainly small consumers are connected, DR programs can provide valuable services taking advantage of the fact that heat and cooling requirements are in high priority for this class of customers. In addition, DR programs can actively collaborate with CHP system operators for optimally managing the surplus of heat energy, which they unavoidably produce in many cases and they waste by chilling it in power absorption chillers/refrigerators. Power-to-heat solutions, especially when used in district heating networks, can thus increase system flexibility both in the short term and in the long-term perspective [77].Under this scope, DR programs could facilitate a lot of different schemes for providing valueable services to the grid operator as well as to the other participants. Such services areanalyzed in the following sections.

First of all, DR aggregators can provide services to the grid operator either by contracting bilateral agreements with energy market participants or by directly participating into the energy market. Thus, DR aggregators that are connected with both customers and heat-storage systems can absorb the surplus of the energy that RES provide to the grid by either shifting thermal loads (upon agreement with customers) or store energy to heat-storage systems. This would facilitate the system operator to both balance a certain mismatch between generation and consumption and smooth the price of the energy at the energy market due to this balancing action.

Another important point to which P2H solutions can contribute is grid support, as they can provide frequency and voltage stability for electrical networks. Flexibility further increases when the system is combined with emergency power generators that can be connected and disconnected according to the needs. Electric boilers can be versatile and cost-effective to provide negative secondary control power. In addition, by disabling the P2H system on request, positive control power may be offered during the bidding period [78].

Additionally, surplus of heat energy that is produced by CHP systems operators could be absorbed directly by DR aggregator upon bilateral agreements. In this case, the CHP systems increase their efficiency (otherwise they waste this part of their production) and the DR aggregators achieve higher profits than participating at the energy market.

Stored power can be provided to the customers in order to cover their requirements for heating or alternatively to be fed again to the CHP system or to the heating network.

4.1.1.1 Wasted energy of the CHP systems

Over the past twenty years there has been a new trend in power generation, which consists of the installation of combined cycle units, related to the existence of large quantities of natural gas for electrical energy, as it is relatively cheap fuel in gas turbines. It is also very common that where there is demand for power exist demand for thermal energy. A lot of industries need steam for processing goods and, of course, numerous residential customers need thermal energy for heating. It is shown that the combined cycle has the higher thermal efficiency than any other thermodynamic cycle. For this reason, it is increasingly used worldwide for production electricity [79].

The main idea for using combined cycle plants is to exploit the cogenerated energy by using the exhaust heat of one or more gas turbines in order to produce steam and then move another steam turbine [80]. As it is shown in Figure 14, the air is compressed at the beginning and mixed with the fuel in a combustion chamber of the gas turbine. The exhaust gases, after being thrown into a turbine, are driven to a heat exchanger, which makes heat recovery used for steam production that in turn drives a steam turbine [81].

However, the exploitation of the wasted steam of the plants is not always possible as demand does not always match production. One solution to this is thermal storage. In practice, thermal storage increases the flexibility of the plants and, as expected, their efficiency. Specifically, during low demand hours, stations are usually operated to a minimum load so there is the possibility of charging an array of thermal tanks with steam removal. When it is necessary, either for financial reasons or obliged by the network operator, this extra power can be used cumulatively and additionally to the plant's existing power. Although the idea of thermal storage is used in a wide variety of applications, e.g. in solar thermal plants as analyzed and described in [82] and [83], all systems are designed to operate in a circular mode base, usually daily, occasionally, or seasonally.

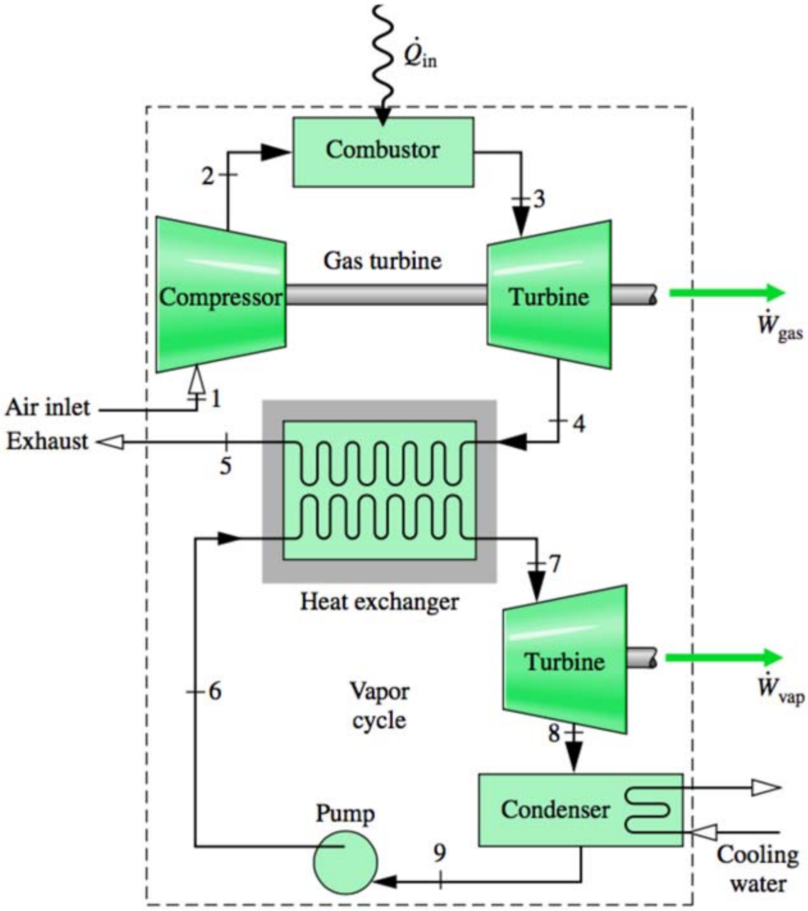


Figure 14 – Cogeneration process in combined cycle plants.

The systems achieve benefits by fulfilling one or more of the following purposes:

- Increasing the reliability of the system [83]. The posibility of lowering power peaks, even turning off the station for specific hours based on daily energy planning increases the likelihood of damage. Thermal storage enables stations to avoid turn-offs when operating at lower limits.
- Increasing station capacity [84]. Energy demand is rarely stable during the day. Surplus power of the station, which is available during low demand hours can be used to charge thermal storage in order to increase the station's efficient production capacity at high demand hours. Thus, the power of the station increases at high demand hours.
- Reducing production costs. Energy that is needed in commercial, industrial and residential areas varies in daily, weekly and seasonal basis. In most countries, the energy is produced in the form of heat, thus the proper study and use of one thermal storage system that works in collaboration with the unit production can be optimized and substantially reduce costs of production of electrical power.
- Providing flexibility to the network operator. The existence of a secondary unit that can operate either simultaneously or autonomously from the plant enables the operator, especially this that operates in non-interconnected networks to avoid load curtailment.

4.1.1.2 Surplus energy of RES

Excess production of power from RES units may result in grid overloads, which require monitoring by the grid operator. If this is the case, wind power plants are switched off during periods of strong wind, but the operators of these plants are still eligible for subsidies. The otherwise curtailed power can be utilized with a power-to-heat system, thereby resulting in economic benefits. This principle of grid relief is achieved by the so-called feed-in management.

Electricity rates at the wholesale energy market can reach negative values in some situations. This happens when supply exceedsdemand. If the power-to-heat operator purchases this electricity, it allows him to use this excess supply in a meaningful fashion in order to produce heat at low cost. Thus, the ecologically clean power generates heat in a very efficient manner. However, the hours with negative electricity rates presently account only for a very low share in the course of a year. In 2014, negative rates were recorded during 64 hours, which was equivalent to a low percentage of 0.73% relative to the entire year. But overall, there has been an upward trend. In 2015, the share of negative energies has almost doubled, to a value of 1.4%.

4.1.1.3 Storage

A key component for the wide use of P2H conversion systems is the heat storage. These systems enable the energy market participants to store the excess of energy that is mainly produced by the RES and offer it to the customers whenever it is necessary. These systems are characterized by high efficiency, especially when they are installed in large scale.

4.1.2 European and International projects

Germany is the European leader in P2H projects. A recent project has been realized at Südzucker, one of the world's largest sugar producers and one of the largest food groups in Germany. The facility has a year-round demand for heat, which will be covered by surplus electricity through a power-to-heat plant, which will offer 10 MW of uptake capacity and will be able to ramp by 2 MW per minute. The plant is integrated directly into the steam network of the composite site and the heat produced can be removed at any time. The plant is thus ideally suited to provide regulating power and is connected to the medium-voltage grid. It should be noted that the signals for power storage as heat are not negative wholesale market prices, but AS. In other words, power is absorbed from the grid when the frequency rises. The entire storage tank takes up 60 square meters [85] and [86].

The city of Flensburg installed in 2013 a 30MW power-to-heat plant with six large electric immersion heaters in order to produce low cost heat for the district-heating network. The plant makes use of the surplus renewable energy and is thus providing flexibility and DR services to the system [87].

A similar project is operating since late 2015 in a facility in Augsburg. Surplus wind energy is used to heat up water in a large dive sink, almost the size of an oversized dive boat. The heated water is then either directly fed into the 150 km district heating network of Augsburg or stored into a heat accumulator for later use. The plant has an output of 10 megawatts (MW), and the efficiency of the conversion of electricity into hot water is by the way almost 100 percent, according to the facilitators [88].

Also in Germany, runs the project NEW 4.0 - Norddeutsche Energiewende with the goal of reaching 100% renewable energy in Hamburg and Schleswig-Holstein by 2035. The subproject "Encountering feed-in management with electric heaters" focuses on Power-to-Heat methods used in order to avoid curtailment of wind power plants, and has recently began installing a 800KW electric heating boiler plant in the city of Tarp, which is intended provide heat for the district heating network by converting excess electricity into storable heat. The system is designed to provide DR services, by reacting within seconds to a fluctuating supply of electricity [89].

The first power to heat plant in Switzerland opened in August 2017 in Niedergösgen. The plant is designed to offer negative balancing energy on the AS market and provide DR services to the national power grid, by using surplus energy to produce steam for a nearby paper mill. The steam is fed in underground directly into the existing heating steam network [90].

4.2 ELECTRICAL POWER TO NATURAL GAS (P2G) CONVERSION

4.2.1 Basic/Possible DR strategies

The Power-to-Gas (P2G) process chain links the power grid with the gas grid by converting excess electricity into a gaseous energy carrier like hydrogen or synthetic methane and thus provides the means for distributing energy among different systems [91]. This technological concept can perform various roles in the energy system and become a useful tool in the energy transition, sustainable mobility applications, and medium and long-term storage of alternative energy [92]. It is also theoretically able to ease situations of grid congestion, as it enables stable renewable power supply, and the exploitation of renewable energy for long-distance transport and process heat. As a storage method it is considered very promising, given that gas can be easily stored for a long time without alteration of its chemical properties, offering long-term capacities and good discharge times [93].

A distinction needs to be made concerning the power-to-gas end product, being either hydrogen or methane. The simplest synthetic fuel is hydrogen. As an energy carrier, hydrogen is a versatile intermediate, which can be applied in fuel cells or combustion devices directly or after conversion, while being friendly to the environment [94]. As a storage option however, hydrogen presents some disadvantages such as high costs, security challenges, missing infrastructure and short lifetimes of fuel cells, which are limiting its use [95]. Methane on the other hand, has higher volumetric energy density and, as a synthetic fuel, presents several advantages, in terms of the P2G process. The technology available concerning the power conversion, use and storage of natural gas is very well developed and already commercial. In addition to this, the existing gas distribution network expands all over Europe and is considered the largest existing storage facility, which can be exploited to allow energy transport and provide theoretically unlimited storage potential [96].

Principally, the Power-to-Gas process is completed in two steps, one for the production of hydrogen and one for the production of methane. During the first step, the excess renewable electric energy is converted via electrolysis into renewable hydrogen [97]. The electrolysis is performed with alkaline or proton exchange membrane (PEM) or high-temperature electrolyzer [92]. Subsequently, the hydrogen is combined with CO_2 to produce methane, known as substitute natural gas (SNG). This thermochemical synthesis can be performed using either a methanation reaction, such as the Sabatier reaction, or by biological methanation, with the latter though being less energy efficient. For the CO_2, many sources are available, such as fossil power generation, CCS, biogas plants, gasification, upgraded and purified CO_2 from industrial processes like lime or cement production, or CO_2 can be recovered from the air [95], [98].

Process products can be utilized in a variety of ways and sectors. The produced methane can be stored and distributed in the natural gas network, it can be used in natural gas facilities, or it can be further converted into LPG. The renewable hydrogen is also commonly used as motor fuel for hydrogen vehicles, which is currently the most commercial use of the technology **[99]**, or as a raw material for the chemical industry. Alternatively, with the Power-to-Power process chain, the produced renewable gases can be used as a fuel to generate power and reproduce energy, or through the Power-to-Heat process in order to produce heat **[100]**. The whole process is presented schematically in Figure 15.

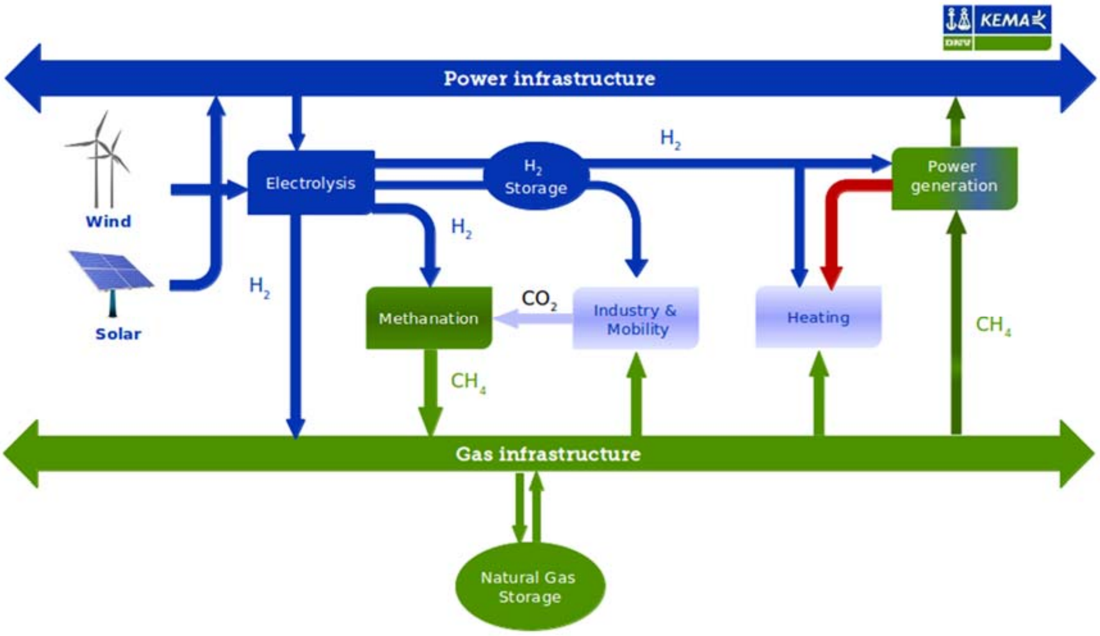


Figure 15 – Schematic of the P2G process [92].

Based on this principal concept, many advantages arise. P2G could help decrease import dependence on fossil fuels and thus also reduce geopolitical tensions, given that SNG can be produced locally based on the availability of water, air and renewable power. In that manner, energy demand can be successfully covered by RES and partial or even total energy autonomy can be achieved in industrialized regions [101]. P2G also strengthens the coupling between gas and power systems, providing the opportunity of a unified management, and thus further enhancing security of both systems [102]. In addition to this, the coupling of different sectors provides more revenue streams. Furthermore, through the exploitation of CO2, this concept aids in the reduction and recycling of greenhouse gas emissions in the energy system, which as a benefit can be further extended when combined with a CO2 storage system, in order to act as a carbon sink [95].

The main disadvantages of this system are the relatively low efficiency in addition to the high costs [101]. In particular, the power-to-hydrogen efficiency is in the range of 55-77%, while the overall efficiency of the P2G process usually ranges from 30% to 60% depending on the type of energy usage, such as power storage, heat or transport [92]. Nonetheless, although the process imposes some energy losses, using part of the surplus power is still more useful than curtailing all of it. Investment costs are still very high, thus making operation viable in very limited cases [103], however costs are expected to decrease as the research progresses and the technology evolves allowing higher penetration in the energy market. In addition to this, in future projection models higher penetration of P2G can provide the optimal choice for long-term storage capacity while also integrating higher shares of renewable energy, resulting in lower system prices ([101] [103] [104]). Moreover, in comparison to the use of batteries, P2G can lead to lower Levelized Cost of Energy (LCOE) due to the high storage capacity of the existing grid [104].

On a research level, the potential implementation of P2G in the electricity systems has been evaluated by several European countries in order to identify maximum capacities and potential barriers, such as system, geographical of framework limitations, so as to reach economic optimum. The general conclusion is that the use of P2G will be necessary in order to achieve 100% renewable generation [101]. In [93] the necessary storage capacity of P2G for the integration of surplus renewable energy was evaluated for the Spanish case. For Great Britain, the results of [94] show that the domestic transport sector energy needs could be covered 100% by renewable energy through the implementation of Power-to-Hydrogen systems, in the case of 100% penetration of hydrogen fuel cell vehicles. In [100] it was estimated that the Power-to-Power option for RES integration in Italy can achieve 46% efficiency. In Germany, studies [103] and [105] have estimated the economic optimum P2G capacity in order to reach 85% or 100% renewable generation in the future, and have also concluded that these percentages can be reached only with the implementation the particular energy storage system.

4.2.1.1 DR strategies

With P2G electricity and gas networks can be merged and the gas infrastructure can be used for balancing power, for process heat and for long-distance transportation, by accommodating temporarily and spatially flexible large volumes of electricity that are converted into gas. In that manner, renewable power methane plants can be appropriately controlled and integrated into power management, in order to provide grid stability, power storage and DR. The P2G process can thus be used in DR strategies in several ways.

- To begin with, P2G can be used to match power supply and demand and prevent curtailment by power shifting using power storage when the supply of renewable power is larger than the grid capacity or the electricity demand. Thus, P2G facilitates the integration of intermittent energy sources and can therefore be the key in achieving 100% renewable energy systems [106].
- P2G can also provide flexibility to the system, through its fast response time, ranging from seconds to minutes [92].
- In reverse situations, P2G can provide AS and balance active power by reconverting renewable methane or hydrogen into power and stabilizing grid operation. It should be reminded though that power-to-gas in combination with electrification results in lower energy efficiency. Currently, the only commercial and also efficient technology for the on-site Power-to-Power process is the fuel cell. The alternatives are gas turbines, which have not yet reached a commercial level, and hydrogen fuelled internal combustion engines, which present lower efficiency [100].
- Another option is the use the renewable power methane in distributed and small scale CHPs, which can also be coupled and controlled as one large gas power plant (swarm power principle). The use of renewable fuel improves the efficiency of the CHP while the coupling of small units can help distribute heat and 'balancing power' widely and more effectively. Moreover, CHP can ensure uninterrupted operation in case of large power system failures, as power can be locally produced and consumed by the renewable power methane RPM supplied from the gas grid [95].

  Furthermore, the bi-directional energy conversion enhances the interaction between the gas and electricity system, offering several advantages. Natural gas pipelines are larger than electrical power lines while the infrastructure can sometimes be better accessible [107]. Thus, the use of the existing natural gas network can offer larger energy storage and transfer capacities, while facilitating energy transportation over long distances or in remote areas.

Other primary services that it offers are:

- Offsetting CO2 emissions at natural gas end users by providing hydrogen enriched natural gas. With the goals of achieving carbon-neutral gas supply in 2050 in mind, P2G innovation can be proved very useful, as it achieves zero emissions [94].
- Providing pure hydrogen to the chemical industry and the mobility sector, thus enhance decarbonisation and contributing in the increase of sustainability. SNG can be now used as a range extender for electric hybrid vehicles or it can be used in aviation as liquefied renewable power methane and renewable fuel for combustion engines and turbines [92] [98].

4.2.2 Actors

P2G system is both producer and consumer. It will fit in these already existing market roles. The combination provides a role as flexibility service provider which supports the integration of renewable energy into the energy system. The related actors and their roles are described below.

- **Gas Distribution Company** - P2G uses existing infrastructure of natural gas network and natural gas storage facilities. The technology available concerning the power conversion, use and storage of natural gas is very well developed and already commercial, while the use of the existing natural gas distribution network allows conceiving larger energy storage and transfer capacities, while facilitating energy transportation over long distances or in remote areas.
- **TSO** - As an electricity storage method, P2G can contribute to compensating the increasing fluctuations in electricity generation from wind and solar energy and facilitate long-term use of electricity which could not be integrated directly into the electricity grid at times of particularly high renewable generation, and improve grid stability.
- **Electricity DSO** - P2G provides flexibility for the electricity system, through power storage and DR. It can also provide AS, in case of power regeneration from the produced natural gas.
- **Balance Responsible Party** - P2G can also provide AS, in case of power regeneration from the produced natural gas.
- **RESCO / ESCO** and **VPP / Aggregator / Producer / Prosumer** - P2G can store excess renewable energy and, combined with a regeneration system, it could be used to provide backup power. The hydrogen gas could be also used in refueling stations for fuel cell vehicles.

4.2.3 Communication technologies

Communication technologies allow communication between machines and people, in order to facilitate the connection of the various parts of the grid, which include operations, service providers, customers, distribution and transmission [108].

The case of P2G is more complex as communication systems are required to connect the two separate networks of electricity and gas. In order to do so, the operator of this system should be able to simultaneously handle wholesale electricity markets, deal with the supply of gas for bulk generators and participate in real-time gas markets and in service pipelines [109]**.** Taking these issues into consideration, it seems clear that there is a convergence between many aspects of the control systems and markets. Furthermore, in order to simplify the technology's integration efforts, it is very important to develop open architecture communication protocols between different component manufacturers [110].

Based on the identified actors and roles the following information exchange and communication methods are deemed necessary.

- **EMS**

The EMS will exchange information

- with the TSO, in order to be informed when RES electricity production exceeds demand and to start operating,
- with the DSO / RESCO / ESCO, for the provision of DR services,
- with the RESCO / ESCO and VPP / Aggregator / Producer / Prosumer in order to exchange information for the necessary and the available loads for the provision of backup power and
- with the Gas Distribution Company, in order to know the range and rate of change of the hydrogen content in natural gas, and availability for storage [111].

Information will also be exchanged concerning the electricity and gas wholesale market prices.

- **Load Controller**

A Load Controller will send control signals for the operation based on the information exchanged with the EMS.

- **Gas detection devices**

Gas detection devices are necessary in order to know the range and rate of change of the hydrogen content in natural gas. Gas detection devices designed for natural gas may not be accurate for mixtures of natural gas and H_2. [111]

- **Electronic Meter / Smart meter / Sensors**

These devices are used for measuring hydrogen storage levels, and other parameters regarding the function of the system.

4.2.4 European and International projects

The P2G process chain was first proposed in Japan in the 1980s-1990s. In recent years, the increasing share of wind and solar power has increased the interest, especially in Europe. A significant amount of Power-to-Gas research is now present in Europe, in several countries such as Switzerland, Denmark, France, and Germany, where pilot plants are already in operation or under construction. Some examples are presented here.

- The first Power-to-Hydrogen pilot plant was built in Neunburg vorm Wald, Germany on an industrial scale at a demonstration facility as part of Phase 2 of the SWB project running from 1993 to 1999. The technologies demonstrated included a solar hydrogen plant using PV energy to produce hydrogen and a LH2 filling station for testing of hydrogen fueled cars [112].
- The first Power-to-Gas pilot plant was built in 1995, in the Tohoku University in Japan. The plant converts PV energy to hydrogen, using seawater for electrolysis, which is then combined with CO_2 in two reactors in order to produce methane. The methane is subsequently combusted and the released CO_2 is captured and reused as feedstock to the methanation process. A similar larger plant was installed in 2003 in the Tohoku Institute of Technology in Japan. The plant is relatively small, with an electrical power less than 10KW and uses seawater for electrolysis [91], [113].
- The first industry-scale Power-to-Gas is the Audi e-gas plant, which was realized by ETOGAS in Wertle, Germany. The plant has an installed capacity of 6 MW-e and is considered the biggest worldwide. Three alkaline electrolysers produce hydrogen, which is then combined with CO_2 from a waste-biogas plant to produce synthetic natural gas (SNG). The waste heat that is given off during methanation is retrieved in reused to sanitize the waste and prepare the biogas, thus further increasing overall efficiency. The produced synthetic natural gas is directly fed into the local gas grid since 2013 and used as a CO2 neutral fuel in standard CNG [114].
- The first power-to-gas plant in Germany to utilize biological methanation on an industrial scale is operating at the Viessmann company headquarters in Allendorf, since 2015, and was built as a demonstration plant with the support of the "BioPower2Gas" funding project. The plant uses surplus power from renewable sources and produces synthetic natural gas using a purely biological P2G method, where the carbon dioxide contained in the raw biogas is processed and used directly. The produced SNG is used in the mobility sector and is the first to be certified as sustainable fuel and marketed as biofuel. The plant includes a CHP unit to produce energy and district heat and is also used to provide flexibility and balancing to the grid [113], [115].
- In England, the Hydrogen Mini Grid, sited on The Advanced Manufacturing Park in South Yorkshire uses renewable wind energy to generate hydrogen on site, which will then be used in fuel cell EVs. The facility, realized by ITM Power as a demonstration site, is used to provide retail hydrogen fuel services and is smartly located in a highly populated area. The site consists of a 225kW wind turbine, which generates renewable energy to be used in the buildings of the park. The turbine is directly coupled to an electrolyser that uses the excess energy to produce renewable hydrogen gas, which is subsequently compressed and stored in the 200kg hydrogen storage unit. Hydrogen is then dispensed into hydrogen fuel cell vehicles or used by a 30kW fuel cell system installed in order to provide backup power generation for nearby buildings. The project has received funding from Innovate UK [116].

- The BioCat project in Denmark funded a power-to-gas installation project in 2014, in order to upgrade the anaerobic digestion biogas from sewage sludge in Avedøre wastewater Services in Avedøre, Kopenhagen (Denmark). Hydrogen is produced in a 1 MW alkaline electrolyzer plant and is then combined with the carbon dioxide from the biogas in a Sabatier reaction in order to produce methane. The produced methane will be injected to the grid, while product heat is recycled and reused in buildings on site. The project aims to demonstrate the ability of the P2G process to provide DR, ancillary and frequency regulation services, and to also investigate the feasibility of recycling the byproducts emerging from the process such as the produced oxygen and heat [113], [117].
- In Italy runs the four-year INGRID project, since 2013, located in Apulia. The project aims at demonstrating through cutting edge technologies how P2G systems can facilitate renewable energy integration, in order to balance energy supply and demand, and ensure security and grid stability. The site consists of a 39MWh storage unit and a 1.2 MW electrolyser for the production of hydrogen which will then be used for grid balancing, transport, industry, and injection into the gas network. The project comprises also tools for energy management and simulation tested with ICT platforms [113], [118].
- European demonstration project STORE&GO, involving 27 partners from six European countries, started in March 2016 with a runtime of four years with the aim of investigating the technological maturity of Power-to-Gas and capabilities in terms of storing large amounts of renewable energy. The technological concepts are investigated in three demonstration sites in Europe (Falkenhagen/Germany Solothurn/Switzerland, Troia/Italy). The technologies involved include three different methanation processes, direct capture of CO_2 from atmosphere, liquefaction of the synthesized methane to bio-LNG, direct injection into the gas grid and integration into the existing power grid. The project has received funding from the “Horizon 2020 Research and Innovation programme” of the European Union [119].

4.2.5 DR regulatory framework in place

The P2G process chain links the power to the gas supply system, but also to the heating and transport energy systems. The regulatory framework is compounded by the existing conditions associated with the taxation, regulatory and market environment, indicates and implicates drivers or barriers concerning the penetration of P2G as a flexibility and storage options in the energy system and can thus significantly affect the development of the technology [120].

At present, P2G is mostly considered as a storage option and most EU countries do not have specific commercial regulations for energy storage. The operation of the energy market in Europe is currently defined by the Electricity Directive [121] and the Gas Directive [122], which perceive energy storage in a rather different way. In particular, the Electricity Directive does not include a specific mention on energy storage applications, which are generally treated as generation systems. On the contrary, storage plays a very important role in the natural gas market and is one of the key elements of the distribution system, as detailed in the Gas Directive and its scope. In addition, security of supply issues are a powerful driving force, particularly in terms of geopolitical conditions, while obligations on Member States regarding storage arrangements are clearly laid down. [123]

Gas storage is also addressed in the European Energy Security Strategy [124] and considered to be important strategic element regarding supply security. According to this, the good functioning of the gas market and the clear regulation of access to storage facilities are very important and necessary, and are determined by a number of factors which affect energy security, such as available storage capacity, actual use of storage and access to storage. Furthermore, in order to increase the resilience of the European gas system and to ensure energy security at European level, the necessity to complete the transposition of internal energy market legislation into national legislation, including the separation rules, reverse flow and access to gas storage facilities, iis clearly mentioned and required to be implemented by the end of 2014 [123].

The commercial model of the gas treatment chain is influenced by the individual laws that determine the different stages of the process, such as directives and laws regulating the power purchase, the sale of hydrogen and methane from RES as well as the storage of energy. In most countries, the lack of such concrete framework hinders the development and penetration of the technology [99]. As regards to storage applications, the possibility of providing frequency reserve and transmission and distribution referral is only foreseen in a limited number of countries, although their access to the time shift market is foreseen in all EU countries. In addition, in energy storage systems there are fees relating to both modes of operation, namely feed-in and feed-out, making the remuneration system unfavorable [120], [125].

Nonetheless, each country requires an individual analysis, as the situation and rates of evolution of the P2G framework conditions differ significantly. In particular, Germany could be considered a pioneer on the basis of prevailing conditions, as it has not only adapted the technology to its current regulations but it is also constantly exploring the possibilities of promoting and widening the integration of this storage system into its energy system. However, a competitive start of the market is not yet favored by regulations [125].

A new package of "Clean Energy for All Europeans - Delivering Europe's Growth Potential" was announced by the European Commission in late 2016, which specifically refers to the transformation of the electricity into another energy carrier, such as hydrogen, in the definition of energy storage. With this in mind, P2G system applications, electrolysis stations and hydrogen refueling stations will be able to offer storage facilities in the electricity market and sell the renewable hydrogen in the mobility and gas markets. In this way, these directives will play an important role in the absorption of P2G storage energy and renewable hydrogen produced in Europe [116].

Although a widespread deployment of P2G will not take place by any measure in the next decade, some aspects of the present regulatory framework seriously curtail the development of demonstration projects. A supportive regulatory framework should include [120], [126]:

- Removal of existing barriers mainly due to the absence of specific legislation addressing renewable hydrogen and P2G.
- Provision of a financially attractive environment to stimulate investments and strengthen the business cases of P2G applications. As a primary measure, focus should be given on the structure and level of grid tariffs and PSO charges, while a secondary measure would be to provide subsidies that can reduce the operational cost in any of the steps of the P2G value chain, or the investment cost of P2G-related infrastructure.
- Implementation of a green/renewable hydrogen certification mechanism.
- Implementation of effective climate policy, aiming at a significant and satisfactory increase of CO_2 price.
- Accurate evaluation of the growing needs for flexibility in the market, in order to fulfill them at the lowest social cost.
- Definition of safe levels of hydrogen in the natural gas infrastructure, through the relevant regulations on gas quality and limits of hydrogen at EU level [127], [128].

5 DR OPERATIONS PROVIDED TO THE GRID

DR can be useful to prosumers and aggregators for obtaining monetary benefits by means of changing their consumption patterns. However, this kind of mechanisms can also help to mitigate and avoid some problems related to the stability of the grid. DSOs can facilitate Explicit DR strategies in order to get a cheaper solution of some of the stability grid problems that they confront.

A study [129] shows the convenience of DR in order to address some grid problems and the timescale in which these strategies are more effective. In Figure 16 its conclusions are shown.

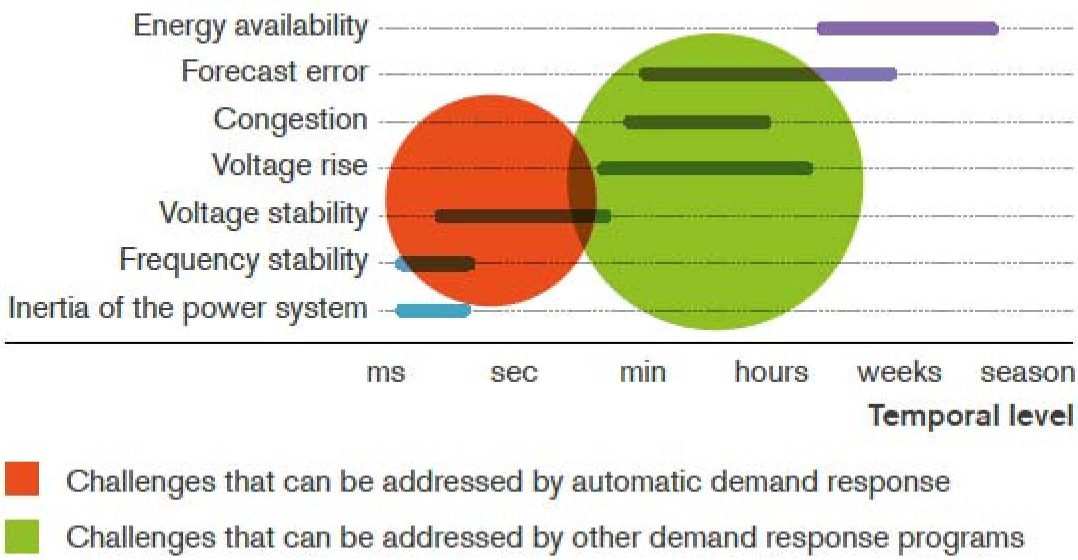


Figure 16 – Grid related challenges where DR could be effective.

Load modification measures have both short and long-term benefits in accordance with the demand side management that is incentivized. End-users can adjust their consumption in the following ways:

- Peak clipping/shaving refers to a consumption reduction at peak hours; as load decreases so does the demand during peak hours.
- Valley filling considers the exploitation of low utilization (i.e. valley) hours, at which additional electricity use is encouraged; such a modification improves the ratio between the peak and minimum load of the entire system (i.e. the load factor), which can bring overall benefits in electricity prices.
- Load shifting refers to incentivizing shifting of end-user consumption to another time of the day, a modification that relieves the system peak; customers obtain a financial advantage by purchasing cheaper electricity.
- Strategic conservation refers to the reduction of the total energy use due to increased efficiency i.e. energy efficiency.
- Strategic load growth considers the strategic increase of consumption for an agenda, e.g. tax benefit for EV owners, in turn promoting mobility electrification and consequently strategic load growth.
- Dynamic energy management focuses on the system in real-time operation where supply and demand flexible loads mutually optimize the system load.

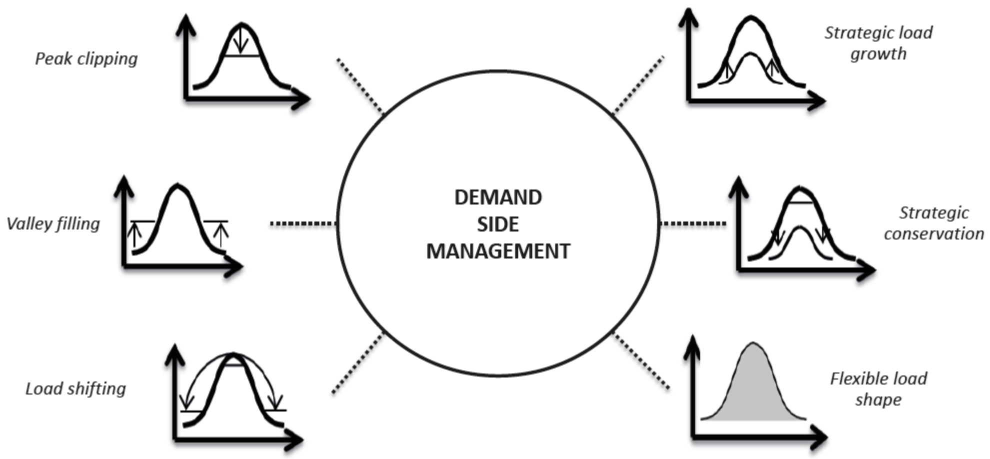


Figure 17 – Demand side management load shape objectives [130].

There are some European experiences that show the convenience of DR strategies. Figure 18 shows some of them:

Owner	Initiating parties	Country	Description
Statnett	TSO	Norway	The TSO is using DSR to manage and balance the system
Fingrid	TSO	Finland	The TSO is using DSR to manage and balance the system
DONG Energy	Supplier, generator	Denmark	Provides an example of intelligent energy management of different types of generation or demand and how a VPP model may work
National Grid	TSO and in some cases end users or third parties (aggregators)	Great Britain	The role which DSR plays in the various National Grid products such as Short Term Operating Reserve market, the TRIAD management and the Demand-Side Balancing Services requirements
UK Power Networks	DSO, third parties and suppliers	Great Britain	A large scale smart energy project testing a number of issues from the introduction of innovative contractual arrangements between customers and DSO and the use of tariffs to change behaviour and patterns of consumption
ESB and EirGrid	Supplier, generator, TSO	Ireland	Time of use tariffs in Ireland being mandated as part of the smart metering roll out
EirGrid	TSO	Ireland	The Winter Peak Demand Reduction Scheme (WPDRS) was introduced as an incentive to business customers to reduce electricity consumption during the power system's peak hours in winter months.
Elektro Ljubljana	Aggregator	Slovenia	Participation of VPPs in the provision of tertiary reserve services to the TSO
RTE	Supplier, TSO	France	An overview of how DSM is integrated within the French market design. DSR is used in the balancing mechanism, as part of the market and for portfolio optimisation
German TSOs	TSO	Germany	Use of large consumption units connected to high-voltage networks to maintain grid and system security

Figure 18 – European case examples [131].

In the following chapters, some of the grid problems that can be solved or mitigated thanks to the implementation of DR strategies are presented and their characteristics are detailed.

5.1 VOLTAGE CONTROL

5.1.1 Context

The high penetration of RES in the distribution system provokes some incertitude and technical challenges (in comparison with the current centralized model) that should be studied and solved in advance. These new challenges are mainly motivated by the intermittency and fluctuating characteristics of the new Distributed Energy Resources (DERs).

The change from unidirectional power flow to bidirectional flow that characterizes Active Distribution Networks brings imbalance between generation and production due to voltage rise, voltage imbalance and line overloading [132]. The intermittency of wind or solar power sources has a high impact on the voltage variability at the feeder bus where the respective DER is connected. The voltage limits are frequently violated because the current electricity system is not designed to include DERs [133].

Most common perturbations on the voltage waveform include:

- Voltage gaps: abrupt diminution of supply voltage below 90% of the nominal, with reestablishment of nominal parameters after a short lapse of time (before 1 minute);
- Supply interruption: voltage at supply points lower than 1% of the nominal, during a long time lapse (more than 3 minutes);
- Overvoltage: increment of voltage over the nominal value. They can be classified as temporal (relatively long duration) or transient (duration of some milliseconds);
- Undervoltage: reduction of voltage below the nominal value;
- Imbalance: different RMS values found in each of the phases of the three-phase system;
- Harmonics: modification of the sinusoidal form of the wave, by presence of voltage in frequencies that are multiply of the fundamental one;
- Interharmonics: modification of the sinusoidal form of the wave, by presence of voltage in frequencies that are not multiply of the fundamental one;
- Voltage fluctuation: cyclic variations of the amplitude of the voltage wave.

Main problems that these issues may cause to the customers include:

- Incorrect consumption and active/reactive power metering (leading to incorrect billing);
- Industrial devices with temporal reference based on voltage wave losing synchronism (therefore leading to problems in the industrial process);
- Reset of electronic devices, possibly leading to physical damage;
- Incorrect behavior of protection devices;
- Transformer overheating;
- Industrial machinery overheating;
- Diminution of the service life and efficiency of electronic devices;
- Interferences on communication networks;
- Misbehavior of power factor correction devices.

Voltage management [134], and especially the increased voltage levels, is a key factor that limits the penetration level of DERs that can be integrated in the grid. During heavy-load conditions, voltage levels may drop below the accepted values. This is due to relatively large DER generation decreasing the current value of the circuit seen by the Load Tap Changer (LTC) of the transformers in the substation side.

Since the LTC sees a smaller current value (the equivalent of a light load) than the actual value, the LTC will lower the tap set point to avoid a “light-load, high-voltage” condition. This process makes the actual “heavyload, low-voltage” condition even worse. As a general accepted rule, if the DER contributes less than 20% of the total load current, then the DER effect will be negligible in most cases.

Figure 19 and Figure 20 show examples of a grid with DERs connected downstream from the bidirectional line voltage regulator (VR). During “normal” power flow conditions (Figure 19), the VR detects the actual power (P) flow condition from the substation toward the end of the circuit. The VR will operate in “forward” mode (secondary control). This operation is as planned, even although the “load center” has shifted toward the voltage regulator.

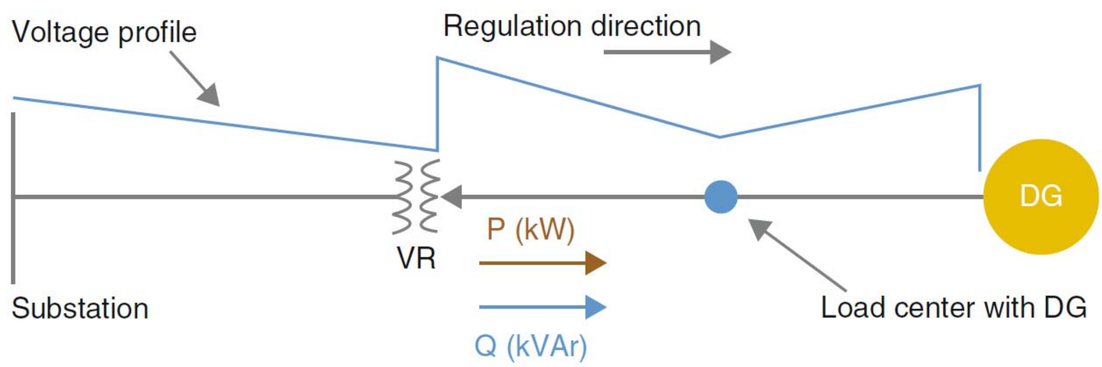


Figure 19 – VR bidirectional mode (normal flow [134].

Nevertheless, if active power flow is reversedtoward the substation (Figure 20), the VR will operate in the reverse mode (primary control). Since the voltage at the substation is a stronger source than the voltage at the DG (cannot be lowered by VR), the VR will increase the number of taps on the secondary side. Therefore, voltage on the secondary side increases dramatically.

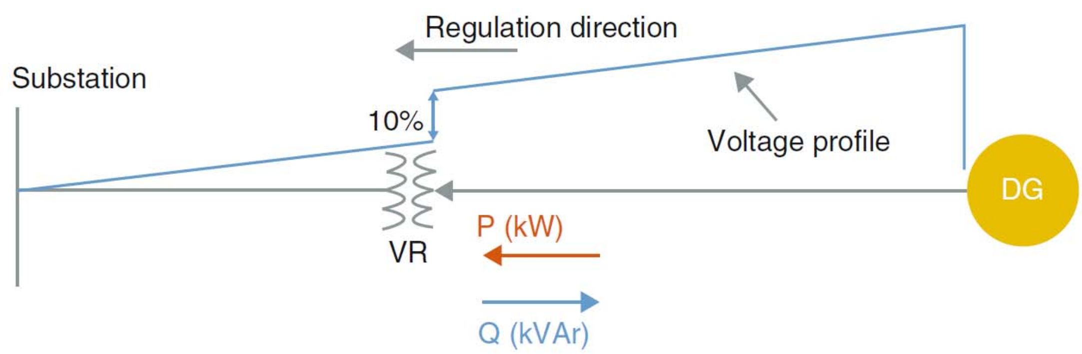


Figure 20 – VR bidirectional mode (reverse flow) [134].

The voltage profile will vary due to the fluctuation of weather conditions that affect solar and wind energy resources. So smart distribution systems need real time voltage management in order to handle the high penetration of RES. AMI is a key communication system in the smart electricity system. Integrating AMI with

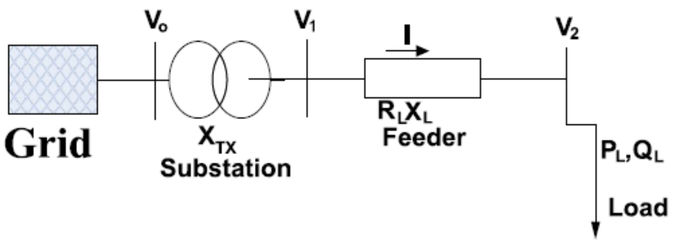
DMSs makes it possible to enable new distribution application systems and improve the existing capabilities of the grid. With the use of AMI, the real time operation model can use DR strategies to reach voltage control approaches [135].

Some of the voltage deviations provoked by DERs can be solved thanks to some Smart Grid precepts, which enhance grid reliability. Voltage analysis from [136] shows that DR mechanisms have a huge potential to regulate voltage at nearly all the critical nodes. The infrastructure of the current electricity system is so costly that DR strategies become one of the cheapest mechanisms for operating the system according to the new challenges that will be faced [137].

As it has been mentioned in the previous sections, there are two basic types of DR: implicit and explicit. In the case of voltage control, the explicit DR will be the most relevant one.

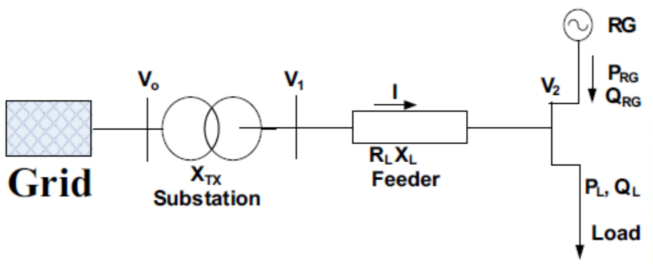
5.1.2 DR as voltage controller

In order to understand the changes due to the integration of DERs in the electricity system, Figure 21 and Figure 22 showing the usual scenario an the DER scenario with the respective voltage variation equations are presented.



$$\Delta V = \frac{R_L P_L + X_L Q_L}{V_2} \quad (1)$$

Figure 21 – Usual simplified distribution system [132].



$$\Delta V = \frac{R_L(P_L - P_{RG}) + X_L(Q_L - Q_{RG})}{V_2} \quad (2)$$

Figure 22 – DER simplified distribution system [132].

(R_L= Line resistance; X_L=Line reactance; P_L=Active Power Load; Q_L=Reactive Power Load; P_{RG}= Active Power Production; Q_{RG}= Reactive Power Production; X_{TX}=Reactance of the transformer).

In the previous Figures it is possible to see the main changes between the standard scenario and the new scenario envisaged for the distribution system. In the new scenario, the prosumer can change the voltage variation by means of changing one (or more) of the next parameters: PL; PRG; QL; QRG. The effectiveness of each change depends on the X/R ratio (LV network are mainly resistive so the X/R ratio is low). Thus, three main actions can be done by a prosumer in order to respond to a voltage control request [137]:

- End users can decrease their energy consumption during critical peak periods. That implies a temporary loss of comfort.
- End-users may answer to elevated electricity prices by moving some of their consumption to off-peak periods.

- Prosumers can vary their own electricity usage pattern.

For example, in an emergency condition like an outage of a production plant, the use of demand curtailment can be a solution. If the end users involved in DR programs can vary their consumption as requested, the DSO can turn again the voltage of critical nodes into their permissible ranges. This prevents the connection of other power plants that can be more pollutant (such as fossil fuel power plants).

There are some specific voltage control characteristics and actions regarding the explicit DR mechanisms used by the prosumer:

- Presence of smart appliances (controllable batteries, EVs, HVACs, heat pumps).
- These campaigns present the advantage that devices are fully controllable, and results and limits of the energy that can be modulated within the campaign can be calculated on advance with small error.
- These campaigns can be also used to perform short and long-term control (preventive).
    - Day-ahead planning can take into account the bidirectional flexibility offered by smart assets and schedule them accordingly in order to achieve a demand/production plan that is balanced.
    - Real-time voltage deviations (in particular, overvoltage due to excess of production) can be corrected in real-time by dispatching commands to modify the set-points where needed.

5.1.2.1 Modification of the local consumption

The location of the loads and the DERs determine the value of the voltage rise [138]. Maximum voltage can appear at the substation bus, DER buses or capacitor buses. Minimum voltage points can appear at the end of the feeder or between any DER connecting buses [139].

After the calculation of the voltages of every section of every feeder, the voltage controller calculates the maximum and the minimum voltages of the network. In order to limit the voltages inside their respective ranges, the voltage variation between the maximum and the minimum voltage along the feeders has to be lower than the predefined permissible range [139].

Once a DR campaign is started, the difference between the highest and the lower voltages depends on which loads participate in the DR program [139]. So the Aggregator (through a DSO request) has to select the most suitable end user in order to perform a reliable and useful DR campaign that can solve the voltage problems that appear in the distribution grid. When the local production is lower than the demand, the DSO should turn off some of the peak loads (under voltage), or turn off peak generation (overvoltage) [140].

When some loads accept to decrease their consumption, both active and reactive power flow in the feeders will compensate the voltage drop in the system nodes because (as previously shown) the variation of the active and the reactive power can boost the voltage profile [135].

5.1.2.2 DR strategies for Voltage Control (undervoltages)

Peak Clipping

- Reduction of system peak load by utilities using direct load control.
- Means to reduce peak capacity procurement.
- Programs are expanded to also address transmission distribution congestion management.

Load Shifting

- Shifting load from on-peak to off-peak periods (i.e. from high prices periods to low price periods).
- Displacing conventional appliances served by electricity.
- Use of storage water heating, storage space heating.

* Programs are expanded to address transmission distribution congestion management.

Flexible load shapes (dynamic energy management)

* Concept related to reliability and planning constraints.
* When the anticipated load shape is forecasted customers are presented with options as to the variations in quality of service that they are willing to allow in exchange for various incentives.
* Interruptible/curtailable load.
* Dynamic (manual and automated) control of devices.

Strategic Conservation (energy efficiency)

* Results from overall efficiency (such as the installation of energy efficient light bulbs, buying energy efficient appliances, unplugging appliances when not in use, etc.).
* Changes in the overall patterns of appliance use.
* Programs reduce overall electricity consumption, also at times of peak demand.

5.1.2.3 DR strategies for Voltage Control (overvoltages)

Valley Filling

* Building off-peak loads (especially useful at times when long run incremental cost is less than the average price of electricity, in this way decreasing average cost to customers).
* Space and water heating systems can provide such flexibility.

Flexible load shapes (dynamic energy management)

* Concept related to reliability and planning constraints.
* When the anticipated load shape is forecasted customers are presented with options as to the variations in quality of service that they are willing to allow in exchange for various incentives.
* Interruptible/curtailable load.
* Dynamic (manual and automated) control of devices.

Load Building (Strategic Load Growth)

* General increase in the consumption of electricity (stimulated via certain incentives).
* Heat pumps, electrification of mobility and heating.

The strategies for control voltage through modifications in the consumption can be complemented by strategies of modification of the local generation.

5.1.2.4 Modification of the local generation

The main objective of conventional Volt/VAr control (VVC) in distribution systems is the coordination between the on-load tap changer (OLTC) and all of the switched shunt capacitors. Currently, DERs have achieved great interest. DERs are normally operated with a power factor close to 1 in order to not interference with the ancient VVC devices placed in the distribution system [141].

Using DERs as voltage regulators, it is possible to raise the voltage reliability and decrease the capital and the operation costs. In addition, the voltage regulation is practically instantaneous and can be performed locally [142].

5.1.2.5 PV inverters

The inverter installed in some DERs (such as PVs) can provide reactive power control based on a request from the DSO [141]. The inverter can keep the AC output voltage at the specified range despite the variation of the DC voltage with fluctuation of ambient temperature and/or solar irradiance [143].

PV systems are designed to work at unity power factor. This is a kind of accepted agreement, not a technical constraint so the inverters can also have the possibility of providing reactive power in DR campaigns.

The amount of reactive power that an inverter can produce depends on its S (apparent power) ratings and the active power supplied by the PV array. In Figure 23, the inverter's ratings are represented by a vector with magnitude S and the semicircle with radius S denotes the boundary of the inverter's feasible operating limits.

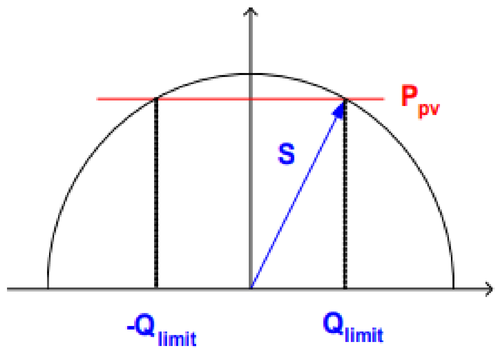


Figure 23 – Reactive power limits of an inverter [143].

It is noteworthy that this graph is only valid with a PV inverter system without storage capabilities. In presence of batteries in the system, the figure becomes a 4-quadrant graph.

In addition to the traditional reactive power control, inverters can operate very fast (milliseconds to microseconds) in comparison with current capacitors, which can cause switching transients [143]. So DR campaigns involving PV inverters can be very useful in primary and secondary voltage regulation actions.

PV inverters have a great potential to be one of the most important devices in Volt/VAr management. According to the studies made in [143]:

- With a 5% penetration level, PV inverters don't make significant impact on the feeder's voltage control.
- At a 10% PV penetration level, it is possible to reduce the size of capacitors by nearly 40%.
- At high penetration levels (30%-50%), PV inverters could displace voltage control capacitors.

Furthermore, the inclusion of batteries in combination of inverters can even provide more possibilities to the voltage control thanks to the possibility of dumping the stored energy to the grid or being another load in which the energy is consumed.

5.1.2.6 Wind turbines

Current wind turbines can use synchronous or asynchronous generator to produce the electricity output. The small wind turbines (the most used in the domestic field) generally use synchronous generators. This kind of alternator will be more explained in the next section. The asynchronous generator is the most used in the industry field, but these kind of conventional alternators cannot provide reactive power (they can only consume reactive power). However, doubly-fed induction generators, which are mostly used nowadays, can manage their reactive power generation thanks to its power electronic components [140].

The maximum voltage and current allowed by the wind turbine impose the constraints on its own reactive power capabilities. The available reactive power capability of a wind turbine is shown next.

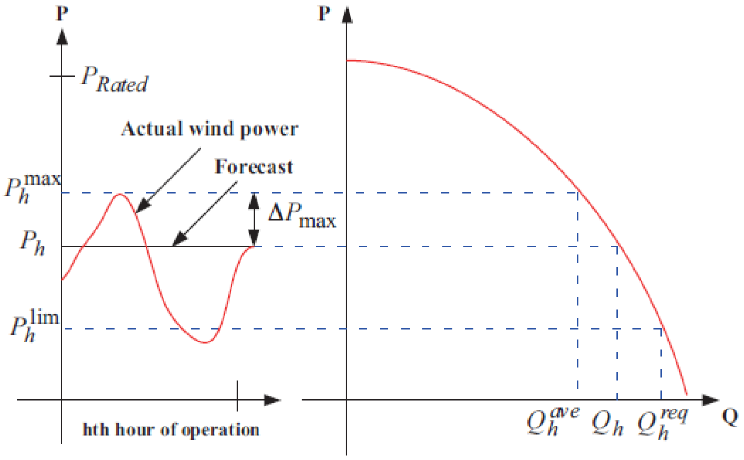


Figure 24 – Reactive power capability of a wind turbine considering the hourly wind power fluctuations [141].

If the DSO makes a request to the Wind turbine to provide a certain quantity of reactive power (Q_h^{req}) that is higher than the current reactive power production (Q_h^{ave}) then its power production is restricted to P_h^{lim}. So the DSO has to compensate to the wind turbine owner the lack of energy production that couldn't be offered to the market.

5.1.2.7 Synchronous generators

Synchronous generators can also provide Voltage regulation to the Grid in DR mechanisms. This kind of generator can be found in small wind turbines or in small generator groups.

Generator groups can deliver extra active power if the DSO requests it so they can participate in DR campaigns by the active power side. All synchronous generators can also provide reactive power control so they can provide voltage control by this way.

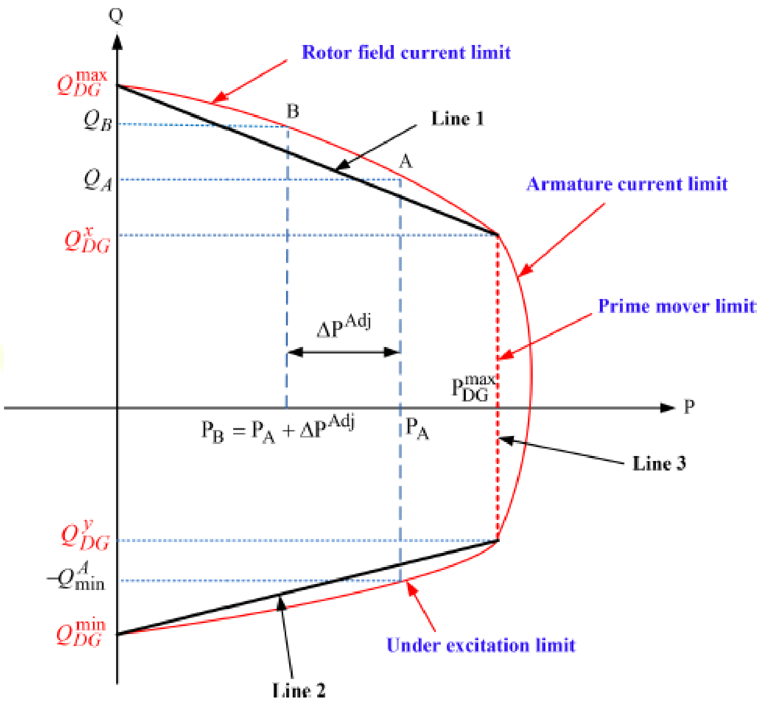


Figure 25 – Capability diagram of a synchronous generator [141].

Taking Figure 25 as a reference, if the generator is producing a certain amount of active energy (P_A) and consequently also reactive power (Q_A) and, for example, the DSO starts a DR campaign requesting the generator to operate in Q_B point, the generator has to reduce its active production (ΔP^{Adj}). These changes can take positive and negative values and in both cases the generator operator has to be compensated by adjustment prices.

5.1.3 Technical implications/barriers (equipment, communication, regulatory framework) and recommendations

- Presence of the required assets that support voltage control operations needs to be larger in numbers:
  - Smart appliances (controllable HVACs, heat pumps, batteries, charging points etc.) will allow execution of explicit DR campaigns with higher reliability and faster response times;
  - Adoption of domestic and grid-level batteries as the presence of RES in the low voltage grid increases will help mitigating some of the problems that the intermittency of those resources may introduce;
  - Adoption of EVs and EVSEs with Vehicle-to-grid capabilities transform the EV capabilities into a very valuable asset for stabilizing the low voltage grid, enabling advanced control mechanisms to assure in real-time that local demand and generation are met, by increasing the flexibility that those devices offer.
- Identification of proper incentives to promote participation of the users in DR programs;
- Necessity of evolving the current interconnection requirements (including the communication infrastructure);
- Inverters need to have reactive power capabilities at all the levels of the grid;
- The management of the DERs in DR strategies has to be coordinated with the operation of traditional voltage control equipment to fully profit from both resources;
- The creation of DR legislation and ancillary market regulation in all the EU countries where there are not still implanted.

A list of recommendations for future research based on [143] is presented next.

- Develop a set of recommended practices to meet the existing voltage management operations with the future high penetrations of DERs;
- Unify criteria for modeling PV inverters for voltage analysis/control;
- Create benchmark cases to test the models and the associated software. In addition, it should be necessary increase the number of options in the voltage analysis software;
- Implantation of automated screening tools that could assess the impact of DER in the distribution system when a voltage campaign is requested. This would help to establish low installation costs while allowing for detailed evaluation;
- Invest in demonstration cases aiming to develop significant RES penetration.

5.2 FREQUENCY SUPPORT

5.2.1 Detailed Description of the service

The Continental European synchronously operated transmission grid is the largest synchronous electrical grid (by connected power) in the world. It lies from Portugal in the West to Western Denmark as well Estonia in the North, to Turkey in the East and Northern Africa in the South. Over 400 million customers in 25 European countries plus Morocco, Tunisia and Algeria are connected to the grid. It is fed with AC, which has a nominal frequency of 50 Hz. This frequency is common in large parts of the world with exception of North America, northern parts of South America, as well as some parts of Asia where 60.00 Hz is the defined grid frequency. The following figure illustrates the existing grid frequencies and voltages for each country.

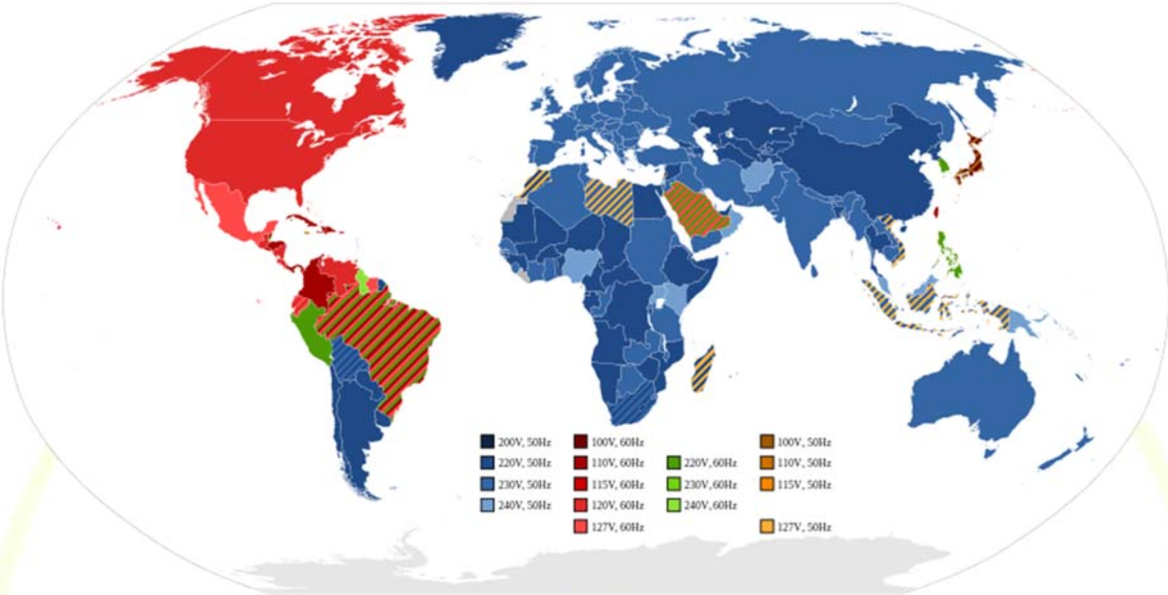


Figure 26 – Grid frequency and grid voltage by country [144].

In order to keep the grid frequency stable the amount of electricity that is generated by traditional or renewable power plants must be equal to the amount of energy that is consumed. If the power demand is higher than the current energy generation the necessary power is taken from the rotational energy of generators. As a consequence the speed of the generators is decreased resulting, in a lower frequency. Similarly, the speed and thus the frequency increase if there's a surplus of energy.

Various staggered control mechanisms are installed in order to keep the generation and demand in balance. The overall system balancing process is illustrated in Figure 27.

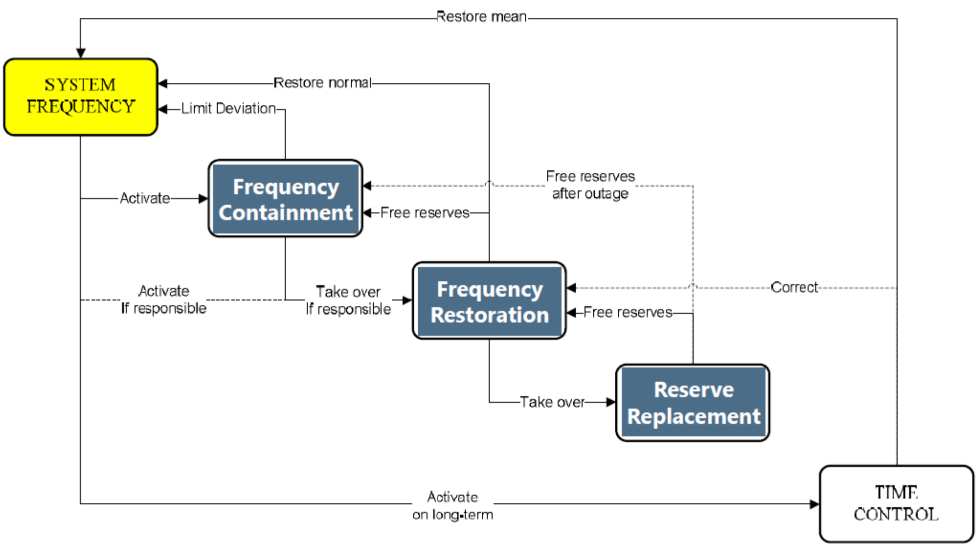


Figure 27 – System balancing process [145].

A certain deviation from the nominal frequency from up to ±20 mHz is tolerated with no counter measure. This range is derived from the sum of the accuracy of the frequency measurement and the insensitivity of the controller. However if the deviation exceeds the ±20 mHz the so-called frequency containment reserve (FCR) or primary control reserve is activated. It is the first step in the mechanism in order to bring back the frequency to the nominal value of 50.00 Hz. If the frequency exceeds 50.02 Hz all units that are committed to provide frequency containment service have to reduce the power output. For DR units it means that they have to increase the load since there's more power in the system than currently consumed. Similarly, the units have to decrease the load if the frequency falls below 49.98 Hz. FCR is provided linear up to 50.2 Hz respectively 49.8 Hz. The characteristic is illustrated in Figure 28.

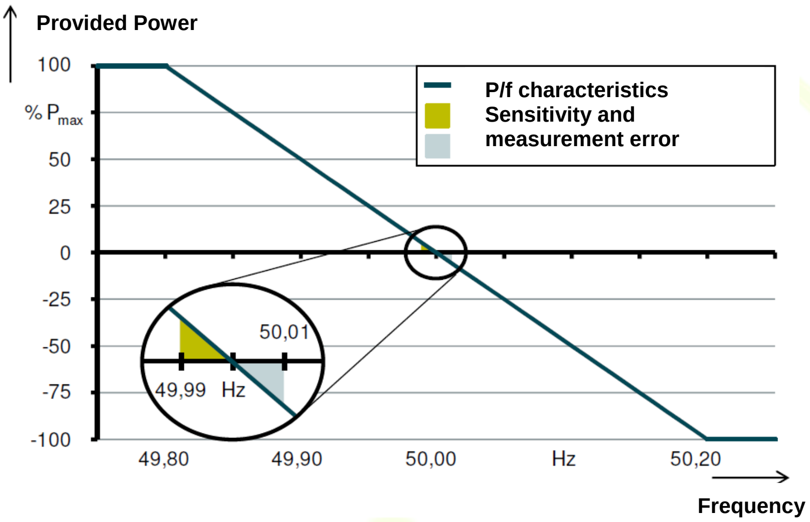


Figure 28 – P/f characteristics for Frequency Containment, referring to [146].

However the main purpose of the FCR is not to bring back the frequency to 50.00 Hz but to limit the frequency deviation and thus stabilize it. Since a quick response is required these reserves are activated fast, typically within 30s. It is a symmetrical product meaning that each unit has to provide power in both directions making it complex for demand-side units to participate. In order to support the frequency containment the droop or the reserve margin of synchronous generators are typically set. Nowadays, new players such as Energy Storage Systems enter the market as well. All participants have to pass a so-called prequalification process see chapter (5.2.3).

The required volume of FCR is at least equal to the largest single fault incident (usually largest generator tripping) and should be able to contain all incidents that can occur within the time to restore the frequency [145]. In the synchronous grid of continental Europe the overall primary control reserve (PCR) is 3,000 MW [147]. Due to an international FCR cooperation the German, Belgian, Dutch, French, Swiss and Austrian markets were coupled recently forming the largest PCR market in Europe with a total capacity of 1,250 MW [148]. There are two ways in order to procure the required capacity. The first one is a mandatory participation of each synchronous generator as specified in the grid code. The remuneration could be based on capacity, energy, market price, imbalance price or tariff or there is no numeration [145]. The second one is a reserve capacity market that uses contracts, tender or auctions in order to procure the capacity. The auctions for the PCR are usually held on a weekly basis, whereas other time periods such as daily are also possible. Figure 29, Figure 30 and Figure 31 give an overview of FCR characteristics in different European countries.

FCR (Frequency Containment Reserve)	Austria	Belgium			Denmark	Estonia	Finland		
Terminology	Primary Control	Primary frequency control (R1)			Primary Reserve (DK1)	FCR	Frequency containment reserve for normal operation (FCR-N)	Frequency containment reserve for disturbances (FCR-D)	
		R1-200 mHz	R1-Down	R1-Load(Up)				linear or partly linear	on-off model
Tot. Capacity	+/- 67 MW	28 MW	27 MW	27 MW	23 MW	0 MW	140 MW	220 - 260 MW	
Load Access & Participation	0	0	0	1	1	0	1 (1 MW)	1 (240 MW)	
Aggregated Load Accepted	0	0	0	1	1 (23 MW)	0	1	1	
Aggregated Generation	0	-	-	-	1	0	1	1	
Minimum Size	+/- 1 MW			1 MW	0.3 MW		0.1 MW	1 MW	1 MW
Notification Time	< 30 sec.			15 sec. (50%) 30 sec. (100%)	30 sec.		3 min.	50% in 5s, 100% in 30s	5s 49,7 Hz or 3 s 49,6 Hz or 1 s 49,5 Hz
Activation	Automatic			Automatic speed, rotation and frequency control system	Automatic		Automatic out of 49.90 - 50.10 Hz	Automatic < 49.9Hz	Automatic < 49.7Hz or 49.6 Hz or 49.5 Hz
Triggered (max. times)	No limit			No limit, but reasonable number of activations per year, about 80 min/year	10-20%		Several times per hour	Several times a day	Several times a year
Availability payments Utilisation Payments	22,01 €/MW/h			5-6 €/MW/h	Range: 50,000 to 200,000 DKK/MW per month		13,00 €/MW/h for yearly	4,7 €/MW/h for yearly	
Utilisation Payments	Not provided			0 €/MWh	Part of imbalance		0 €/MWh	0 €/MWh	
Access	tender-based			Monthly tender	Daily auction		Yearly Tender Hourly Market	Yearly Tender Hourly Market	

Figure 29 – FCR characteristics in different countries based on [149].

FCR (Frequency Containment Reserve)	France	Germany	Great Britain		Ireland	Italy	The Netherlands	Norway	
Terminology	Primary Control (Réglage Primaire de Fréquence)	Primary control reserve +/-	Frequency Control by Demand Management (FCDM)	Enhanced Frequency Response	Primary Operating Reserve	Primary Frequency Control	Primary Control	Frequency controlled normal operation reserve (FCR-N)	Frequency controlled disturbance reserve (FCR-D)
Tot. Capacity	600 - 700 MW	830 MW	not public	201 MW	50 MW (Short-Term Active Response)	1,5% of the total installed power	101 MW	214 MW	353 MW
Load Access & Participation	(1) 60 MW through FCR cooperation	1	1	1	0	0	0	1	1
Aggregated Load Accepted	1 through FCR cooperation	1	1	1	0	0	0	1	1
Aggregated Generation	1 through FCR cooperation	1	1	1	0	0	0	1	1
Minimum Size	1 MW	1 MW	3 MW	1 MW	None		1 MW	1MW	1MW
Notification Time	< 30 s	30 sec.	2s	1s	2s		max 30s	100% within 2-3 minute	50% in 5s, 100% in 30s
Activation	Automatic	Automatic	Automatic	Automatic	Automatic		Automatic	Automatic between 49,9-50,1Hz	Automatic < 49,9Hz
Triggered (max. times)	Triggered continuously	Up to several times per day	Around 11 times per year	Continuous operation	10-20 times per year		Permanent	Several times per hour	Currently approx. 10.000 min/year outside normal operating band
Availability payments Utilisation Payments	According to bid	Based on auction outcome	~£4/MWh	£7/MWh - £12/MWh	Not provided		Yes	Yes	n/a
Utilisation Payments	According to spot price	None	Not available	Not available	8,20 €/MWh		No	Marginal cost for zone: 1-40 €/MWh (hourly mkt); 1,12-18 €/MWh (weekly mkt)	n/a
Access	Weekly tender together with AT, DE, NL & CH TSOs (from 17 January 2017)	Weekly Auctions	Bilateral Contracts	Tender-based	Fixed		Common platform, weekly	Hourly-/Weekly Market	Hourly-/Weekly Market

Figure 30 – FCR characteristics in different countries based on [149].

FCR (Frequency Containment Reserve)	Poland	Portugal	Slovenia	Spain	Sweden		Switzerland
Terminology	Primary Reserve	Primary Control	Primary Reserve	Primary Control	Frequency Containment Reserves for normal operating band (FCR-N)	Frequency Containment Reserves for disturbances (FCR-D)	Primärregelleistung
Tot. Capacity	155~170 MW	Not applicable	Not available	Not applicable	230MW	412MW	75 MW
Load Access & Participation	0	0	1	0	1 (100kW Pilot)	1	1
Aggregated Load Accepted	0	0	0	0	1	1	1
Aggregated Generation	0		0		1	1	1
Minimum Size					0,1MW	0,1MW	1MW
Notification Time					63% in 60s, 100% in 3 min	50% in 5s, 100% in 30s	30s
Activation					Automatic when frequency is out of 49,9-50,1 Hz	Automatic with frequency under 49,9 Hz	Automatic
Triggered (max. times)					Contantly	Approx.1 500 times per year	Up to several times per day
Availability payments Utilisation Payments					Yes (Pay as bid)	Yes	19.67 CHF/MW/h
Utilisation Payments					Yes (Marginal price at RPM)	No	Not offered
Access	0				Daily	Daily	Tender-based

Figure 31 – FCR characteristics in different countries based on [149].

In the next step the frequency restoration reserve (FRR) kicks in and starts to replace the FCR. The objective of the FRR is to restore frequency to the target frequency of 50.00 Hz. It is activated within 15 minutes since the FCR is designed to provide power for the same period of time. The FRR can be activated manually (mFRR) or automatically (aFRR). Via a central Load Frequency Controller (LF Controller) the aFRR is instructed by the TSO and automatically activated at the aFRR provider. Every 4 to 10s the LF Controller may provide new activation requests to the units, which provide the necessary power within typically one minute [150]. Yearly contracts or weekly as well as daily auctions are common procurement channels for aFRR. The procurement of mFRR is mostly done through the submission of bids to a bid ladder with volume and energy price. The bidding for up- and downward regulation is separated [145]. Figure 34, Figure 35 and Figure 36 illustrate the characteristic of the aFRR in different countries in Europe.

aFRR (automatic Frequency Restoration Reserve)	Austria						Belgium		Denmark	Estonia	Finland	France
Terminology	Secondary Control						Secondary Reserve (R2)		Secondary Reserve (DK1)	aFRR	Automatic frequency restoration reserve (aFRR)	Secondary Control (Réglage Secondaire de Fréquence)
							R2-Down	R2-Up				
Tot. Capacity +/-	+200 MW			-200 MW			140 MW	140 MW	100 MW	0 MW	70 MW	600 - 1000 MW
Load Access & Participation +/-	1			1			0	0	1	0	0	(1) Q3/Q4 2016, for arounf 10 MW
Aggregated Load Accepted +/-	1			1			0	0	1	0	0	(1) via secondary market
Aggregated Generation +/-	1			1			-	-	1	0	0	1
Minimum Size +/-	+ 5 MW			-5 MW					1 MW		5 MW	1 MW
Notification Time	> 30 sec., < 15 min.								15 min.		2 min.	< 400 sec.
Activation	Automatic								Automatic		Automatic	Automatic
Triggered (max. times)	No limit								0,2 %		Several times a day	Unlimited
Category	+ Peak	+ Off Peak	+ Weekend	- Peak	- Off Peak	- Weekend						
Availability payments/	7,38 €/MW/h	9,75 €/MW/h	7,82 €/MW/h	6,72 €/MW/h	14,20 €/MW/h	20,28 €/MW/h			Long term contract with Norway		0 €/MW/h	160k€/MW/y for obligations. Free deals on secondary market.
Utilisation Payments	119,03 €/MWh			-123,09 €/MWh					no		0 €/MWh	Spot price
Access	tender-based	tender-based	tender-based	tender-based	tender-based	tender-based			Long-term tender (5 years) Auctions if more is needed		Hourly Market	Obligation to provide (or contract a substitute) for generators, DSR participation through secondary market only; pro rata activation

Figure 32 – aFRR characteristics in different countries based on [149].

aFRR (automatic Frequency Restoration Reserve)	Germany		Great Britain			Ireland	Italy	The Netherlands
Terminology	Secondary control reserve		Firm Frequency Response (FFR)		FFR Bridging	Secondary Operating Reserve	Secondary Frequency Control	Regulating Capacity
	SCR +	SCR -	Dynamic	Non-Dynamic				
Tot. Capacity +/-	1976 MW	1907 MW	354,6 MW	0 MW	10 MW	50 MW (Short-Term Active Response)	568,41 MW	300 MW, yearly procurement; Additional voluntary/spontaneous
Load Access & Participation +/-	1	1	1	1	1	0	0	1
Aggregated Load Accepted +/-	1	1	1	1	1	0	0	1
Aggregated Generation +/-	1	1	1	1	1	0	0	1
Minimum Size +/-	5 MW (1 MW if no other offer)		1 MW	1 MW	1 MW	None		4 MW
Notification Time	5 min.		10s - 30s	10s - 30s	10s - 30s	2s		30s
Activation	Automatic		Automatic	Automatic	Automatic	Automatic		Automatic
Triggered (max. times)	Up to several times per day		Pre-fault dynamics: continous Post-fault static: 11 times per year	Pre-fault dynamics: continous Post-fault static: 11 times per year	Post-fault static: 11 times per year	10-20 times per year		per 4s
Category								
Availability payments/	Based on auction outcome		£3,39/MWh	£3,39/MWh		Not provided		Yes
Utilisation Payments	Based on bids		£1,47/MWh	£1,47/MWh		8,20 €/MWh		€70/MWh over day ahead price
Access	Weekly Auctions – likely to be changed to daily in 2017		Tender-based	Tender-based	Tender-based	Fixed		Yearly call for tender + voluntary bids

Figure 33 – aFRR characteristics in different countries based on [149].

aFRR (automatic Frequency Restoration Reserve)	Norway	Poland	Portugal	Slovenia		Spain	Sweden	Switzerland
Terminology	Automatic frequency restoration reserve (FRR-A)	Secondary Reserve	Secondary Control	Secondary Reserve +	-	Secondary Control	Automatic Frequency Restoration Reserves (aFRR)	Sekundärregel leistung
Tot. Capacity +/-	300 MW in the Nordics (105 MW Norwegian share)	540~500 MW	2.559 GWh	60MW	60MW	2.559 GWh	~100MW	378.23 MW
Load Access & Participation +/-	1	0	0	1	1	0	1	1
Aggregated Load Accepted +/-	1	0	0	1	1	0	1	1
Aggregated Generation +/-	1	0		0	0		1	1
Minimum Size +/-	5MW						5MW	5MW
Notification Time	2min						2min	200s
Activation	Automatic based on Nordic frequency						Automatic	Remote-controlled
Triggered (max. times)	No maximum						Constantly	Up to several times per day
Category								
Availability payments/	Yes						Yes	25.68 CHF/MW/h
Utilisation Payments	Best price either mFRR or spot						Yes (Marginal price at RPM)	Based on SwissIX
Access	Weekly Market	0					Monthly	Tender-based

Figure 34 – aFRR characteristics in different countries based on [149].

The last step in the mechanism for frequency regulation is the activation of RR. As soon as the frequency is restored the FCR is deactivated. The activation of the FRR ends when the RRs have taken over. In contrast to FCR and FRR the RR have no defined activation end. Instead it is terminated through a market reaction [145]. The complete imbalance recover process is illustrated in Figure 35.

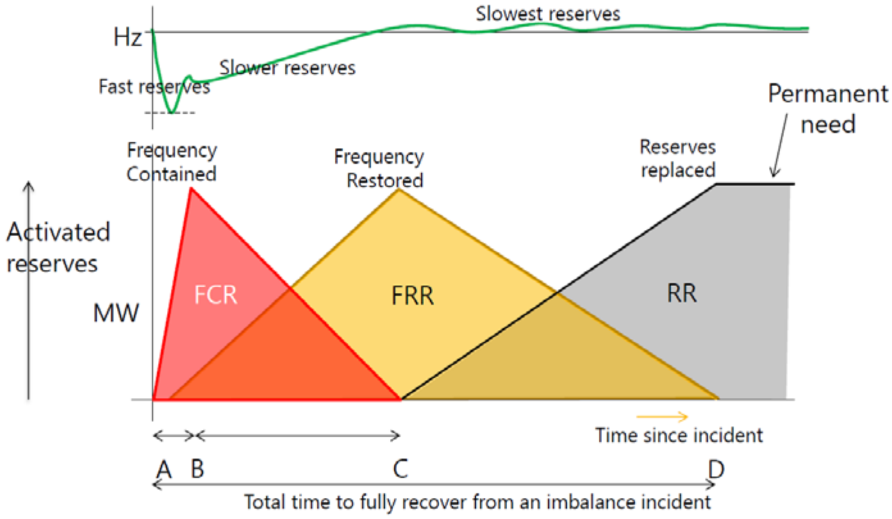


Figure 35 – Imbalance recovery process by staggered activation of reserve products [145].

5.2.2 Types of resources for providing this specific service

There are several types of resources that can be used for frequency support. These units range from small demand appliances, e.g. electrical boiler, refrigerator, washing machine, lightning devices as well as EVs to large-scale appliances such as electrolysis, heating or cooling devices in production processes. In commercial and residential buildings mostly cooling, heating, lightning and ventilation devices can be found. For municipal functions outdoor lightning as well as fresh and waste water pumping are of relevance. Last but not least data centers, agricultural pumping as well as refrigerated warehouses feature potential for DR services.

As Figure 36 illustrates those devices can be used for different bulk services. According to [151] especially heating, cooling as well as lightning devices can be operated flexible and thus are suitable devices for frequency regulation.

	Bulk Power System Services			
Resources	Frequency Regulation	Ramping Reserve	Contingency Reserve	Energy
Commercial Buildings				
Cooling	X	X	X	X
Heating				X
Lighting		X	X	
Ventilation	X	X	X	
Residential Buildings				
Cooling	X	X	X	X
Heating	X	X	X	X
Water heating	X	X	X	X
Municipal Functions				
Outdoor lighting	X	X	X	
Freshwater pumping				X
Wastewater pumping				X
Industrial Non-Manufacturing				
Data centers			X	X
Agricultural pumping			X	X
Refrigerated warehouses				X

Figure 36 – Eligibilities of different resources for Bulk Power Services [151].

Besides, industrial processes consume a lot of power and thus are able to provide DR services as well. Not every industry might be suitable for providing specific services but, as Figure 37 shows, there are a number of processes that can be used for frequency regulation.

		Bulk Power System Services			
Industry SIC	Dominant Process	Frequency Regulation	Ramping Reserve	Contingency Reserve	Energy
Food and Kindred Products					
20	Packaging				X
20	Chiller	X	X	X	X
Textile Mill Products					
22	Wrapping				X
22	Weaving				X
Apparel, Finished Products from Fabrics and Similar					
23	Wrapping				X
23	Weaving				X
Lumber and Wood Products, Except Furniture					
24	Sawing				X
24	Planning				X
Furniture and Fixtures					
25	Sawing				X
25	Planning				X
Paper and Allied Products					
26	Chipper				X
26	Dewatering Press	X	X	X	X
Printing, Publishing and Allied Industries					
27	Chipper				X
27	Dewatering Press	X	X	X	X
Chemicals and Allied Products					
28	Electrolysis	X	X	X	X
28	Compressor	X	X	X	X
28	Grinding				X
Petroleum Refining and Related Industries					
29	Catalytic Cracking	X	X	X	X
Rubber and Miscellaneous Plastic Products					
30	Mixing	X	X	X	X
30	Mill				X
Leather and Leather Products					
31	Mixing	X	X	X	X
31	Mill				X
Stone, Clay, Glass, and Concrete Products					
32	Electric Furnace	X	X	X	X
32	Crushing				X
Primary Metal Industries					
33	Electrolysis	X	X	X	X
33	Crushing and Classifying				X
Transportation Equipment					
37	Metal Cutting				X
37	Final Assembly	X	X	X	X

Figure 37 – Eligibilities of industrial resources for Bulk Power Services [151].

In order to estimate the flexibility that load devices can provide the operation profile and in particular the availability needs to be well known. Each DR resource has different hourly, daily, weekly, and seasonal availabilities. As an example Figure 38 depicts the average hourly availabilities for ramping reserves in Colorado, USA. It can be observed that the availability of municipal lighting tends to peak between 8 pm and 4 am. In commercial and residential buildings availability of DR resources is given during the whole day with peak availability around 5 pm.

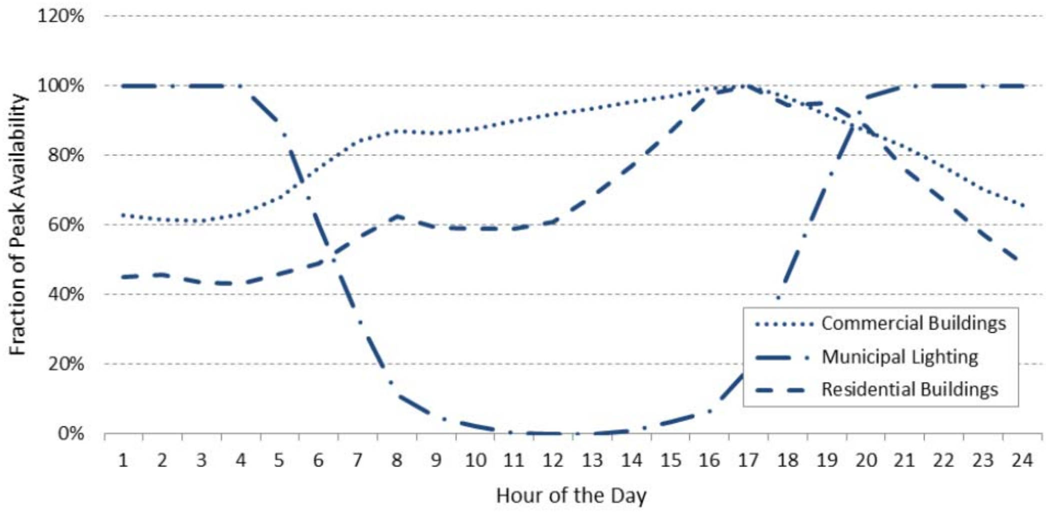


Figure 38 – Average hourly availabilities for ramping reserves from different types of DR resources in the Colorado system model compared with the average system load [151].

By looking at different months and seasons of the years it becomes obvious that cooling in residential as well as commercial buildings and refrigerated warehouses have peak availabilities in the summer time. On the other hand municipal lighting, commercial heating, and residential heating have peak availabilities in the winter. Data centers, residential water heating, commercial lighting, commercial ventilation, municipal pumping, and wastewater pumping loads are daily used and thus have fairly constant availabilities over the whole year, with regular weekday-weekend usage patterns [151]. The overall analysis in Figure 39 illustrates that especially during summer months, availabilities are higher than in winter months.

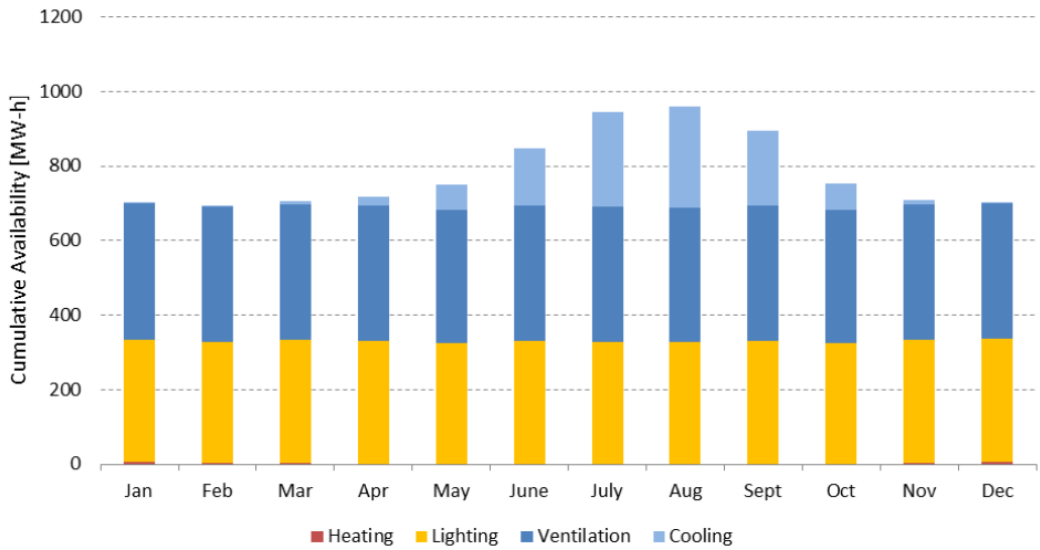


Figure 39 – Monthly availabilities for ramping reserves from different types of demand resources in Colorado.

5.2.3 Technical implications/barriers (equipment, communication, regulatory frame-work)

First of all, from a technical point of view, any DR unit must be able to adapt its load, at least in one direction. For the provision of aFRR a continuous ramp up and down is a requirement. In order to provide frequency support each DR unit must be connected to a frequency measurement unit or in the case of aFRR to the LF controller via an aggregator. In addition, supporting ICT infrastructure must be in place in order to receive signals and to provide data.

Through the so-called pre-qualification process, potential suppliers of frequency support provide the proof that their DR units are capable to ensure the security of supply. In order to qualify for market participation for frequency support services DR units first need to provide geographical and technical information such as

- Location of supply;
- Technical realization;
- ICT infrastructure;
- Available power;
- Accuracy of frequency measurement;
- Response time;
- Ramp rate;
- System availability.

Potential suppliers can choose to qualify for one frequency-support mechanism or several ones. Each DR unit has to demonstrate that it can change its load within a specified period of time. The required power profile for FCR is illustrated in Figure 40. As it can be seen DR units have to provide the full power for 15 minutes. After a pause of 15 minutes the provision of full power is required again. The activation and deactivation time is in both cases less than 30 sec. In order to guarantee that the time requirements are met not only the reaction time of the DR unit but also the time for the processing of signals and commands needs to be considered.

In case that more power is generated than consumed the frequency rises in the grid. As a consequence, power generators have to increase their load, which is represented on the right y-axis of Figure 40. On the contrary for a DR unit it means that the load must be increased.

For providing FCR usually positive as well as negative power adjustment needs to be performed depending on the frequency in the grid. Out of this reason not only the profile in Figure 40 but also a profile mirrored around the x-axis must be fulfilled during prequalification.

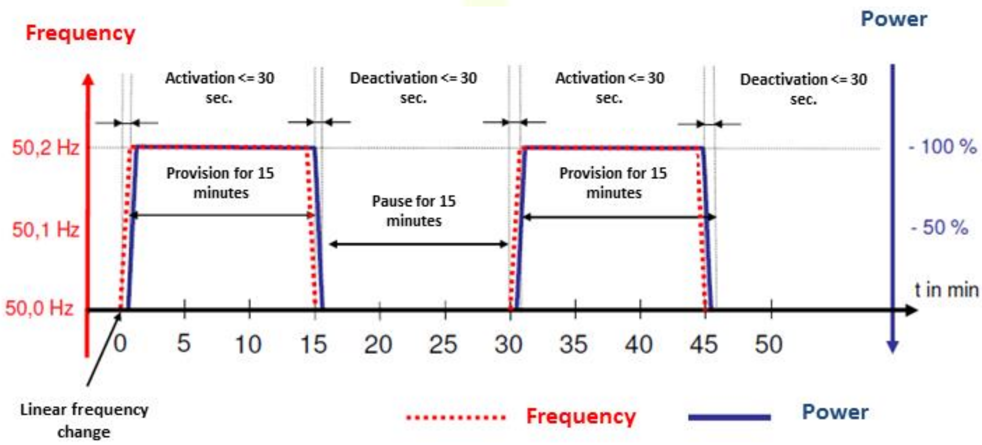


Figure 40 – Required power profile of FCR during prequalification.

The power profile for prequalifying for aFRR is somewhat comparable to the FCR. Instead of an activation and deactivation time of 30 sec there's an allowed time span of up to 5 min. After activation the DR units need to provide the full power for 10 minutes before being deactivated. Afterward there's a pause for 10 minutes. The profile in Figure 41 represents the deactivation of load in case positive FRR is demanded. In some markets DR units just have to provide either positive or negative FRR and not necessarily have to qualify for both directions.

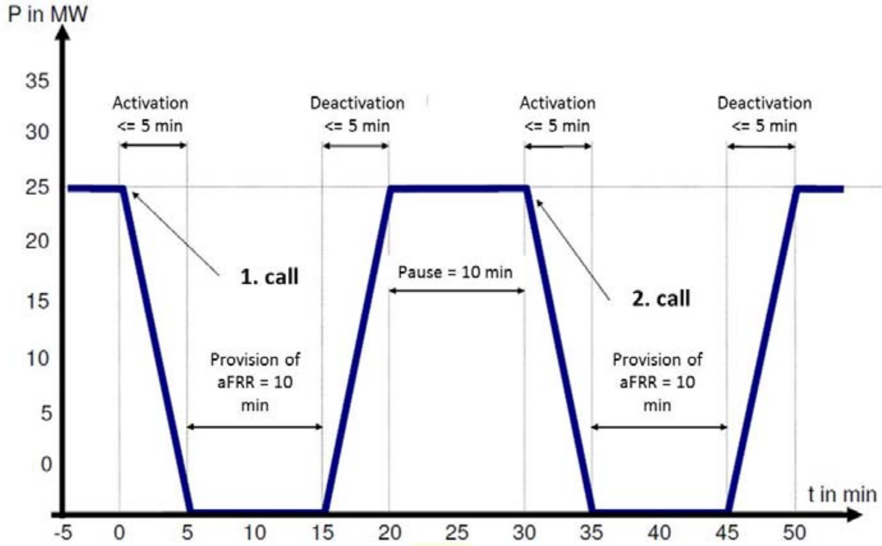


Figure 41 – Required power profile of aFRR during prequalification.

After a positive prequalification the supplier is entitled to participate in the market via tenders or auctions. However as illustrated in Figures 29-34 frequency support services require in many countries a minimum size, often several Megawatts. In order to reach that threshold either large-scale DR or several aggregated small-scale units can participate.

Another technical requirement that has to be fulfilled is the frequency measurement accuracy. Here an accuracy of at least ±10 mHz is required. Nowadays meters with an accuracy better than ±1 mHz and a resolution of 0.1 mHz are available. These devices also feature time synchronization via GPS [152].

If one or several DR units are not able to provide the agreed service penalties will be imposed. This includes either a time-limited exclusion from the participation in the balancing markets and also punitive damages. In the case of repeated non-delivery/under-performance, the prequalification process has to be repeated. [149]

5.3 CONGESTION MANAGEMENT

5.3.1 Detailed description of the service

5.3.1.1 Problem description

Grid congestion occurs when the existing transmission and/or distribution lines cannot handle the required load during periods of time with high demand or during emergency load conditions. Grid congestion not only impacts reliability, it also reflects a decrease in energy efficiency [153]. The network constraints set the amount of power that can be transported between two points on the grid.

Network congestion has two important implications. First, it reduces the amount of electricity at low cost that can flow through the network and finally this reverts into the consumers' bill. Second, the increasing load on the network results in high transmission and distribution losses [154]. Under high load conditions, line losses grow exponentially. If the lines are congested and operating at/or near their thermal limits, they would also have important line losses during high load conditions [153].

The main goal of congestion management is to minimize both the congestion and the operational costs. But focusing in minimizing the congestion, this objective can be represented mathematically with the following equation [155]:

$$Minimize\ OL = \sum_{I=1}^{nl} (S_i - S_i^{max})^2$$

OL= cumulative overload; nl=overloaded line; S_i=apparent power on line i; S_i^{max}=maximum apparent power capacity

5.3.1.2 Root causes

Congestion in Smart Grids is a usual problem most of all because of peaks of demand of the customers supplied by the DSO, the high penetration of intermittent RES and the diminution of spare capacity of the grid. In a competitive energy market, the grid usually operates very close to its maximum capacity limits [155]. In the near future, in accordance to the prevision of EV penetration in the market, this problem is likely to become worst due to the extra nightly concentrated load introduced to the grid by the charging needs of those vehicles.

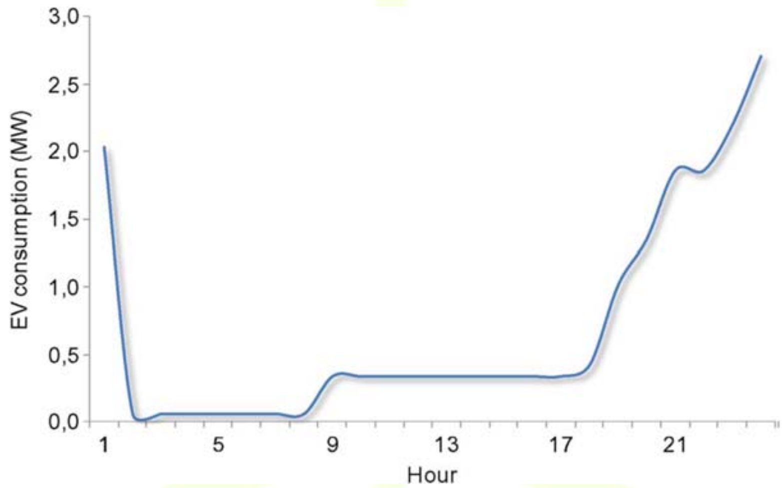


Figure 42 – EV consumption along a typical day for dumb charging (10% EV penetration) [156].

Generally, congestions in a distribution grid may be caused by diverse factors such as: [155] [157] [158]

- Very high power consumption during peak hours;
- Concentrated charging of EVs;
- Excessive power generation from DERs;
- Lack of coordination between generation and transmission companies;
- Unexpected line outages;
- Generator outage;
- Failures in essential equipment.

The lack of coordination of DERs operations may create unexpected congestion in the distribution grid. The most critical negative impact that DERs can introduce into the distribution grid is the congestion because it may result in the damage of some devices, such as transformers and feeders [157].

5.3.1.3 Solutions

The main solution of congestion issues in a long-term horizon is the construction of new transmission and distribution lines. However, this solution is usually followed by political and environmental issues that require huge expenses and a considerable amount of effort and time. There are also short-term solutions such as the re-scheduling of contracts, load shedding in critical conditions and generation re-dispatch. These short-term solutions are costly and also raise the prices, which finally trickle down to the consumers. Nevertheless in some cases, some control devices such as FACTS (Flexible Alternating Current Transmission Systems) are available to solve the problem having low operational costs [159]. There are other cost-free ways to solve the congestion issues that affect the grid, such as the network reconfiguration and the operation of transformer taps.

In general, three main forms of congestion management in electricity markets exist [158]:

- Centralized optimization with some form of optimal power flow program;
- Use of tariffs and/or price signals derived from the market in order to mitigate congestion by generation re-scheduling;
- Allowing or not allowing bilateral agreement between producers and consumers.

Moreover, DSOs and TSOs are able to use some new techniques, such as DR campaigns, that can be used to alleviate or mitigate the congestion problems. Deploying DR mechanisms at appropriate places would allow the grid to operate at lower cost and, in addition, the investment in new transmission lines can be postponed maintaining the current reliability level [158]. DR programs can be used for motivating the interactions between power system dispatchers and power consumers.

DR seems to have many benefits such as the better utilization of RES, the enhancement of network reliability and the improvement of the load capacity of the transmission lines. In addition, these new techniques may allow new degrees of freedom as an additional decision variable to be considered in the optimization problem. It seems to be so advantageous and beneficial than other means when applied to relieve congestion [160] [161].

5.3.1.4 DR Strategies for Congestion Management

Peak Clipping

- Reduction of system peak load by utilities using direct load control;
- Means to reduce peak capacity procurement;
- Programs are expanded to also address transmission distribution congestion management.

Load Shifting

- Shifting load from on-peak to off-peak periods (i.e. from high prices periods to low price periods);
- Displacing conventional appliances served by electricity;
- Use of storage water heating, storage space heating;
- Programs are expanded to address transmission distribution congestion management.

Flexible load shapes (dynamic energy management)

- Concept related to reliability and planning constraints;
- When the anticipated load shape is forecasted customers are presented with options as to the variations in quality of service that they are willing to allow in exchange for various incentives;
- Interruptible/curtailable load;
- Dynamic (manual and automated) control of devices.

Strategic Conservation (energy efficiency)

- Results from overall efficiency (such as the installation of energy efficient light bulbs, buying energy efficient appliances, unplugging appliances when not in use, etc.);
- Changes in the overall patterns of appliance use;
- Programs reduce overall electricity consumption, also at times of peak demand.

There are several studies and experiences that show the convenience of using DR for tackling congestion issues. One of them made by [162] shows a European scenario in which three different cases are studied: A reference case with no DR envisaged, a case where 10% of the load for a region during an hour can be delayed up to six hours and one with 20% and a delay time of up to 24 hours (all of that mapped with the wind power production).

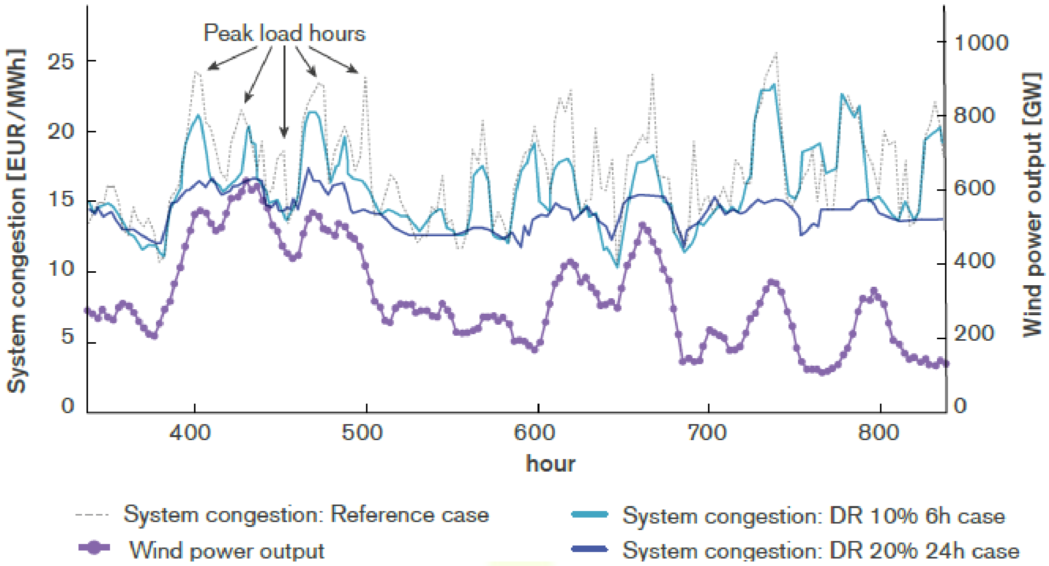


Figure 43 – System Congestion and total wind power generation for three winter weeks [162].

As it is possible to see in Figure 43, a delay of 10% in a region during an hour is not so relevant in order to alleviate congestion but, the third scenario; with a 20% of delay and a time close to 24 hours, can provide substantial benefits to the grids in terms of managing the congestion.

The DSO has to choose and apply the best technique taking into account the technical, economic and environmental variables with the help of models that should incorporate the impact of the congested lines and also the analysis of the different possible scenarios [159].

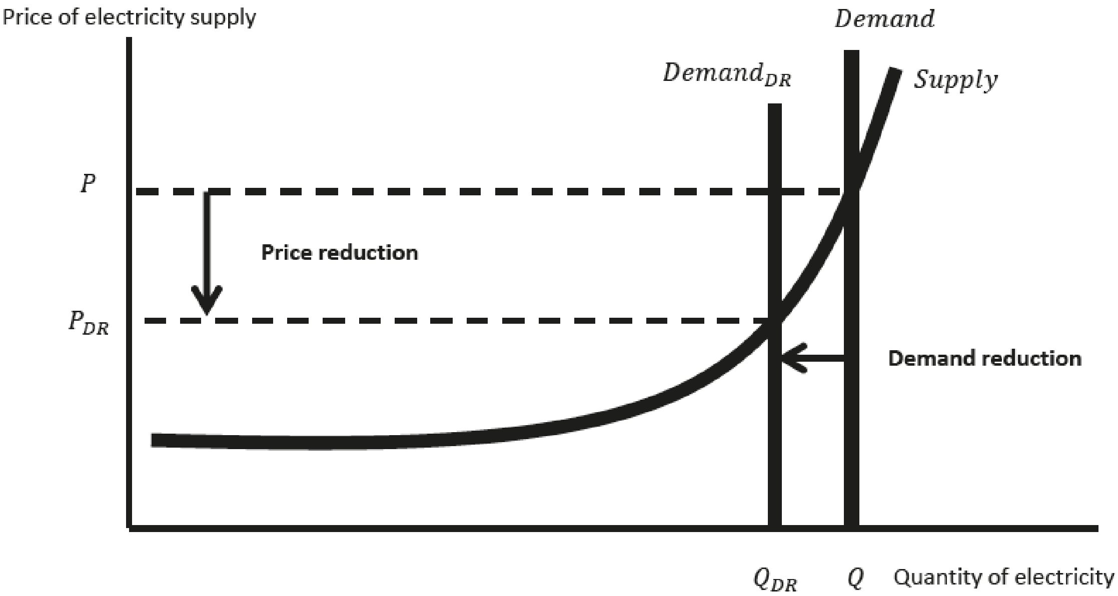


Figure 44 – DR effect on price [163].

As it is possible to see in the picture showed above, the demand reduction motivated is not only beneficial for the system operator and it is also useful for the consumer. A DR campaign can result in a significant price reduction of the electricity supply – at least in the wholesale energy market - than can be even more interesting thanks to its exponential shape.

In order to perform correctly these DR strategies, some type of technologies have to be deployed such as:

- Application of sensors at the very ends of the distribution grid and smart meters as well as other sensors on distribution stations.
- Efficient collection of data must be validated by putting it into context and if necessary supplemented by the inclusion of a picture of the network (state estimation).
- Simulation of the load flow model of the grid with the forecasted production and demand, in order to identify occurrence and location of future congestion threats.

5.3.2 Types of resources for providing this specific service

The congestion produced in the distribution grid can be mitigated by the optimal utilization of DR resources by means of nodal prices and other incentives. It is possible to divide into flexible loads and ILs taking into account their different characteristics. Flexible loads such as EVs and smart household electric appliances could be shifted within a specific period of time without affecting the comfort and lifestyle choices of consumers as long as the processes could be completed. ILs such as industrial loads, lighting devices and some others have to be economically compensated with incentives [157].

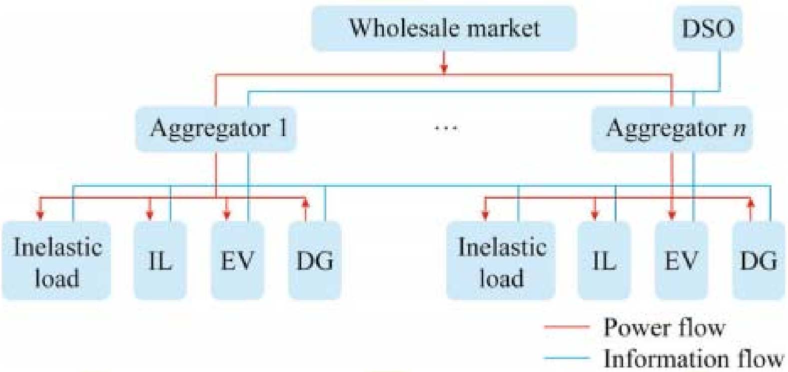


Figure 45 – Market structure of Smart Distribution Grid [157].

For achieving a successful implementation of DR strategies, a set of possible load buses should be selected in advance according to their influence on the network response. Regarding that, are chosen the loads with the higher impact on the affected grid. The highest priority has to be given to the resources with greatest volumes. Nevertheless, this criterion is subject to the availability of the responses from the demand side at the specified places [158] and the degree of implication in DR campaigns of the clients of the affected zone.

In the congested places, in order to solve the congestion issue, local facilities are more effective than the remote ones. Despite that, remote facilities may be cheaper than the local ones. So it is essential to choose the optimal set of utilities in order to minimize the operation costs [155].

5.3.3 Technical implications/barriers (equipment, communication, regulatory framework)

The following list includes necessary consideration for properly integrating DR mechanisms to deal with congestion management:

- Deployment of extensive sensor devices and smart meters in the grid, providing detailed operation data, and particularly providing fine-grained measurements of production units;

- Deployment of the necessary ICT infrastructure and mechanisms to retrieve the sensor and smart meter information in real time;
- Integrating proper demand/production forecasting models into the toolset used by the DSOs to manage their grid;
- Adoption of state estimation algorithms, increasing the visibility of the grid and allowing estimation at future times (by being fed with forecasted data);
- Existence of an operational mechanism to put in contact the DSO (handling the problem) with the aggregators (providing support by means of adjustable flexibility):
    - USEF framework defines a market suitable for long-term operations;
    - OpenADR defines an open and interoperable information exchange model targeting dispatch of controllable assets, thus suitable for automated DR campaigns with lower response times;
- Identification of proper incentives to promote participation of individuals in DR programs.

5.4 RES CURTAILMENT AVOIDANCE

5.4.1 Detailed description of the service

5.4.1.1 Description and operation

Power plants, regardless of size, which use renewable energies for electricity generation have intense problems linked to RES behavior. These are, in most cases, intermittent and dispersed, characteristics that do not favor their integration in the market, because they can cause problems arising from the fluctuations in the energy injection to the distribution network.

In spite of these difficulties associated with RES, they are an ideal source for the production of electricity and must, as much as possible, optimize these resources and their operation, in order to achieve an overall improvement in the network through their penetration and integration.

Figure 46 – Load profile whole Spanish System, 18-10-2017.

The correct integration of RES, either through large power plants or DER, involves the end user to an active implication, with a greater or lesser impact. This effect depends on the demand for quantity and schedule.

Irrespective of the renewable energy used, as mentioned above, volatility and intermittency are intrinsic characteristics of their behavior. However, as the technology and the study of each one of them independently progresses, the behavior or generation, of the available resources are improved. With this information, RES could be used as conventional energy sources, limited to certain periods of time.

Nevertheless, it is important to bear in mind that the evolution of the social mentality and the awareness about the preservation of natural resources and the state of the planet (environment) favor the use of these energy sources as opposed to the conventional ones (coal, nuclear, fuels fossils etc.).

As mentioned previously, RES are intermittent in their production, becoming null during some periods of the day. Therefore, a correct modulation of the demand is important, transferring, as much as possible, the consumption to hours when renewable energy, of any kind, are at maximum production points.

This action is carried out by the so-called DR mechanism. The aim is to achieve, through various methods, a change in the users' consumption habits; focusing, in this case, on the increase of the consumption of the renewable energies at the expense of the conventional ones.

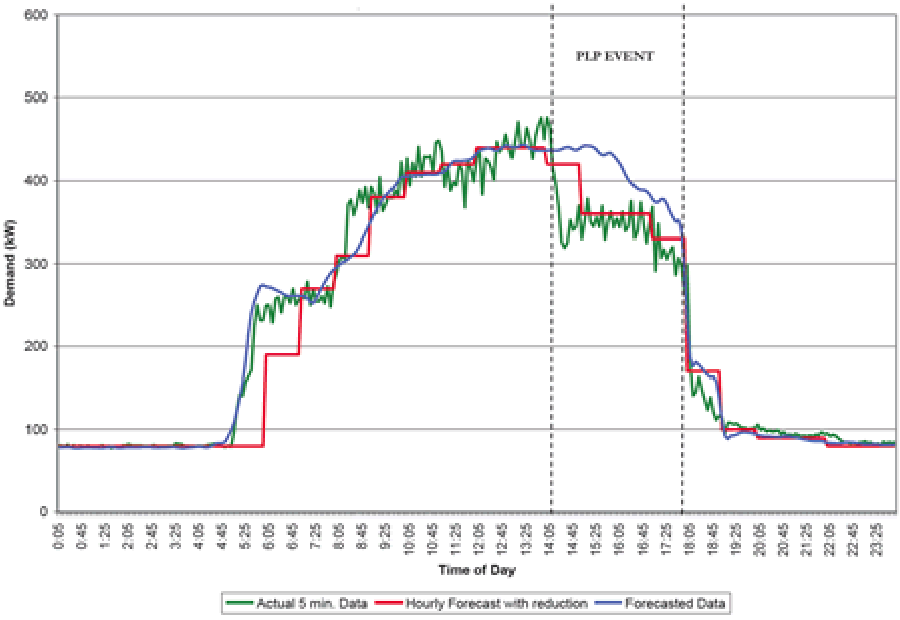


Figure 47 – DR example [164].

First of all, as mentioned in previous paragraphs, we must assume the volatility of the RES and look for increasingly accurate ways to obtain reliable predictions about their production, by performing forecasts as accurate as possible. This plays a crucial role for integration in the electricity market, along with the rest of productions.

Once the forecasts are obtained with a sufficient precision, the demand curve must be modulated to follow RES generation to the extent possible. This concept has a double function, because it is not based on a simple addition of loads, but on a transfer of the loads from the hours without production, or with a low production, to those of RES maximum performance.

The fact that consumers, with a crucial role in this process, modify their loads and consumption habits has an associated cost. On the one hand, users should be encouraged to eliminate loads at times that are not attractive from the point of view of RES, and, on the other hand, to make it easier for consumers to move to high production hours out in those periods. The easiest way to carry out this process is through economic incentives in two ways: positive and negative. The positive incentives will materialize in form of economic benefits for users, in other words, when they do not consume during a certain period they are assigned a remuneration according to not used power; this power has been labeled with the term negawatt. As opposed to these, to encourage consumption at certain times, the price must be enough competitive to make this an attractive option. It should be noted that not only are consumptions migrated, due to the user is a very active role in this system some consumption can be deleted. It all depends on the users.

In addition to the users who always act actively in this process, the concept of DR from the point of view of RES forces the existence of a kind of consumers who play the role of ancillary reserves. These users will not always actively participate in this process, they will only act when the forecasts, both generation and consumption, differ enough from the planning. These users should be prepared to consume, or stop consuming, at certain times, like normal users, but with a smaller reaction time the order of minutes or an hour.

For presenting this option to the users as an attractive offer, a system similar to that of the usual consumers of the DR process should be proposed, but offering even more interesting incentives, either by offering lower prices or by repaying larger amounts. This increase of the benefits for the auxiliary consumers will favor, consequently, an improvement in the aspect of the appraisal of generation and demand of the generating plants through RES.

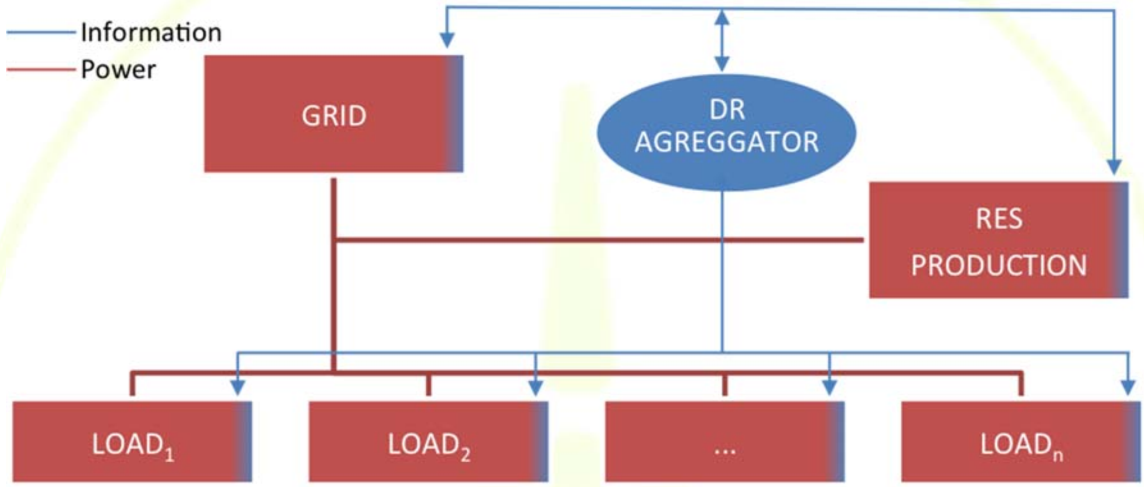


Figure 48 – Power and communication flux view.

5.4.2 Types of resources for providing this specific service

As discussed in Section 5.4.1, the way in which the grid can notice a load displacement, or complete elimination, can be divided into two subgroups depending on the perception of the user of the state of the loads. This load' perception has a direct implication in the user consumption habits, because they are different concepts depending on they are modified or not.

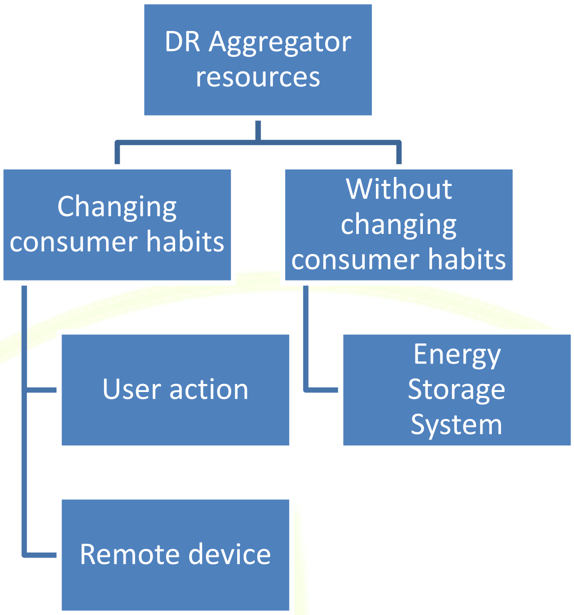


Figure 49 – Schematic view of DR Aggregator resources.

First of all, it is necessary to take into account the consumption curve modulation, from the DR aggregator, by means of a modification in the consumption habits of the user. As has already been in certain countries, such as the United Kingdom, the operator establishes a communication channel, via telephone, for example, informing the customer about the periods of the day when they must consume or not. These periods, as already mentioned, should have an economic advantage by contributing, overall, to a normalization of the whole system consumption curve. This type of control does not have any technological implication behind-the-meter, since it is the user who is responsible of the entire process, after the warning of the DR Aggregator.

The next technological step involves automation about the connection and disconnection of loads. This control of the loads can be done by monitoring some individual lines of the house, through a meter with several inputs or even directly measuring certain appliances or devices in general, by means smart plugs. In this type of load control, the possibility must be raised that the DR Aggregator can connect (turn on the power) or disconnect certain loads, or always must be authorized by the user to modify the load state.

Finally, there is a third option whose operation is not based on the modification of the users demand curve: energy storage systems. With the implementation, and use, of these devices, it is possible to unlink the actions of the DR Aggregator of the user consumption curve, using the capacity of the battery as a flexible system that allows to act in function of the requirements of RES production Through a real-time control, or a close-to-real-time, a level of efficiency is achieved in the grid, both globally and in the case of RES production, which is not accessible by another method. In this way, the auxiliary consumer figure disappears, since the needs can be diversified in a much more efficient way among all the users of an Energy Storage System (ESS).

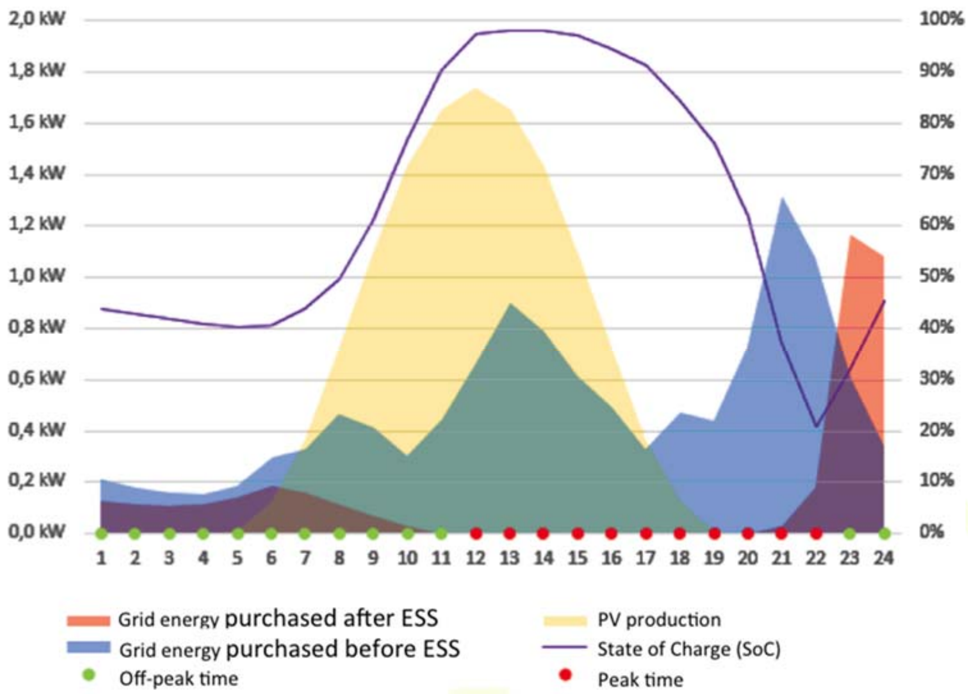


Figure 50 – Estimated operation example of ESS with PV system

In addition, as an added value, it must be taken into account that a DR is guaranteed with almost total independence of the user's needs and therefore it is always feasible, unlike other methods that are subject to the direct action of the user.

5.4.3 Technical implications/barriers (equipment, communication, regulatory framework)

The technical requirements are divided into three groups, in function of the user action level required.

- Controlled by user
  - Communication infrastructure or platform
  - Knowledge about user status and load profile
    - Preliminary study about load types
    - Periodical studies
  - Low accuracy from users → They are not forced to obey these actions
- Remote control
  - Remote control devices development.
  - Communication and control platform to govern every device.
  - Multiplies devices for ever user
  - Medium accuracy from users → They are able to ignore the DR Aggregator advice
- ESS as DR option
  - Database platform
  - ESS development

- Processor cloud and server
- High accuracy without users → Users requirements and DR Aggregator orders are independent.

6 CONCLUSIONS AND NEXT STEPS

The work presented in this document covers all aspects of DR through systematic enumeration and detailing of existing and new DR technologies and their individual characteristics. This is a necessary first step in order to identify the suitability of each different DR strategy and type of resource in achieving the objectives as set by the interested stakeholder, while –within WiseGRID– a special focus on services provided to the distribution grid is given.

The analysis performed within T10.1 and documented here indicates that the potential for exploiting DR in its various forms, as identified here, is significant and can be beneficial –if properly designed–for all stakeholders of the distribution grid. Without remaining oblivious of several challenges (pertaining to aspects of technical, economical and –most importantly– social nature) to be faced during the design, promotion, adoption and operation phases, the great variety of DR strategies allows their integration to the operation of the distribution grid in diverse situations and operational time scales, which –along key enabling technologies– constitutes a strong driver for promoting DR. Keeping in mind that the ultimate goal of SP5 is the development and implementation of the functionalities of the WiseHOME app, the work presented in this document will prove to be of practical use within the proceedings of WP10 and WP11.

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7.2 ACRONYMS

Acronyms List	
AC	Alternating Current
ACER	Agency for the Cooperation of Energy Regulators
AEMO	Australian Energy Market Operator
aFRR	automatic Frequency Restoration Reserve
AMI	Advanced Metering Infrastructure

Acronyms List	
ARENA	Australian Renewable Energy Agency
AS	Ancillary Services
BEMS	Building Energy Management System
BRP	Balance Responsible Party
BSP	Balance Service Provider
CACM	Capacity Allocation & Congestion Management
CAISO	Californian Independent System Operator
CHP	Combined Heat and Power
CPP	Critical peak pricing
DER	Distributed Energy Resource
DG	Distributed Generation
DLC	Direct Load Control
DMS	Distribution Management System
DR	Demand Response
DSO	Distribution System Operator
EB	Electricity Balancing
EMCS	Energy Management Control System
EMS	Energy Management System
ESS	Energy Storage System
EU	European Union
EV	Electric Vehicle
EVSE	Electric Vehicle Supply Equipment
FCA	Forward Capacity Allocation
FCP	Frequency Containment Process
FCR	Frequency Containment Reserve
FRP	Frequency Restoration Process
FRR	Frequency Restoration Reserve
HAN	Home Area Network
HV	High Voltage
HVAC	Heating, Ventilation and Air Conditioning
ICT	Information and communications technology
IGCC	International Grid Control Cooperation
IL	Interruptible Load
IoT	Internet of Things

Acronyms List	
IP	Internet Protocol
ISO	Independent System Operator
ISP	Internet Service Provider
IT	Information Technology
LCOE	Levelized Cost of Energy
LTC	Load Tap Changer
LV	Low Voltage
MAF	Mid-term Adequacy Forecast
MARI	Manual Activation Reserve Initiative
mFRR	manual Frequency Restoration Reserve
MV	Medium Voltage
OLTC	On-Load Tap Changer
OpenADR	Open Automated Demand Response
OSGP	Open Smart Grid Protocol
OTC	Over-the-counter
P2G	Power-to-gas
P2H	Power-to-heat
PCR	Primary Control Reserve
PCT	Programmable, Communicating Thermostats
PG&E	Pacific Gas and Electric Company
PICASSO	Platform for the International Coordination of the Automatic frequency restoration process and Stable System Operation
PLC	Power Line Carrier
PPR	Project Periodic Report
PV	Photovoltaic
QM	Quality Management
QR	Quarterly Report
RES	Renewable Energy Source
RM	Risk Management
RR	Replacement Reserves
RRP	Reserve Replacement Process
RTP	Real-time Pricing
SCADA	Supervisory Control and Data Acquisition
SO & AF	Scenario Outlook & Adequacy Forecast
TA	Transnational Access

Acronyms List	
TCP/IP	Transmission Control Protocol/Internet Protocol
TERRE	Trans European Replacement Reserves Exchange
TOU	Time-of-use
TSO	Transmission System Operator
UK	United Kingdom
US	United States
VPP	Virtual Power Plant
VR	Voltage Regulator
VVC	Volt/VAr Control
WLAN	Wireless Local Area Network
WP	Work Package
WPAN	Wireless Personal Area Network