*Smart system of renewable energy storage based on **IN**tegrated E**V**s and b**A**tteries to empower mobile, **D**istributed and centralised **E**nergy storage in the distribution grid*

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Abbreviations and Acronyms

Acronym	Description
AVC	automatic voltage control
BDEW	German Association of Energy and Water
BESS	Battery Energy Storage System
BRP	Balancing Responsible Party
CEN	European Committee for Standardisation
CENELEC	European Committee for Electrotechnical Standardisation
CES	Community Electricity Storage
CHP	Combined Heat and Power
DER	Distributed Energy Resources
DG	Distributed Generation
DG	Distributed Generation
DR	Demand Response
DSM	Demand Side Management
DSO	Distribution System Operator
ETSI	European Telecommunications Standards Institute
EV	Electrical Vehicles
EV-FO	EV fleet operator
FCR	Frequency Containment Reserves
FLIR	Frequency management, Isolation and Restoration
FO	Flexibility Operator
FPR	Flexibility Plans and Reserves
FR	Flexibility Reserve
FRR	Frequency Restoration Reserve
GHG	Greenhouse Gas
HC	Hosting Capacity
ICT	Information and Communications Technology
KWmax	Max Consumer Load
LCOE	Levelized cost of energy (LCOE)
LEM	Local Energy Market

Acronym	Description
LFM	Local Flexibility Market
LV	Low voltage
MV	Medium Voltage
OLTC	on-load tap changers
PCC	Point of Common Coupling
PEV	Plug-in Electric Vehicle
PV	Photovoltaic
RES	Renewable Energy Sources
RNM	Reference Network Model
SESP	Smart Energy Service Provider
SF	Storage Factor
SOC	state of charge
STATCOM	Static Synchronous Compensators
TLC	The Traffic Light Concept
ToU	Time-of-Use
TSO	Transmission System Operator
V2G	Vehicle to grid
VR	voltage regulators
VVO	Volt/VAr Optimization
WG	Working group

Executive summary

The growing share of variable generation in Europe is increasing the need for flexibility in the electricity system. Flexibility on the demand side could be used by market players to optimise their portfolio as well as by system operators for balancing and constraints management purposes.

This document gives an overview of the main grid challenges caused by distributed generation, and how flexibility services from stationary and mobile batteries can be utilized to revile such problems. In this context, we have reviewed official documents and the literature of power systems to address the problems caused by distributed energy resources (DER) and the solutions proposed to solve these issues. The increasing diffusion of DERs in the distribution networks can change power flows, which eventually leads to operational issues, i.e., odd voltage profiles, overloaded components, decreased short circuit power and incorrect operation of protection systems. Therefore, from the DSO perspective, it is extremely important to estimate the available capacity of electrical networks or the so-called distribution grid hosting capacity.

Moreover, literatures have been extensively reviewed for standard definitions on flexibility. Flexibility in the power system has been a popular topic in recent years, but its definition and terminology use varies among authors, which can make it unclear what the term represents. This document provides some definitions and categorizations that provide a foundation for further work in the INVADE project.

Furthermore, the services for the distribution grid is discussed in relation to the other uses of the batteries (such as transmission system operator (TSO) support and balancing responsible party (BRP) support) and limitations of use (e.g. due to locational uncertainty of electrical vehicles (EVs) and driver range requirements). In this respect, the services that are most relevant for the INVADE-project are identified.

The document is closely related to “D4.1 INVADE Concept Design” which goes more in detail on the flexibility operator concept and defines which grid and power system services that should be emphasized in the further project work. This deliverable lays down a theoretical foundation and standard definition for necessary terminologies that can be used for remaining tasks in WP5, and can be applicable in both WP4 and WP8 as well as for pilot sites.

1 Flexibility and flexibility services

Introduction

As stated in the European energy roadmap 2050, EU has committed to reduce greenhouse gas (GHG) emissions in developed countries below 80-95% of 1990 levels
1.1 by 2050. Two of the main polluting industries are the power industry and the transport sector, with 30 and 20.3 % of the global GHG emissions. Central parts of reducing the emissions in these industries are the deployment of distributed renewable energy in the form of wind and solar power, and electrification of the transport sector by transitioning to electric vehicles. These solutions result in major changes in how the power system is organised from the traditional top-down flow of power with big power plants covering all the power demand, to a more integrated model where power and consumption is located on the same grid level.

Higher levels of intermittent energy resources and demand results in problems for distribution system operators (DSOs) as more distribution capacity is needed for short time-periods. Congestions in the distribution grids are traditionally treated by grid reinforcement. However, with increasing amounts of uncontrollable distributed generation and higher demand peaks new methods are needed to handle congestions in a technically and economically efficient way. As a result of the evolution of a new paradigm for electricity generation and distribution, distribution grid capacity will in many cases have low utilization. Hence, constructing new distribution lines represents a high marginal cost. Utilizing local flexibility to handle congestions is a more appealing alternative than upgrading the distribution grid capacity, especially when considering the ability of consumers to contribute flexibility based on the developments in smart metering and battery technology. New actors such as aggregators and new local markets to handle congestions in the local grid have emerged as a popular topic recent years. In the literatures, the terms “flexibility” and “flexibility services” are used interchangeably making it difficult to get an accurate understanding of what they encompass. The main purpose of this document is to review the literatures in the domain of power systems for definitions of “flexibility” and “flexibility services”, and to review the literature for the problems caused by Distributed Energy Resource (DER) and the solutions proposed to solve them.

2 Effect of DER on Distribution Grids

Distributed energy resources are an important part of the future power system or smart grids. DER compose both generation and demand, the most central resources are:

- Distributed generation from wind and solar power
- Distributed storage or flexible demand, in the form of thermal storage, stationary batteries or mobile batteries in electric plug-in vehicles

DER have different effects on the distribution system, and integration of these resources can result in large problems for the DSOs. It is important to deploy and operate these resources in a coordinated way to resolve these issues, and in many ways, the effects of different DER on the distribution system can be mitigated by their complementing characteristics. The main issues for the distribution system related to deployment of DER are elaborated in the following sub-chapters.

2.1 Distributed Generation

One of the most important resources to reduce GHG emissions in the power industry is solar power. A major advantage with solar power is the opportunity to locate the generation where the demand is located, by utilizing e.g. rooftop areas, thus reducing the need for power distribution. On the other hand, solar power is a highly intermittent resource, which means it is hard to predict and the power output varies significantly within short time periods, this result in the need for high distribution capacity to avoid power curtailment. Installing higher distribution capacity to avoid curtailment of wind and solar power is expensive and inefficient as the utilization of this capacity is low on average and only fully utilized in a small amount of hours. In addition to distribution capacity issues, the so-called distribution grid hosting capacity is an issue, which is elaborated in the next sub-section.

Wind and solar generation also cause several issues related to the system/TSO level such as balancing production and demand (frequency control), but since here the focus is on the distribution level, these issues are out of the scope for this deliverable.

2.2 Distribution grid hosting capacity

The challenge for distribution grids, and INVADE project as well, is to host as much renewable energy as possible. This topic has been deeply discussed in many congresses, working committees and associations like IEEE, CIGRE, EPRI, EURELECTRIC and others. Instead of producing new content on the topic know as "hosting capacity problem", the INVADE project will use and take the main conclusions from previous reports.

Based on CIGRE WG C6.24 – Capacity of distribution feeders for hosting distributed energy resources [1], technical issues related to the interconnection of DER to the network are described below. The description of these technical issues have been extracted from ELECTRA [2] and CIGRE's report [1].

1. **Thermal ratings:** Connection of DER has the effect of changing current flows in the network, which may lead to violation of the loading levels of network elements (thermal rating), especially under maximum generation and minimum load conditions.
2. **Voltage regulation:** Voltage regulation is primarily achieved through on-load tap changers (OLTC) controlled by automatic voltage control (AVC) schemes at the high voltage and medium voltage substations, as well as by step voltage regulators (VR) installed along MV feeders. Switchable capacitor banks also contribute to this task. Concerns include the excessive tapping of OLTC and VR, which increases wear of the equipment and increases maintenance costs, the required extended range of regulation and the need for improved regulation algorithms.
3. **Fault level:** Distribution networks are characterized by a design short circuit capacity, which corresponds to the maximum fault current that can be interrupted by the switchgear used and does not exceed the thermal and mechanical withstand capability of the equipment and standardized network constructions. Since DER contribute to the fault current, their interconnection may lead to exceeding the short circuit capacity of the network.
4. **Reverse power flows:** The possibility of reverse power flows in transformers can sometimes present a problem with the operation of the transformer's automatically controlled tap changers fitted to provide voltage regulation on the low voltage side of the transformer.

5. **Rapid voltage change:** Rapid voltage changes can be caused by variation in generation output, tripping of plant (such as PV and wind where generation changes rapidly) and switching of devices.
6. **Islanding:** Island forms when a generator continues to supply the load in a part of the network disconnected from the upstream grid. Safety measures called Anti-Islanding requirements have been defined and embodied in standards to provide guidelines for testing the performance of automatic islanding prevention measures installed in or with distributed generation (DG) interconnection components. For instance, IEEE 1547-2008 requires that the DG interconnection system detects an islanded condition and ceases to energize the area electric power systems within two seconds after the formation of an island. IEEE 1547.1-2005 describes also a test procedure that is intended to verify that the DG meets this requirement. However, it is important to note that this test procedure involves the testing of a single DG unit, which is a somewhat idealized scenario for which reliable islanding detection can be achieved relatively easily.
7. **Protection**: Interconnection of DER to the grid introduces some protection challenges to the grid, which are the following ones:
    a. If the generator does not produce a source for single line to ground (L-G) faults on the distribution feeder, it might create over voltage on the unfaulty phases when the utility breaker has detected the fault and tripped, thus the feeder load has lost the ground source from the utility.
    b. If the aggregate generation exceeds the load on the distribution bus, power will back feed into transmission system. If the transmission system is ungrounded, detection of L-G faults on transmission system is problematic if the transmission side of the substation transformer is not equipped with zero sequence ground over voltage protective relay.
    c. If the generator provides a ground source to the faults on the distribution feeder, the fault current contribution from the utility system to the fault will decrease. If the utility feeders have time-inverse over current relays, the operation time increases because of the decrease in the fault current contribution. This may result in discoordination with the upstream relays.
8. **Power quality:** The high DER penetration may affect adversely power quality, raising issues such as voltage fluctuations, flicker, harmonics and effect on mains signaling.

As far as PV plants are concerned, impact on power quality could be caused by fluctuations of solar radiation. For example, the voltage fluctuation causes excessive feeder voltage regulator operation at the substation. Hence, in order to reduce the impact of the cloud transients on the feeder voltage regulator operation, it has been proposed that the PV contribute to the regulation of the voltage at the point of common coupling (PCC).

Additionally, [1], [2] collected the practices followed by DSO in several countries allowing new DG connections. For example, for low voltage grids aggregated DG could be up to 25% of the nominal power of the MV/LV transformer. Moreover, DG contribution to the short circuit cannot exceed 10% at the PCC and voltage rise due to all DG connected to the network is limited to 2%.

Matt Rylander, from EPRI, presented “Increasing Hosting Capacity with Advanced Inverter Functions”, at the PV Distribution System Modelling Workshop, May 6, 2014. In this study, the author analysed thousands of cases and concluded that to increase the hosting capacity of the current distribution grids, all PV inverters have to include Volt-Var and Volt-Watt control functionalities. This is under consideration of IEEE standard association to be included in the review of IEEE std 1547.

Figure 1 shows the simulation cases in which photovoltaic generators (household and utility scale units) may cause or not technical problems defined as V>1.05 p.u. without advanced inverter capabilities. Yellow and red areas represent technical problems and green areas are completely secure DER integration.

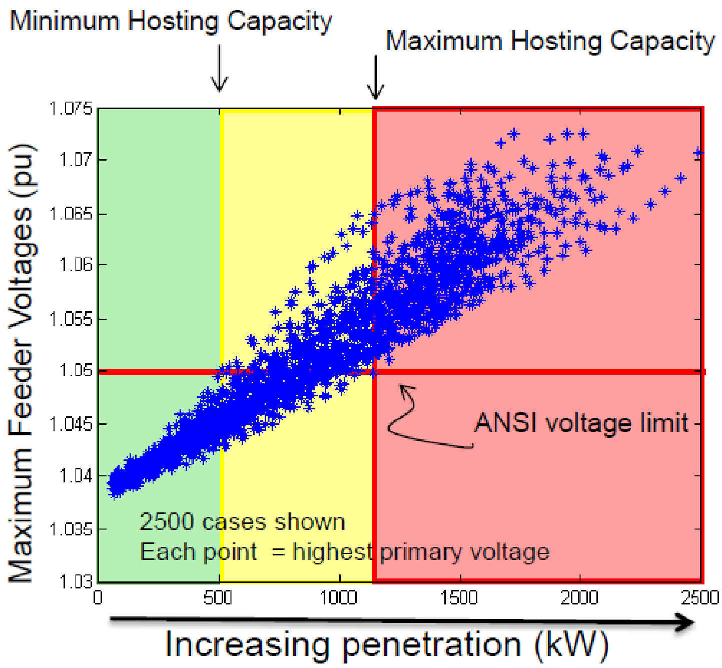

Figure 1. Minimum and maximum HC simulated by [3] *integration DER combining utility and household scales without advanced features inverters.*

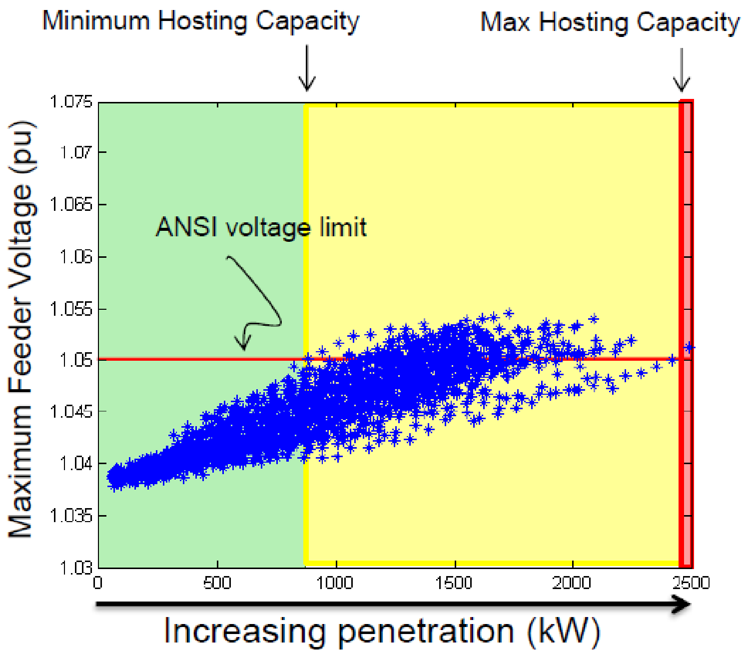

Figure 2. Minimum and maximum HC simulated by [3] *with advanced inverters.*

The IEEE Standards Coordinating Committee 21 elaborated a guide for conducting distribution impact studies for distributed resource interconnection Std 1547.7-2013 [4].

Previous studies analysed different PV inverter strategies to reduce over-voltages like Liu et al. [5] and Turitsyn et al. [6] without considering storage units.

Recently, The IGREENGrid Project defined the grid hosting capacity as *the maximum distributed generation (DG) penetration for which the power system operates satisfactorily* according to Varela et al. [7]. Figure 3 shows a typical hosting capacity calculation referred to electrical distance measures in Ω. The figure shows how the current is the limiting factor up to 2 Ω approx. and later on the voltage is the limiting factor.

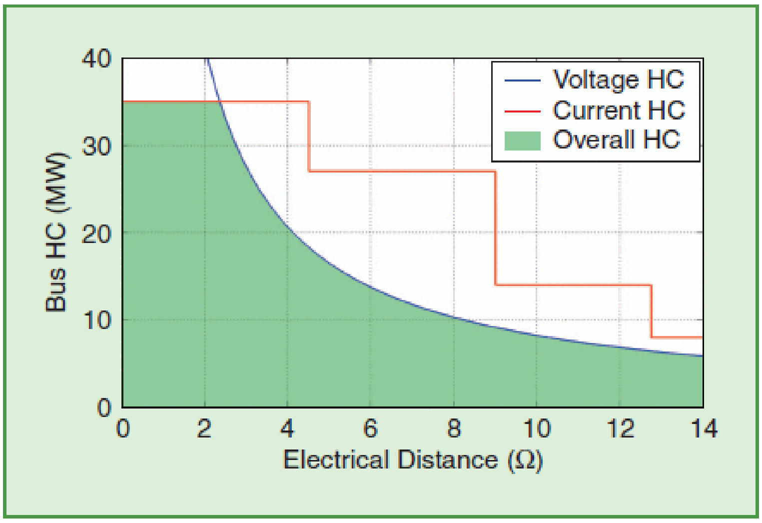

Figure 3. The traditional approach for network hosting capacity estimation [7].

The CIGRÉ reported in the document entitled *Capacity of Distribution Feeders for Hosting DER*, the rules that DSO around the world are applying to estimate the hosting capacity (HC) in their grids based on rule of thumbs [1].

The solutions to increase the HC in distribution grids analysed in [1] are on-load tap changers (OLTC), static synchronous compensators (STATCOM), DG-reactive power control and field measurements. Nevertheless, "*the performance of distributed solutions highly depends on the position of the DER units. The performance of centralized/supervised technologies, however, is almost the same in all of the scenarios considered"*. Later on, non-conventional solutions are addressed like autotransformers and flexibility operators. About flexibility operators, they commented as follows: "*Additionally, Flexibility can be also obtained from third parties such as generators and consumers. Active demand techniques or energy storage installed at customers are some of the possibilities to regulate the loads in the lines. In some countries, generation curtailment is allowed under exceptional conditions. In France, for instance, the use of special contracts to agree on the limits of curtailment has been tested."*

Finally, it is important to mention that the recently published European standard for DER connection in MV and LV grids IEC TS 62786:2017 [8] states three important aspects related to the hosting capacity:

1. About active power management

Generation plant connected to a MV network and those connected to a LV network with a capacity above a certain level shall have the capacity to be disconnected or curtailed for instance, when the distribution line or a distribution transformer, etc., become overloaded.

2. About reactive power control

DERs connected to MV network and those connected to a LV network with a capacity above a certain level should have reactive power capability and maintain the power factor at POC as per national requirements. DERs should be able to adjust reactive power output within its reactive power capability range and participate in steady state voltage regulation in response to network voltage conditions or network operator or system operator instructions.

3. About active power response to frequency deviation

Depending on local system requirements, all DERs connected to MV and those connected to LV network with a capacity above a certain level shall have active power capability. They should be able to adjust its active power output in response to frequency change ensuring the secure operation of the network.

Table 1 summarises the potential pros and cons of DER in distribution systems.

Table 1. Pros and cons for the distribution grid as a result of distributed generation.

Pros	Cons
Distributed generation - Less need for distribution capacity	**High intermittency** – Higher need for balancing capacity
More independent consumers	**Rapidly changing voltage level, overvoltage**
	Reverse power flow
	Fault detection and protection issues
	Islanding issues

3 Flexibility

The term flexibility has multiple applications in the power system ranging from the system level to the unit level. In [9] the impact of the transmission grid on the “system flexibility” is investigated and a methodology to assess the flexibility of a power system considering transmission grid limitations is suggested. The term “system flexibility” is defined as “the ability of a system to deploy its resources to meet changes in net load.” The authors pointed out that the power system flexibility is not determined only by resources available and changes in net load but also scheduling decisions.

An example of the definition of flexibility focusing on the technical aspects on an individual level is given in [10], “Operational flexibility is the technical ability of a power system unit to modulate electrical power feed-in to the grid and/or power out-feed from the grid over time.” Thus when talking about flexibility it is important to emphasise if it is on the unit or system level, in this document the focus is on the unit level. Unit flexibility can often be interpreted as a subset of system flexibility as system flexibility includes unit flexibility, the power grid and the sum of all scheduling decisions.

An overview of different definitions of flexibility from multiple sources is provided in [11], these are listed in the following:

- “The ability of a system to deploy its resources to respond to changes in net load, where net load is defined as the remaining system load not served by variable generation.”
- “Flexibility expresses the extent to which a power system can modify its electricity production and consumption in response to variability, expected or otherwise.”
- From an operational point of view, flexibility is seen as “the potential for capacity to be deployed within a certain time-frame” to respond to changes in net load.
- “In terms of power capacity (MW), ramp rate (MW/min), i.e., the ability to increase energy production with a certain rate, and ramp duration (min), i.e., the ability to sustain ramping for a given duration.”
- “The ability of a power system to cope with variability and uncertainty in both generation and demand, while maintaining a satisfactory level of reliability at a reasonable cost, over different time horizons.”
- “The system’s capability to respond to a set of deviations that are identified by risk management criteria through deploying available control actions within predefined time-frame and cost thresholds.”

The organizations CEN, CENELEC and ETSI are developing a framework to enable continuous standard enhancement and development in the field of Smart Grids. In [12], an overview of the main concepts of flexibility management is given. The definition of flexibility is the same as in [13] and is defined using the following definition: “On an individual level, flexibility is the modification of generation injection and/or consumption patterns in reaction to an external signal (price or activation) in order to provide a service within the energy system. The parameters used to characterize flexibility in electricity include: the amount of power modulation, the duration, the rate of change, the response time, the location etc.” This definition of unit flexibility encompasses several of the elements of the lost above and is originally used in the “TSO – DSO Data management report” [14] which gives inputs for the European Commission regarding communication between the TSOs and DSOs in the future when the power system is operated closer to its limits and flexibility is the prime response to variable renewables.

The technical capability needs to be characterized and categorized by appropriate flexibility metrics. A valuable method for assessing the needed operational flexibility of power systems, for example for accommodating high shares of wind power in-feed, has been proposed by Makarov et al. in [15]. There, the following metrics have been characterized, and represented graphically in Figure 4:

1) Power provision capacity π (MW),
2) Power ramp-rate capacity ρ (MW/min.),
3) Energy provision capacity (MWh)
4) Ramp duration (min.).

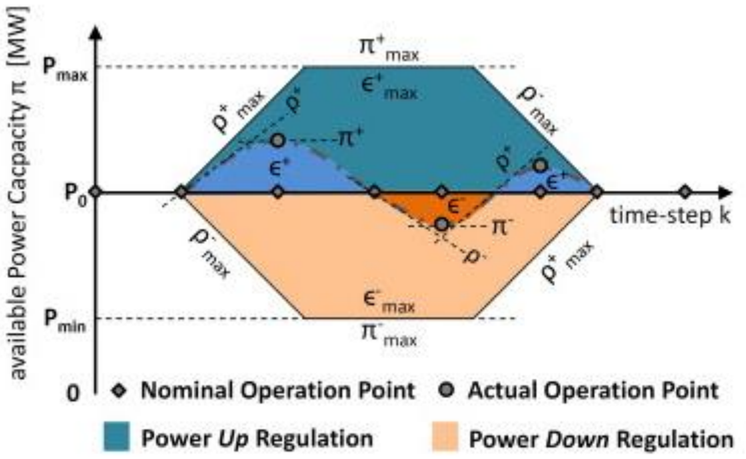

Figure 4. Flexibility Metrics in Power Systems Operation

A categorization of flexibility is provided in [12] which is adopted from [16] and shown in Figure 5, ranging from no flexibility for uncontrollable sources to freely controllable sources. Both generation and load are part of the different groups, some examples of different classifications for load can be: most normal load is curtailable, washing machines are shiftable while water heaters and batteries are buffered. Other types of load have several flexibility properties, like electrical vehicles which can be categorized as both curtailable, shiftable and buffered. For generation examples of curtailable sources can be wind or solar power, while gas turbines is an example of freely controllable generation. Hydro power can be categorized as curtailable or buffered dependent on if it is run-of-river hydro power with no storage capacity or hydro power with reservoir.

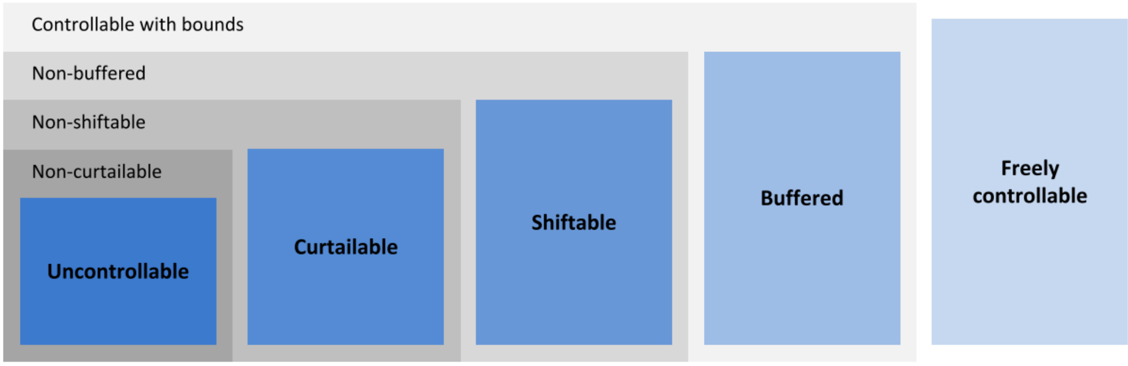

Figure 5. Categorization of Flexibility Sources from [12]

The differences between the categories is sometimes unclear, for example for shiftable and buffered sources. The main difference between shiftable and buffered sources is that for buffered flexibility sources the end-use service and power consumption is decoupled by storage. In general, shiftable loads can reduce consumption followed by an increase in consumption afterwards while buffered loads can increase consumption first followed by a reduction in consumption compared to normal levels.

Flexibility management can be performed in different ways where the two extremes are activation by central control or locally using price signals. Flexibility management encompasses other terms such as demand side management (DSM), demand response (DR) and explicit provisioning of flexibility. DSM is a centrally controlled top-down approach where load and generation is altered by the utilities through generation ramping, peak-load shaving, load shifting and increasing energy efficiency. On the other hand, DR is a locally controlled bottom-up approach where costumers react to price signals that are intended to alter the demand pattern. DSM usually consists of long term measures while DR measures are more short term. Explicit provision of flexibility is when parties connected to the grid actively produce offerings of flexibility (flex-offers) in load and (distributed) generation.

3.1.1 Operational flexibility in power systems

Ulbig et al. [10] have analysed operational flexibility in power systems as a necessary prerequisite for the effective grid integration of large shares of fluctuating power in-feed from variable RES, especially wind power and PV. Hence, power system dispatch optimization and real-time operation are more and more driven by several major trends which include notably:

1) Wide-spread deployment of variable RES: Variable RES power in-feed causes nondeterministic power imbalances and power flow changes on all grid levels

2) Growing power market activity: It has led to operational concerns of its own, i.e. deterministic frequency deviations caused by transient power imbalances due to more frequent changes in the now market-driven operating set-point schedules of power plants as well as more volatile power flow patterns.

3) The emergence of a smart grid notion or vision as a driver for change in power system operation

Altogether, these developments constitute a major paradigm shift for the management of power systems. Operating power systems optimally in this more complex environment requires a more detailed assessment of available operational flexibility at every point in time for effectively mitigating the outlined disturbances.

4 Flexibility Services

4.1 Distributed Stationary Storage and Flexible Load

Increased distributed stationary storage and flexible load is not an objective in itself in the same way as RES or plug-in electric vehicle (PEV) deployment, but a valuable resource in terms of helping with the integration of RES and PEVs. Stationary storage and flexible load can help to reduce the need for costly grid investments by shifting load from high load hours to low load hours, helping with the integration of RES and PEVs as it reduces peak export and import. Batteries can be a viable option for the DSO compared to building new transmission lines and expanding transformer capacity as it results in more efficient utilization of the grid capacity. Installing batteries should be considered as an alternative to grid investments as it might be cheaper and faster to employ. However, DSOs are in general not allowed to explicitly own batteries as it is indistinguishable from generation when discharging, while generation and transmission is commercially separated in most modern electricity markets. Batteries can be owned by prosumers, generators or by an actor in the newly proposed aggregator role, managing many prosumers and trading in traditional and future local energy markets. Distributed batteries can also help with voltage support by supplying or consuming reactive power in addition to active power. Distributed storage and flexible load are also useful from a consumer point-of-view as it can contribute to reducing the power costs from spot market, reducing tariffs by both reducing the maximum power consumed (KWmax) and increasing the amount of own generation consumed.

Table 2. Pros and cons for the distribution system as a result of distributed batteries.

Pros	Cons
Congestion management – Long or short term by reducing load and generation peaks	**New markets and actors are not in place yet** – Local markets or new contracts for flexibility, and aggregators are needed
Voltage support – Reduce need for investments as lines, transformer or VAR-compensation to ensure power quality	**Need for communication technology (ICT)** – Some control strategies requires direct communication/ control
Loss minimization – Reduce losses in distribution grid by controlling power flow	
Redundancy – Improve distribution grid redundancy (N-1)	
Power quality – Improve power quality by smoothing fast changing DER	

Table 3. Pros and cons for consumers owning distributed batteries.

Pros	Cons
Reducing Electricity Cost – Consuming power at cheaper prices, and possibility to increase self-consumption of local generation	**Battery investment cost**
Reducing Tariffs – Reducing tariff drivers as max power consumed, time-of-usage or total power consumed from grid	
Redundancy – Backup power	

4.2 Distributed Mobile Storage

The increasing deployment of PEV is both a challenge and an opportunity for the power system. PEV integration can result in more volatile load profiles with higher load peaks, which is a challenge for the distribution network in terms of voltage level and transformer and transmission grid power limits. On the other hand, batteries in the PEVs can be used to balance integration of distributed generation such as roof-top solar panels, and to provide similar system services as stationary batteries such as relieving congestion or providing voltage support.

Developing smart charging systems and strategies is critical to the integration of PEVs as it results in more efficient use of existing distribution infrastructure, thus reduces the needs for costly grid investments, making PEVs a valuable resource instead of a burden for the distribution system. The three main charging strategies for PEVs are:

1) Uncoordinated charging
2) Smart charging
3) Smart charging and discharging (vehicle to grid (V2G) capability)

Smart charging has significant advantages in regards to line saturation compared to uncoordinated charging as shown by comparing four different charging strategies in [17]. In [17] the impact on the distribution grid from slow charging with different strategies and fast charging is studied. The study use an agent-based model with stochastic variables to model the PEV demand. The model is applied for a case study representative of a highly loaded 11 kV distribution grid, the results show saturation of transmission lines for two different passive charging strategies, while the voltage drop is within acceptable levels. Two active charging strategies, tariff based and smart charging (filling the valleys in the demand profile), are tested and both reduce the level of line saturation significantly. However, the tariff based charging strategy results in a power gradient which can be difficult to supply. Smart charging on the other side, needs significant ICT infrastructures and energy management systems to be implemented. Fast charging stations cannot be controlled in the same way as normal charging due to the nature of this service in terms of time requirements, thus the grid needs to be reinforced often resulting in replacing numerous grid elements due to cascading effects.

Table 4. Pros and cons for the distribution system due to PEVs with uncoordinated charging

Pros	Cons
Increased hosting capacity for RES	**High power peaks**
	Line congestions
	Voltage limit violation
	Increased grid losses

Table 5. Pros and cons for using PEVs with smart changing/ V2G for distribution grid services

Pros	Cons
Congestion management – Long or short term by reducing load and generation peaks	**New markets and actors are not yet in place** – Complicates the current system and cause additional costs
Voltage support – Reduce need for investments as lines, transformer or VAR-compensation to ensure power quality	**Need for communication technology (ICT)** – Some control strategies requires direct communication/ control
Loss minimization – Reduce losses in distribution grid by controlling power flow	**Availability** - Not always connected to the grid
Redundancy – Improve distribution grid redundancy (N-1)	**Conflicting use** – Batteries are used for transportation needs
Power quality – Improve power quality by smoothing fast changing DER	**Location –** Not always on the same place
Low additional investment costs	**Battery degradation** – One of the main issues when using PEVs for system services, especially with V2G

Location – Can be moved to another area (e.g. self-driving), for providing power or relieving load [18]	

4.3 Services from DER

DER can contribute to different services on four different levels of responsibility; these levels are traditionally defined as:

- **TSO** - Responsible for the power system as a total, keeping it operational by balancing generation and demand. Building and maintaining the central grid, the backbone of the power system, where most of the generation is connected.
- **DSO** – Responsible for distribution of power from the central grid to end costumers. Keeping the distribution grid operative and expanding it when needed.
- **BRP** – Power retailers and producers are bidding in energy markets. They are responsible for fulfilling obligations from day ahead bids by balancing deviations in intra-day regulating markets.
- **Consumer** – Sign contract with retailer and DSO and pay electricity bill.

As the power system changes towards a smarter system with more DER, the traditional roles are changing and the differences are getting smaller. More generation (and storage) is moving to the consumer side of the system turning the consumers into prosumers. The DSO will play a more active role in the balancing of the power system as more generation is located at the distribution level. New markets and market actors are under development to manage the different services offered by the DER. The main type of actor mentioned in the literature is the aggregator, with the responsibility of coordinating the different services provided by the DER and offering them to other system actors such as the TSO, DSO and BPR. There are many variants of the aggregator role described in the literature where it most often is an actor with or without balance responsibility, while other mechanisms are mentioned where it is more like a platform for flexibility services. Regardless, the main objective for the aggregator is to maximize the profit for the prosumers by reducing their costs while providing valuable services for the other actors. This is challenging as some actors will have conflicting interests at different points in time, thus designing good markets for different services and control systems for DER is critical.

This review is focusing on the services most relevant for the INVADE-project, which is organized in three different categories shown in Table 6.

Table 6. Flexibility services to be studied in the INVADE-project

Distribution system	**Balance responsibility**	**Prosumer**
Congestion management	Day-ahead optimization	Time-of-use (ToU) optimization
Voltage control	Intra-day optimization	Demand charge (kW-max) control
	Self-balancing	Self-balancing

5 Traffic Light Concept

The Traffic Light Concept (TLC) is a framework developed within the German Association of Energy and Water (BDEW), which is helpful for identification of interactions between the commercial and technical use of flexibility. TLC defines three states of grid and market operations: green, yellow and red. The green state represents the normal operating state where the local market competitively operates and the system/grid operators may or may not interact with the market. In the yellow state, preventive actions are deployed to keep the system from becoming unstable, either through pre-agreed contracts and activation signals or market tools such as price signals. The red state means that the system/grid operator must take control over the system by overriding the market or apply emergency actions to keep the system stable or re-stabilise the system. Both the red and yellow states are considered temporary and [12] states that there should be regulations on how often and for how long the yellow and red states should occur as there will be a conflict of interests between DSOs/TSOs and commercial actors. Local flexibility services are especially interesting in the green and yellow states where the DSOs can use market mechanisms to keep the distribution system stable and relieve congestions.

Pages 27-28 in [12] include a detailed table of different use cases related to the tasks of a grid operator for the different system states under the TLC framework. The interesting aspects with respect to flexibility services are reiterated in the list below. Two of the most interesting aspects are “Grid capacity controlled demand management” used for grid stability, customer energy management and price incentives in the yellow state and “Price or control signal-based energy management” used for demand side management, demand-response, load management and virtual power plants in the green state. The same flexibility services found in Figure 5 is related to the TLC framework in the list below.

- **Red state** – Grid focused operation
  - Grid construction, operation and maintenance
    - Grid balance, Reduction of grid losses, Grid expansion and Grid improvement
  - Provide system services (WGSP-0100+0200)
    - Volt/VAr Optimization (VVO), Frequency management, Isolation and Restoration (FLIR) and Black start.
  - Capacity management of supply and demand (WGSP-2300)
    - Emergency Signals and Load Shedding Plan Selection
- **Yellow state** – Mixed focused operation between grid and market
  - Third party system services
    - Voltage optimization, Reactive power, Frequency optimization, Black start and Network losses
  - Grid capacity controlled demand management (WGSP-2110+2120)
    - Grid stability, Customer Energy Management and Price incentives
- **Green state** – Market focused operation
  - Energy supply to customers
  - Price or control signal-based energy management (WGSP-2110+2120)
    - Demand Side Management and Demand Response Management
  - Control area balancing
    - Responsibilities with respect to a balance responsible party

Moreover, Zoeller et al. [19] proposed an algorithm to determine each grid state based on forecasting and iterative power flows.

6 Provision of Flexibility Services from distributed RES

6.1 Provision of Flexibility Services from Storage and DER

The impact of storage technology in distribution grids to increase their HC with penetration rates of RES has been analyzed recently in MIT publications [20]. Chapters 7 and 8 focus on the technical and economic impacts of photovoltaic generation into distribution grids and electrical markets. With this aim, Chapter 7 proposes several models to represent electrical distribution grids. Different analysis for each one of the models are shown, and they are characterized by considering a photovoltaic generation penetration rate that can vary between 0 % and 40 % based on annual demand.

Both the network models and the analysis of the scenarios have been done using the specialized software “Reference Network Model (RNM)”, which has been developed by the Technical Institute of *Universidad de Comillas*, in Spain. This software emulates the design process of the distribution systems that would be adopted by the distribution companies, specifying as a result the components located between the substation connected to the grid on one side, and the end-user or consumer on the other side. The optimization of the system is according the minimum cost criteria, and also considering restrictions that assure the required continuity of the energy supply to the consumers. Once the results from the model have been obtained, the added costs for reinforcing the distribution grid infrastructure are studied.

There are twelve different network distribution types. For each one, diverse analysis scenarios are considered. Three of these scenarios include energy storage. Some assumptions have been considered so as to develop the study: the batteries share the connection points of all the medium and high voltage customers who own a PV generator. The batteries are also operated with the aim of limiting the power injected to the network, but always maintaining the same state of charge (SOC) at the end of the day. Storage factor (SF) is the parameter defined for specifying the injection limit, and can vary between 0 and 1, and it represents the ratio between the power absorbed by the storage system and the rated load.

The first scenario is characterized by considering a SF equal to 0. This value shows up that, once it is applied to a PV installation with energy consumes, the battery will absorb any net power injection into the grid beyond the nominal demand in that point. The second scenario considers a SF of 0.2. This means that the batteries would absorb any net power injection into the grid beyond a factor of 0.8 times the nominal demand in that point. On the opposite side, a storage factor SF = 1, considered in the third scenario, implies that the batteries would absorb any PV generation, setting out its distributed generation to cover the local consumer needs.

The study calculates the associated costs for the distribution system operator (taking into account infrastructures reinforcement and energy losses). In order to estimate storage systems' impact, a comparison between the total costs with and without storage is realized. The difference between the costs (saving), is divided by the storage installed capacity so as to obtain an indicator which states the value of the distributed storage. According to the study assumptions, the savings vary from 0 to 35$ per kWh of installed storage. These results suggest that a storage system with an investment cost of 140 $/installed kWh and a lifespan of more than 4 years could be a feasible alternative to the reinforcement of the distribution grids infrastructures. This would also ease a higher penetration of PV generation. Figure 6 shows the correlation between the annual costs for the distribution system depending on PV penetration, taking into account different storage factors (SF). As can be seen in Figure 6, the higher the storage factor SF, the less increase of the total costs is obtained.

The study also states that distributed energy storages could be an alternative to network reinforcements. Distributed energy storages can provide other services like voltage support with reactive power, load peak shaving, spinning reserve or frequency regulation. These facts improve energy storage competiveness, however, benefits are not always equal to all market participants.

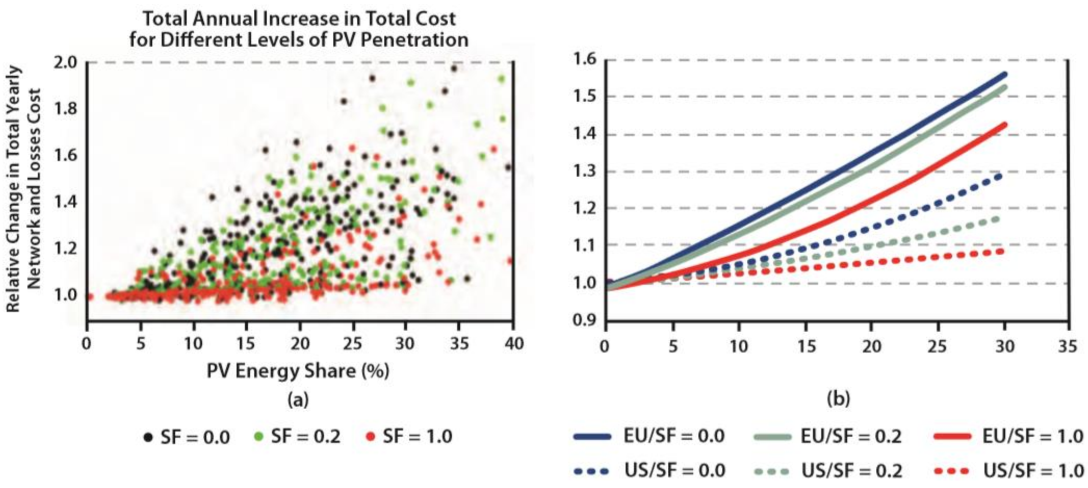

Figure 6. Contribution of energy storage in PV generation Integration. Storage Factor is labelled as SF, while EU and US stand for a grid under European design parameters and American ones, respectively [20].

Before describing other studies from the literature, it is necessary to distinguish between centralized or decentralized battery energy storage system (BESS).

In general terms, centralized storage units are more effective to increase the HC if they are located in the appropriate locations according to [7]. For example, Celli et al. [21] analysed how to integrate storage units in distribution networks owned by the DSO in terms of optimal placement, rating and control strategies to minimize the overall network cost. Nick et al. [22] focuses on the problem of optimally locating storage units owned by the DSO for voltage support.

6.1.1 Flexibility from centralized storage

Resch et al. [50] reviewed four operating strategies of the German Community Electricity Storage (CES) projects like Strombank, IRENE, EEBat and Smart Operators among others:

1. Direct loading: The energy surplus is stored directly in the BESS
2. Schedule mode: Time to charge is scheduled to a typical time with high radiation.
3. Peak shaving: Avoid over-voltages and equipment over-loading
4. Prognosis based strategy: Use load and weather forecasting to schedule the storage unit considering grid constraints.

Additionally, Resch et al. [23] included a review of BESS maximising self-consumption. During a reverse power flow situation, when the grid is exporting power, the battery is used to mitigate the reserve power flow with peak shaving. Moreover, the peak shaving threshold can be fixed like in Smart Operator project or adaptive to the situation like in the EEBat project. Prognosis based control could be applied to reduce reverse power flows but it has not been applied in pilots yet.

6.1.2 Flexibility from decentralized storage

Regarding decentralized storage units, Camacho-Rascon et al. [24] analysed three control strategies: PV invert cos φ (P), Q(V) and PV-storage control under the regulation of Germany. They concluded that the Q(V) and PV-storage controls increase the HC by 16% and 19% respectively in Germany.

De Oliveira e Silva et al. [25] presented a sensitivity analysis about the sizing problem of home installations with of photovoltaic panels and lithium-ion batteries considering economic costs based on the Levelized cost of energy (LCOE) and technical effects.
Additionally, it is necessary to consider the power factor-voltage PF(V), Volt-var and Volt-Watt PV inverter capabilities to offer a holistic approach to increase the distribution grid HC. Hashemi et al. presented an analysis about power quality issues in distribution grids with high penetration of PV generators [26].
Later it is important to distinguish between the three different grid states: green, yellow and red. Once the DSO detected a red status, we can assume that the DSO can send control signals directly. This is not included in any standard yet but during red light situations the probability of grid failure is very close and there is no time for information exchanges between the DSO, BRP and FO. This has been assumed in [19] as well.

Different studies have proposed algorithms for DSO to take decision on direct control flexible assets. Liu et al. [27] presented an optimization algorithm to reduce operation cost, voltage control and power losses reduction. However, this algorithm could not be applied in the European regulatory framework because it is assuming that the DSO, the algorithm executer, has the costs of DGs and this could be conflictive in a liberalized power system.

6.2 Provision of Flexibility Services from PEVs

The role of EV fleet operator (EV-FO) is proposed to handle the services that can be provided to different actors as TSO, DSO or EV owners as a result of smart charging and discharging. This is especially a case at commercial areas, and The EV-FO has more or less the same functionalities as an aggregator and is also called EV aggregator, EV service provider or EV virtual power plant. The review paper [28] outlines four main services that EV fleet operators can provide:

- Ancillary services to TSO
- Ancillary services to DSO
- Storage service to RES supplier
- Charging cost minimization to PEV owner

At homes or residential areas on the other hand, the charge-point operator and/or the immobility service provider can play this role.

6.2.1 Ancillary services to TSO

Using PEVs to provide ancillary services for the TSO have high value, PEVs are especially suited for providing primary frequency reserves or frequency containment reserves (FCR) as this service is short in duration (few minutes) and have to respond fast to frequency changes. PEVs can also provide secondary frequency reserves or frequency restoration reserves (FRR), but here the duration is longer (up to 1 hour) and the prices for this service are lower. In the future, the DSO with the help of aggregators will be more involved in providing these services to the system level (TSO) as the power system changes towards more DER.

6.2.2 Ancillary services to DSO

The two main services that PEVs can provide to the DSO is congestion prevention and voltage regulation, these services are also a central part of the INVADE project as shown in Table 6. A table of references to work regarding these services is adopted from [19] in Table 7. Providing these services by using smart charging is very important for PEV integration as even low levels of PEVs can cause problems in the distribution system which is costly to mitigate by other means. Thus it is important to create incentives for smart charging by creating markets that support this charging behaviour. A penetration level of around 20% PEVs is regarded as the upper limit by distributing the load.

*Table 7. References to work on services for DSOs from PEVs, adopted from **[28]**.*

Service	Title, Year of Publication	Full Reference
Congestion	The impact of electric vehicle deployment on load management strategies, 1983	[29]

Management	An investigation into the impact of electric vehicle load on the electric utility distribution system, 1993	[30]
	Coordinated charging of plug-in electric vehicles to minimize distribution system losses, 2011	[31]
	Evaluation of the electric vehicle impact in the power demand curve in a smart grid environment, 2014	[32]
Voltage Control	Integration of electric vehicles in the electric power system, 2011	[33]
	PEV-based combined frequency and voltage regulation for smart grid, 2012	[34]
	A multi-objective optimization of the active and reactive resource scheduling at a distribution level in a smart grid context, 2015	[35]

6.2.3 Service to prosumers and BRP

The effect of PEV on integration of RES is interesting for actors in the BRP role as increasing shares of power from RES represents high intermittency and challenges related to bidding in energy markets. PEVs and smart charging can be used to absorb surplus from solar and wind power and also to inject power back into the system when the generation is low, if the PEVs have V2G capability. Thus PEVs can be used to both smoothing the power output for increasing the hosting capacity of the distribution grid and to move energy between hours as a storage device to deliver services for BRPs. Relevant references on the effect of PEVs on RES integration is presented in Table 8.

Table 8. References on the effect of PEVs on RES integration, adopted from ***[28]***.

Service	Title, Year of Publication	Full Reference
Renewable integration	Integration of renewable energy into the transport and electricity sectors through V2G, 2008	[36]

(Increase hosting capacity)	Electric cars and wind energy: Two problems, one solution? A study to combine wind energy and electric cars in 2020 in The Netherlands, 2012	[37]
	Solar-to-vehicle (S2V) systems for powering commuters of the future, 2012	[38]
	Integration of PV power into future low-carbon smart energy systems with EV and HP in Kansai Area, Japan, 2012	[39]
Storage device (Balance service for BRP)	Grid integration of intermittent renewable energy sources using price-responsive plug-in electric vehicles, 2012	[40]
	Plug-in electric vehicles and renewable energy sources for cost and emission reductions, 2011	[41]
	Resource under uncertainty in a smart grid with renewables and plug-in vehicles, 2012	[42]

In [43] a stochastic optimization model is used to analyse the optimal scheduling of a distribution network with high levels of renewables and PEVs. Central control is used to manage the PEVs which has V2G capability, the model is applied to a test system and shows good results. Some interesting observations is that it is economical to sometimes switch off dispatchable units to reduce costs and that the PEVs can help reduce the costs by transferring energy through the fleet.

6.2.4 Services to PEV owner

The FO provides services to the TSO, DSOs and BPRs on the behalf of the electric vehicle owners. The profit from providing these services must be shared between the FO and the vehicle owners. Moreover, the FO provides services to the PEV owner in terms of charging cost minimization with respect to electricity prices and tariffs. If the PEVs have V2G capability the FO can provide more services which reduce the total operational cost for the PEV, on the other hand some drawbacks with V2G charging are additional investments for enabling bidirectional power flow, advanced communication and high degradation of the batteries.

Table 9. References on cost minimization for PEV owner, adapted from [28].

Service	Title, Year of Publication	Full Reference
Smart Charging	Optimal charge control of plug-in hybrid electric vehicles in deregulated electricity markets, 2011	[44]
	Coordinated charging of electric vehicle for congestion prevention in the distribution grid, 2014	[45]
	Optimal charging of electric drive vehicles in a market environment, 2010	[46]
V2G	Optimal scheduling of vehicle-to-grid energy and ancillary services, 2012	[47]
	Coordinating vehicle-to-grid services with energy trading, 2012	[48]

6.2.5 Comparisons of services from PEVs

Provision of ancillary services from PEVs is studied in [48] considering the uncertainties in availability and location of the PEVs. The following services are included: peak power shaving, voltage level regulation, minimization of losses, minimization of transmission costs for DSO, primary frequency regulation and balancing mechanisms. The study focuses on PEVs used primarily for commuting between home and work and includes stochastic variables in regards to vehicle mobility. The results from the study show that biddings for flexibility services are more reliable at work than at home as the uncertainty related to availability is less at work. The study also shows that peak power shaving in medium voltage grids, primary frequency regulation, loss minimization and energy cost minimization are more competitive compared to balancing mechanisms, voltage regulation and peak power shaving in low voltage grids.

Sometimes, different actors can request services that are conflicting with other actors' objective. For example the TSO can request balancing services that cause congestions in the distribution grid, which in turn requires the DSO to take actions to mitigate the congestion, again causing unbalance in the system. To avoid these kind of problems [49] suggests a methodology for handling potential conflicts:

1. Emergency actions (TSO)
2. Alert actions (TSO/DSO)
3. Local voltage control (DSO)
4. Congestion management (DSO)
5. Voltage support (TSO)
6. Voltage control (DSO)
7. Other ancillary services (TSO)
8. Imbalance issues (Aggregator, e.g. FO)
9. Power quality (DSO)

6.3 Control Strategies

Important aspects to consider when designing control strategies are:

- Battery modelling
- Charging standards
- Communications standards
- Driving pattern

To provide these services there are three types of control strategies the FO can use:

- Centralized control
- Transactive control
- Price control

By using centralized control the charging (and discharging) of the PEVs are controlled directly by the FO, this requires a significant ICT infrastructure. Both transactive and price control are decentralized control where a price signal is used to control the charging, the difference is that transactive control requires the ability to send a response to the FO and thus some more ICT infrastructure than pure price based control.

In [50] three control strategies are compared where first is a direct control strategy, the second is an indirect control strategy by using ToU tariffs while the third is an autonomous control strategy with respect to grid voltages using the PEVs internal ICT and sensors. The results show that indirect control by using ToU tariffs can lead to opposite effects than intended, and thus, cause very strong voltage dips instead of relieving stress on the grid. The direct control shows the best results but are related to high investments in ICT infrastructure and is also given perfect foresight in the model. The paper concludes that the autonomous control strategy shows much better results than ToU tariffs and should therefore be considered as an option to help future integration of PEVs in the distribution system.

6.4 Flexibility services in detail

After implementing extensive literature survey on flexibility services, this section is dedicated to the flexibility services that can be applied in specific to INVADE project. The table below shows the flexibility services using two labels from two references [51] (USEF-USEF15) and [52] (EG3). According to the concept design task (T4.1), the last column indicates the flexibility services to be developed in INVADE project. None of the TSO services have to be implemented as the transmission system is out of the project scope.

Flexibility customer	Flexibility services		Flexibility references			
	USEF	EG3	USEF	USEF15	EG3	INVADE
DSO	Congestion Management	Short term congestion management	Y	Y	Y	Y
DSO	Congestion Management	Long term congestion management	Y	Y	Y	N
DSO	Voltage Control	Voltage / Reactive power control	Y	N	Y	Y
DSO	Grid Capacity Management	(Grid losses)	Y	N	Y	N
DSO	Controlled Islanding	-	Y	N	N	Y
DSO	Redundancy (n-1) Support	-	Y	N	N	N
DSO	Power Quality Support	-	N	N	N	N
BRP	Day–Ahead Optimization	Portfolio optimization	Y	Y	Y	Y
BRP	Intraday Optimization	Portfolio optimization	Y	Y	Y	Y
BRP	Self-Balancing	Portfolio optimization	Y	Y	Y	Y
BRP	Passive Balancing	-	Y	Y	N	N
BRP	Generation Optimization	Generation capacity adequacy	Y	Y	Y	N

TSO	Primary Control	Frequency control (FCR)	Y	N	Y	N
TSO	Secondary Control	Frequency control (FRR)	Y	N	Y	N
TSO	Tertiary Control	Frequency control (RR)	Y	N	Y	N
TSO	National Capacity Market	-	Y	N	N	N
TSO	Congestion Management	Congestion Management	Y	N	Y	N
TSO	Grid Capacity Mgmt	(Grid loses)	Y	N	Y	N
TSO	Controlled Islanding	-	Y	N	N	N
TSO	Redundancy (n-1) Support	-	Y	N	N	N
TSO	-	Reactive power control	N	N	Y	N
Prosumer	ToU Optimization	-	N	N	N	Y
Prosumer	KWmax Control	-	N	N	N	Y
Prosumer	Self-Balancing	-	N	N	N	Y
Prosumer	Controlled Islanding	-	N	N	N	N

6.4.1 Flexibility services for DSO

- **Congestion management**: Congestion management refers to avoiding the thermal overload of system components by reducing peak loads where failure due to overloading may occur. The conventional solution is grid reinforcement (e.g., cables, transformers). The alternative (load flexibility) may defer or even avoid the necessity of grid investments [51] (USEF15).

  From the perspective of the flexibility provider and according to the EG3 definition [52], the difference between short and long term congestion management is not significant. Both services try to avoid grid congestions, short term belongs to the operation framework on the daily basis, while long term belongs to the distribution grid planning division on the years ahead term horizon.

  The scope of INVADE project is to solve the short-term problem (with respect to the duration of a grid reinforcement project) for the DSO that requires a relatively swift response.

- **Voltage / Reactive power control**: Voltage control is typically requested when solar PV systems generate significant amounts of electricity. This will "push up" the voltage level in the grid. Using load flexibility by increasing the load or decreasing generation is an option to avoid exceeding the voltage limits. This mechanism can reduce the need for grid investments (such as automatic tap changers) or prevent generation curtailment [51] (USEF15).

6.4.2 Flexibility services for BRP

A BRP has different options for using flexibility at different points in time. It is more difficult to decrease or increase outputs for certain types of generation units such as wind or solar compared to conventional types of generation. Flexibility from other generation/supply units or demand is often necessary for BRP portfolio optimisation. Trading energy is also an option to optimize the portfolio for a BRP [52].

- **Day-ahead portfolio optimization** aims to shift loads from a high-price time interval to a low-price time interval before the day-ahead market closure. It enables the BRP to reduce its overall electricity purchase costs [51] (USEF15). This service is used by BRP to prepare day-ahead market bids.
- **Intraday portfolio optimization** closely resembles day-ahead optimization, but the time frame is constrained after closing of the day-ahead market. This enables intraday trading and load flexibility can be used to create value on this market, equivalent to the day-ahead market [51] (USEF15). This service is used by BRP to prepare intraday market bids.
- **Self-balancing portfolio optimization** is the reduction of imbalance by the BRP within its portfolio to avoid imbalance charges. The BRP does not actively bid on the imbalance market using its load flexibility, but uses it within its own portfolio.

6.4.3 Flexibility services for Prosumers

- **ToU optimization** is based on load shifting from high-price intervals to low-price intervals or even complete load shedding during periods with high prices. This optimization requires that tariff schedules are known in advance (e.g., day-ahead) and will lower the Prosumer's energy bill [51] (USEF15).
- **kWmax control** is based on reducing the maximum load (peak shaving) that the prosumer consumes within a predefined duration (e.g., month, year), either through load shifting or shedding. Current tariff schemes, especially for customers, often include a tariff component that is based on the prosumer's maximum load (kWmax). It should be mentioned that normally this is not about instantaneous power, but energy over some time interval, e.g. one hour. By reducing this maximum load, the Prosumer can save on tariff costs. For the DSO, this kWmax component is a rudimentary form of demand-side management [51] (USEF15).
- **Self-balancing** is typical for prosumers who also generate electricity (for example, through solar PV or combined heat and power (CHP) systems). Value is created through the difference in the prices of buying, generating, and selling electricity (including taxation if applicable). Note that solar PV self-balancing is not

meaningful where national regulations allow for administrative balancing of net load and net generation [51] (USEF15).

7 Flexibility contracts and Flexibility Markets

To organize the trading of demand side flexibility, new contracts or market mechanisms are needed. Moreover new roles such as aggregators (also called flexibility operator) would be introduced in new trading mechanisms.

There are two type of contracts to controlling the flexibility services use: indirect and direct control mechanism. Direct control, also denoted centralised control, of the services use means that the customer allows central agent to remotely control its equipment. It is stated in the contract how the connected appliances will react to events in the grid. The central agent could for instance be the grid owner or the electricity supplier, which communicates with the electrical domestic devices. One option is that the DSO itself enters a flexibility contract with the prosumer and performs the control. Another option is that this task is handled by a third party that professionalizes in flexibility services. The benefit for a grid owner to control the energy use is to handle congestion situations and decrease the risk of blackouts. Flexibility providers are compensated according to their flexibility contribution. In indirect control a central agent sends a signal, e.g., a price to its customers, and the customers respond according to their preferences. Indirect control is also called price-based control and decentralized control, since the decision is taken by each end-user. No certainty of the customer reaction is given by using indirect control but with experience the supplier and grid owner could predict the reactions. For this alternative it is also possible for the customer to have a device (a so called Home Area Network) that controls the appliances according to the electricity price or outside temperature [53].
Flexibility in the distribution system is discussed in [52] where the development of market mechanisms for local flexibility is explored on behalf of Norwegian regulatory authorities. The report focuses on how to design market mechanisms to meet the future challenges in the distribution grid based on the properties of different consumers and produces. Currently there exist some market mechanism for large flexible consumers on the transmission level, but improved market mechanisms can result in higher participation from the demand side and also participation from the local generation.

Market power can become an issue if flexibility is activated through price signals in real time and reference [54] suggests therefore a market mechanism with annual auctions of flexibility contracts where activation is included. Consequently, flexibility would be activated through control signals according to pre-determined conditions and prices. By using annual contracts, the DSO will also have a real option of building more transmission capacity instead of utilizing flexibility thus reducing the concerns regarding market power.

The flexibility operator or aggregator will play an important role in the local energy market for managing flexibility. The role of the flexibility operator is to act as an intermediate between providers of flexibility such as individual consumers, small producers and prosumers and the user of flexibility such as producers, TSOs and DSOs. The flexibility operators manage flexibility both for commercial use at the system level in day-ahead, intraday and regulating markets and for technical use in real time or long term local flexibility markets. There are many definitions of the role of flexibility operators ranging from market actors to market platforms and combinations of these and other roles. A chief distinction between different kinds of flexibility operators is whether it is a BRP or not. Access to information is an issue that could be addressed. Although there is an agreement between the DSO and the flexibility operator, it is not given that the flexibility operator will get access to full information about the grid topology and real-time metering values.

An example of a flexibility operator is found in the Horizon 2020 funded project EMPOWER [55] where the new market role Smart Energy Service Provider (SESP) is proposed with the purpose of managing local energy (LEM) and flexibility markets (LFM). The SESP provides a trading platform called SESP platform for local players as the DSO, local producers, consumers and prosumers and aims to maximize the social welfare of the participants. The SEPS takes several roles such as local market operator, retailer/ aggregator for local members in the whole sale markets and balance responsible party. The local energy market is a local equivalent to the spot market while the flexibility market is a local equivalent to the intraday and regulating markets. Flexible members of the SESP are required to have control mechanisms which can receive control signals from the SESP and can include e.g. flexible households, generators, storage units and electrical vehicle charging stations. The local flexibility markets have three main purposes: support DSO operations by, e.g., preventing local congestions, compensating local deviations in energy due to forecasting errors or other issues and bidding of aggregate flexibility of local participants in balancing markets supporting TSO operations.

The local flexibility market creates flexibility plans and reserves (FPR) by clearing the market using a LFM algorithm both before the operation day and every quarter during the operation day. The LFM algorithm can be formulated as a single-side auction between the flexibility providers represented by a flexibility reserve (FR) portfolio of available flexibility and the SESP. The SESP has contracts with producers, consumers and prosumers regarding both reservation and activation of flexibility, these contracts are dynamic and can change weekly or monthly. Flexibility is prioritised by the SESP in the following order: DSO operations, local energy deviations, TSO operations and flexibility margins. During operation an adjustment algorithm is used to execute the FPR and possibly refresh the FPR if errors occur. In some countries, the number of flexibility providers in a neighbourhood is small, and therefore liquidity could be a problem for a market based solution.

8 Previous and Current Projects on PEV integration

This sub-section includes an overview of projects regarding integration of PEVs in the distribution grid and utilizing them for provision of flexibility services.

8.1 EDISON

Status: Finished

Project period: 2009-2012

“The EDISON project has utilised Danish and international competences to develop optimal system solutions for EV system integration, including network issues, market solutions, and optimal interaction between different energy technologies. Furthermore, the Bornholm electric power system has provided an optimal platform for demonstration of the developed solutions.”

Project web-site: http://www.edison-net.dk/

Table 10. Some selected publications from the EDISON-project.

Title, Year of Publication	Full Reference
Smart Charging the Electric Vehicle Fleet, Book chapter, 2012	[56]
Flexible Charging Optimization for Electric Vehicles Considering Distribution Grid Constraints, 2012	[57]
Prediction and optimization methods for electric vehicle charging schedules in the EDISON project, 2012	[58]
Numerical comparison of optimal charging schemes for Electric Vehicles, 2012	[59]
Implementation of an Electric Vehicle test bed controlled by a Virtual Power Plant for contributing to regulating power reserves, 2012	[60]

8.2 NIKOLA

NIKOLA
INTELLIGENT ELECTRIC VEHICLE INTEGRATION

Status: Finished

Project period: 2014 to April 2016

Project description:

“Nikola is a Danish research and demonstration project with a focus on the synergies between the electric vehicle (EV) and the power system.

With sufficient control and communication it is possible to influence the timing, rate and direction of the power and energy exchanged between the EV battery and the grid.

This ability can be used in a set of "services" that bring value to the power system, the EV owner and society in general.

Nikola seeks to thoroughly investigate such services, to explore the technologies that can enable them and finally to demonstrate them through both simulations and in-field testing.”

Project web-site: http://www.nikola.droppages.com/

Table 11. Some selected publications from the NIKOLA-project.

Title, Year of Publication	Full Reference
Electric vehicle smart charging using dynamic price signal, 2014	[61]
Analysis of voltage support by electric vehicles and photovoltaic in a real Danish low voltage network, 2014	[62]
Distribution grid services and flexibility provision by electric vehicles: A review of options, 2015	[63]

8.3 PARKER

Status: Mid-way

Project period: August 2016 to July 2018

Project description:

“The aim of the Parker project is to validate that series-produced electric vehicles 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. Furthermore, we 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 electric vehicles’ capability to meet the needs of the grid.”

Project web-site: http://parker-project.com/

Table 12. Publications in the PARKER-project.

Title, Year of Publication	Full Reference
Validating a centralized approach to primary frequency control with series-produced electric vehicles, 2016	[64]
Enhancing the Role of Electric Vehicles in the Power Grid: Field Validation of Multiple Ancillary Services**, 2016**	[65]
Management of Power Quality Issues in Low Voltage Networks using Electric Vehicles: Experimental Validation, 2016	[66]

8.4 ACES - Across Continents Electric Vehicle Services

Status: Starting phase (no project web-site yet)

Project period: April 2017 to March 2020

<u>Key points in project description:</u>

- "…investigate technical and economic system benefits and impacts by large scale electric vehicles integration in Bornholm."
- "The Danish Island of Bornholm is a unique environment for testing of smart technologies, as 75% of the produced energy on the island is renewable energy."
- "…initiate a small scale pilot project involving up to 100 privately owned Nissan vehicles and vehicle-to-grid (V2G) chargers for proving that electric vehicles can be used for effectively balancing the system."
- "…understand and quantify the full impact of the electrical vehicle as a provider of flexibility and critical properties to a power system and its markets."

Source: http://www.cee.elektro.dtu.dk/news/nyhed?id=53BC0A5F-BD47-4B90-B495-BCB7774C2FC8

9 Concluding Remarks

Energy storage systems in general can be key ways of contributing to the de-carbonization of the European energy mix. However, despite the remarkable technical advances in energy storage systems and their increasingly keen competitiveness in providing flexibility services to distribution systems, the deployment of storage will not happen by itself. Storages in the form of stationary batteries and mobile batteries can offer services at multiple levels of the grid and in different areas, and they will need the appropriate regulatory and market settings to flourish. In this report we have reviewed the necessary terminologies in order to provide common understanding about the definition of flexibility and flexibility services in INVADE project. Provision of flexibility services from different resources has been reviewed extensively and flexibility resources that are planning to elaborate in INVADE project have been identified.

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