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Abstract:

Current disruptive grid trends in electricity systems are impacting the management of distribution grid. In accordance with WP12 objectives, this document analyse Distribution Grid Management Technologies in a scenario of high penetration of renewable sources in order to identify and specify additional or improved DSO operations that should consider storage and controllability of various components through new technologies, including real time data provided by Unbundled Smart Meters, with a specific focus on the role of RESCOs in advanced services for balancing the grid.

Keywords:

Distribution Management, Grid, RES, DER, DSO, DMS, DSS, RESCO, USM

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EXECUTIVE SUMMARY

In line with the European energy and climate policy targets of reducing the greenhouse gas (GHG) emissions, electricity will be increasingly produced from renewable energy sources (RES) that are largely intermittent and unpredictable, leading to a substantial challenge to grid stability and security of supply. This document describes the attempt to address these problems by researching the following themes: benefit of distributed storage systems (DSS) in grid balancing, innovative DSO operations (grid management) and the promising role that Renewable Service Company (RESCO) might have in smartening the grid.

Updated/upgraded grid applications within Distribution Management Systems (DMS) will create the basis for solving harder challenges to the grid. Small-scale storage technologies, due to their technical characteristics, are best and most appropriate to be installed in the low and medium voltage sections of the grid. Distributed Storage Systems should be seen as a part of the development of a smarter electricity system, and their effectiveness should be assessed and compared to other available options, such as demand-side management (DSM) or other ancillary services related to active power reserves. New tools, services and business models like the ones of RESCOs would boost the uptake of RES and provide information to the consumers for improving their perception of their active engagement in the power system.

The strategic assumption behind WiseGRID WP12 and this deliverable is to identify the requirements of DSOs additional advanced operations that should consider storage and controllability of various components through new technologies based on real time data from Unbundled Smart Meters (USM). It also considers that simultaneous and co-located investments in the local energy storage facilities could be a sustainable solution to the end of public subsidies for renewable energy production and to the falling RES energy prices at peak production hours, which together, obviously make further RES developments economically far less profitable than it used to be. Hence, small and medium sized RESCO partners will achieve significant economic benefits if they install on their premises not only new RES production equipment but also storage based services as a contributing factor for grid stability and power quality.

Innovation has the potential to reshape and redesign the energy sector while also benefiting the customers and the environment. Distributed RES generation, smart meters, smart appliances, electric vehicles and distributed generation combined in-situ with distributed storage will all provide promising options. That makes the pathway towards a low carbon economy to be driven by key trends such as electrification, decentralization and digitalization.

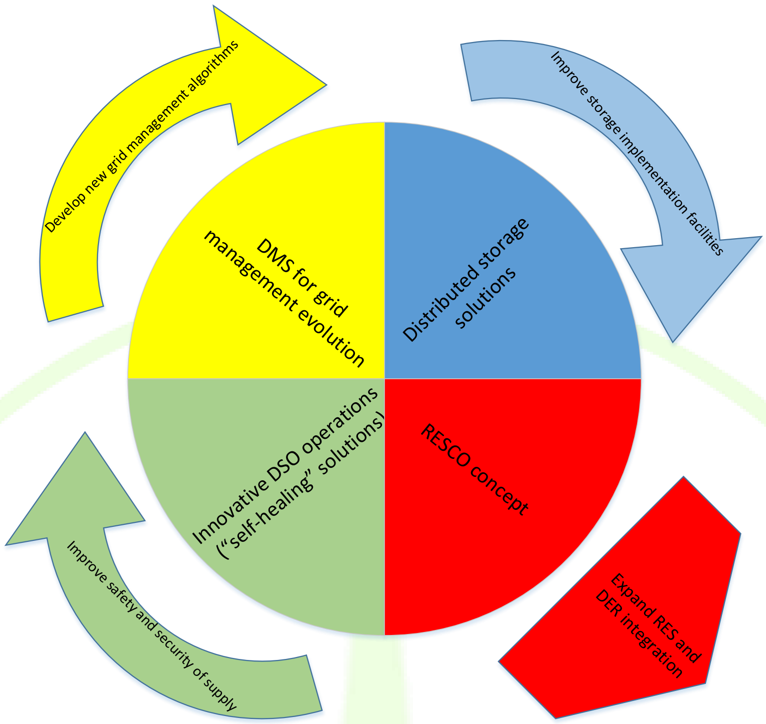


Figure 1 – RESCO approach for RES and DER integration

As illustrated in Figure 1, this deliverable is presenting four research and development directions addressing together the increase of RES generation while keeping the safety of operating conditions above the minimum accepted level, including the reserve stability margin.

Such directions are treated separately in the following sections of the document, as we discuss in more detail below.

"New DMS applications for grid management evolution" is discussed under Section 2 - STATE OF THE ART.

Critical components of DMS have evolved over time, currently having a multitude of individual applications and integrating/interconnecting various IT technologies including SCADA and GIS. One of such application is the Enterprise Service Bus (ESB), a system connecting and harmonizing the data among various interconnected systems. Other critical procedures of grid management that help improve the reliability of the system, the availability of the grid and the quality of service are 1) fault detection, isolation and restoration services, 2) short-circuit analysis, 3) Voltage/reactive power control, 4) short-term load forecasting, 5) power quality monitoring and 6) demand management. Section 2 also presents the case study of the Greek national DSO (HEDNO) examining the current DSO level of technologies and the technical challenges that a typical DSO has to face in order to achieve the integration and interoperability of its own heterogeneous, internal systems. Two different approaches are proposed, integration using data warehouse and Integration at application level using an enterprise service bus (ESB), reaching the conclusion that a combination of two strategies will probably be the best solution.

"Distributed storage solutions" is covered in Section 3 - DISTRIBUTED STORAGE IN THE SMART GRID

The smart grid architecture of the future energy system integrating distributed storage will be composed of two fundamental elements: energy management (dealing with energy products) and system services (dealing with safety products, anti-island operations, security congestion management, power quality management).

Technology wise, different characteristics of storage systems are to be considered, such as capacity, energy efficiency, lifetime and cost, as well as the various technologies such as the fast developing thermal and electrochemical storage, ideal for decentralized operations from household level to even community/district level. In terms of lifetime duration, storage facilities range from 60 years in the case of Pumped hydro storage (PHS), to 40 years for Compressed air energy storage (CAES) and Power-to-gas (P2G), with the design lifetime of a current battery storage system of maximum 20 years [25][26][22]. Energy storage today is still expensive. However, investments costs are decreasing sharply due to economies of scale and the registered decrease of the levelized cost of storage (LCOS) for lithium ion batteries, as well as for other battery technologies becoming competitive to already established energy storage technologies such as PHS. The full range of storage technologies and characteristics, as well as their benefits for grid stability are detailed in section 3.

"Innovative DSO operations" are discussed in Section 4 - INNOVATIVE DSO OPERATIONS: IMPROVING POWER QUALITY.

With the increasing connection of RES and distributed energy resources (DER), the network has become more dynamic and the power flow more often bidirectional. Distribution networks needs systems in place to control a combination of distributed energy resources comprising a multitude of actors, generators and storage facilities. However, increasing the power injected by RES or DER will result in voltage peaks/drops within the distribution network, whose severity will depend on size, location and existing methods of voltage regulation and control. Innovative DSO operations are about extended voltage control solutions, managing of network components, new technologies via real time metering data USMs and development of self-healing algorithms.

Electric networks are traditionally operated with pre-set control strategies. Future networks will have to rely increasingly on technologies which actively shape the grid-users response in an automated feedback mode from RES, consumers and other distributed actors. Aspects such as customers' behaviour and new attitudes, the adoption of new technologies, the Internet of Things (IoT) and emission regulations are making current systems increasingly vulnerable, requiring utilities to identify new ideas for grid management. Transformers, feeders, substations, reactive compensation units (reactors and capacitors), resistors and other grid components are requiring higher monitoring accuracy combined with a dynamic approach in order for the grid to be better monitored as a whole. Also, operating devices could be tuned more efficiently for safety of supply while getting closer to optimum performance. The envisaged grid of the future will predict evolving needs of the customers while, at the same time, deliver safe, reliable and affordable electricity. For this it will be necessary to increase the visibility of the distribution system and move towards extended real time data availability (most probably via new technologies based on real time metering data from USMs). The ability to detect problems directly supports security, including identification of virtual or physical operation of the distribution system and any asset performance or network condition that could endanger the personnel. Real-time observability provides useful information to assess interruptions and re-establish service faster. Early detection of grid problems gives more time to respond before these weaknesses extend to greater security or reliability issues.

Real-time situational awareness would directly address the challenge faced with bi-directional power flows and the minimal or delayed visibility of the distribution system beyond the substation breaker. Moreover, power quality awareness addresses different types of grid conditions not previously monitored on a regular basis. Furthermore, distribution load flow analysis provides a visual load flow tool that assesses all points on the distribution grid for criteria violations in real time. Also, automation of circuit reconfiguration reviews protection settings in the case of distribution topology change. Not least, self-healing strategies achieved by artificial intelligence systems transform events into "lessons learned", functionality strongly linked to fault detection, isolation and restoration capability.

"RESCO Concept" is discussed in Section 5- AN EXTENDED ROLE FOR RESCOS IN SMARTENING THE GRID. Renewable energy service companies (RESCOs) provide RES services to final consumers that do not own nor have the proper capabilities to maintain the necessary equipment, being involved over the entire lifetime of the installed assets. RESCOs operate on a business model in which they partner with investors to own the

resources (e.g. solar panels, domestic wind turbines, and batteries), using long term capital investments, generating power, selling it and collecting revenues from their customers. Usually, RESCOs collect and centralize information from small and medium size RES equipment that have no visibility to the DSO individually, but which together may have a considerable impact in the stability of the network. Moreover, the RESCO model has deep environmental positive impact by encouraging and increasing the share of RES integration into the network.
Within the WISEGRID framework, three potential scenarios related to RESCO business model are proposed, involving three different types of relationships with its customers:

- S1 - RESCO pays a fee to its customers for being allowed to use their premises (e.g. PV installation on their rooftops), installs and maintains the RES assets and sells the entire produced energy;
- S2 - RESCO supplies customers the energy coming from the RES installation owned by the RESCO (i.e. allowing its customers to self-consume the produced energy) and sells the production surplus. Customers under this contractual relationship should pay a fee to the RESCO to cover the provided energy – at prices lower than the ones on the retail market – and the maintenance of the equipment.
- S3 - RESCO provides to customers the installation of RES equipment (e.g. PV panels and batteries) which are still owned and maintained by the RESCO but fully exploited by the end customers. This third scenario describes basically a RES equipment renting business model.

In order to support these scenarios, RESCOs will need to implement management processes to deal with customer contracts (e.g. registration, billing, ceasing), installed asset portfolio (e.g. monitoring, maintenance), energy (e.g. self-consumption contracts) and economic flows (e.g. investments per installation/client).

In WiseGRID, one Primary Use Case (PUC), namely HL-UC 1_PUC 5, and afferent Secondary Use Cases (SUCs) has been defined in order to support the integration of distributed RES in the Grid through RESCOs. Furthermore, to evaluate the impact of RESCOs in the smart grid environment, the following KPIs have been defined: increased RES and DER hosting capacity (ID 1), energy generation capability per investment ratio (ID 26) and self-consumption ratio (ID 46) [1].

Due to the fact that typical RES production involves a certain level of uncertainty, their extensively deployment require the implementation of an effective energy generation forecasting module. Thus, the integration of a RES forecasting module into the RESCO management system will contribute to improve the quality of its services and the economic viability of the final solution. In addition, the RES forecasting module will provide to the DSO prediction profiles of its areas of interest, not necessarily corresponding with geographical areas (e.g. per distribution power lines). Thus, the DSO will be able to perform a better management of its assets and resources using this forecasting division.

Considering the European Commission's Strategic Energy Technology Plan (SET) and the International Energy Agency's guide for Smart Grids in Distribution Networks [2], which forward a cluster of recommendations for improving the European energy system, such as increasing the share of RES, flexibility, advanced metering infrastructure, active customers and energy efficiency; the RESCO business model appears to be an optimal solution and therefore this document is presenting a detailed approach for the RESCO role within energy markets.

In addition, we discuss the advanced business models for aggregators review carried out in the BestRES project [3], reaching the conclusion that independent aggregator can have an important role in creating more competition in the market while combined aggregators tend to stick more to current market schemes.

Power generation is moving towards more and more renewables due to environmental constrains that cannot be withhold anymore. The main characteristic of such renewables is related to spatial distribution that makes a correlation with power grid for distribution as spread within all interested areas. Such RES distribution is challenging the distribution grid and therefore many improvements are going to be in place and these are mostly related to distribution grid management, additional DMS functionalities, storage facilities and RESCO evolution.

All these are presented within this deliverable within main Sections 2-5, and also within auxiliary chapters

(INTRODUCTION and CONCLUSIONS AND RECOMMENDATIONS), all trying to propose solutions that would facilitate large spread of RES, keeping safety operation of the grid above regulated level. The main conclusions of the deliverable are finding that technical solutions like extended DMS functionalities, suitable storage solutions and innovative DSO operations would create the safety and security operating conditions for the power grid to withstand larger amount of RES generation.

Another key conclusion is that the new market actor RESCO can be an institutional solution but also an incentive for the individuals to support more RES installation and operating with higher amount of non-polluting energy. That would be a “natural” incentive with no impact on the final customer bill.

1 INTRODUCTION

1.1 PURPOSE OF THE DOCUMENT

One of the WiseGRID objectives, in line with the EU goals, is to facilitate the active participation of the European consumers and prosumers (households and businesses) in the energy grid and market, through flexible RES generation, self-consumption and storage, or through intermediaries such as aggregators and suppliers. WP12 activities, in particular, are focused on advanced models for smartening the distribution grid and providing advanced services, such as RESCO services, in order to balance the grid.

The content of this document reflect the activities carried out in analysing Grid Management Technologies in order to identify and specify additional or improved DSO operations that should consider storage and controllability of various components through new technologies, including real time data provided by Unbundled Smart Meters, with a specific focus on the role of RESCOs in advanced services for balancing the grid.

1.2 SCOPE OF THE DOCUMENT

This document gives an overview of current grid management technologies for the distribution grid. Starting from challenges and opportunities of current disruptive grid trends that will most impact the management of distribution grid and in accordance with WP12 objectives we focus on functionalities and services for manage and control in a more efficient way the distribution grid in the condition of high renewable penetration and making use of distributed energy storage resources in aggregated way, providing innovative and advanced services such as RESCO services in order to balance the grid.

Distribution grid management technologies have to consider RES and energy storage, as well as EV deployment, when it comes to maintain grid stability and security. Self-healing grid capabilities, enhanced visibility of the LV distribution grid and demand side management (DSM) are just some of the topics to be dealt by DSOs in order to assure the reliability of the distribution systems in the new faced context.

Renewable Energy Service Company (RESCO) is an Energy Services Company (ESCO) which provides energy to the consumers from renewable energy sources, usually solar photovoltaic or wind power [4]. Customers serviced do not own generation equipment, which is owned and maintained by the RESCO. As a consequence, users pay a service fee that includes any required capital replacement cost and all operating, maintenance and repair costs plus a profit for the operating organisation. Considering that prices of distributed energy storage equipment, that used to be too high to prove competitive, in the last few years have been steadily falling, and are expected to fall further [5], it is very likely that in the medium term RESCO financing capabilities will facilitate investment not only in RES but also in energy storage, allowing the consumption of stored energy when is needed at a competitive price.

Thus, it is possible to safely assume that there might be convenient business models for RESCOs and their customers to offer storage based services to investigate as a contributing factor to stabilize the grid.

Despite significant barriers to wide scale adoption of technologies innovations in grid management (related to policies, regulation, investment plans and to greater public engagement), this document will not address this aspect, focusing mainly on technological issues and market consideration, when appropriate.

1.3 STRUCTURE OF THE DOCUMENT

The rest of the document is structured as follows:

- Section 2 gives an overview of current **Distribution Grid Management Technologies**. Starting from grid trends that will most impact the management of distribution grid, we examine current DSO level technologies and the technical challenges that the Greek National DSO (HEDNO) has to face in order to integrate his own systems.

- Section 3 deals with **Distributed Storage** solutions. After an overview of storage technologies and their characteristics (storage types, capacity and duration of discharge), we review the service which can be provided by an ESS depending on the location where the ESS is installed, then we go into the benefit of distributed storage for the distribution grid in terms of System Services and Energy Management Services.
- Section 4 covers **Innovative DSO Operations** in presence of an increasing connection of RES and DER. Three WiseGRID Use Cases addressing the action to be taken by RESCO in case of Voltage Control and Congestion Management are used to introduce the techniques for improved power quality control. Then we consider advanced grid monitoring features, in order to gather real-time observation of the grid, and new techniques based on real time metering data from Unbundled Smart Meter (Nobelgrid SLAM). Finally, we cover self-healing features of the distribution grid (advanced FDIR).
- Sections 5 introduces **Renewable Energy Service COmpany (RESCO)** and examines its role in smartening the grid. After a profitability overview of RESCO business models, we analyse the management activities of a RESCO: contract management, installed assets portfolio management (including monitoring and maintenance management), energy flow management, economic flow management as well as other features needed to act in the wholesale market, such as RES production forecasting. Then we cover the advanced functionality of a RESCO for smartening the grid and, finally, we review advanced business model of Aggregators.
- Section 6 outlines **Conclusions and Recommendations** of this work.

2 STATE OF THE ART OF DISTRIBUTION GRID MANAGEMENT TECHNOLOGIES

This section gives an overview of current distribution grid management technologies. First we cover the grid trends that are potentially bringing disruptive change in the electricity industry, focusing on challenges and opportunities that will most impact grid management. Then we examine current technologies at the distribution system operator (DSO) level, which are composed of a set of integrated systems whose purpose is to assist in monitoring and controlling the distribution system in an optimal manner ensuring safety and asset protection. Needless to say, challenges poses by current energy industry trends will involve all these systems. Finally, in order to better understand the complexities of grid management, we cover the challenges that the Greek National DSO (HEDNO) has to face in order to integrate his own systems.

2.1 GRID TRENDS: CHALLENGES AND OPPORTUNITIES

New technologies have been reshaping most, if not all, major industries worldwide. In the electricity industry, mature and capital intensive, however, much still needs to be done. Many power plants, power distribution stations and a significant part of the electrical distribution infrastructure, were designed, built and installed decades ago: they need be modernized.

According to World Economic Forum [6], innovation has the potential to reshape the sector, while benefiting not only the industry actors, but also their customers and the environment. Value and new jobs will result from new services to be offered to customers, but more importantly we can hope and expect to substantially curb carbon emissions.

Several promising technical options have become or are becoming viable: distributed RES generation (already quite common), distributed generation combined *in situ* with distributed storage, consumer side options technologies such as smart meters, smart appliances and electric vehicles. While there are significant distributed RES installed, independent storage facilities together with V2G technologies are rapidly emerging. However, a wider adoption of these technologies would be possible only with a strong interest of the consumers that should be driven by market levers or specific incentives (e.g. tax credits) together with a “going-green” lifestyle shift.

Three major trends are virtuously affecting the electricity system (Figure 2):

1. Electrification: more equipment is becoming electrically powered, domestic heating and transportation (electric vehicles) being the two most relevant examples. Coupled with increased RES generation, this will reduce the use of fossil fuels. Increasing electrification also provides opportunities to enhance the flexibility and efficiency of electricity systems.

2. Decentralization: to decentralize part of the generation and storage, moving from the high voltage grid to medium and low voltage area. Distributed generation can benefit customers and the system, supplying electricity directly and supporting load growth. Distributed storage offers a way to flatten out the peaks and valleys of supply and could be a viable alternative to “peaker plants”.

3. Digitization: the increasing use of IT and digital technologies. Smart energy systems can enable demand-response measures. Smart meters and smart appliances allow demand management and provide incentives for consumers to play an active role in providing flexibility to the energy systems.

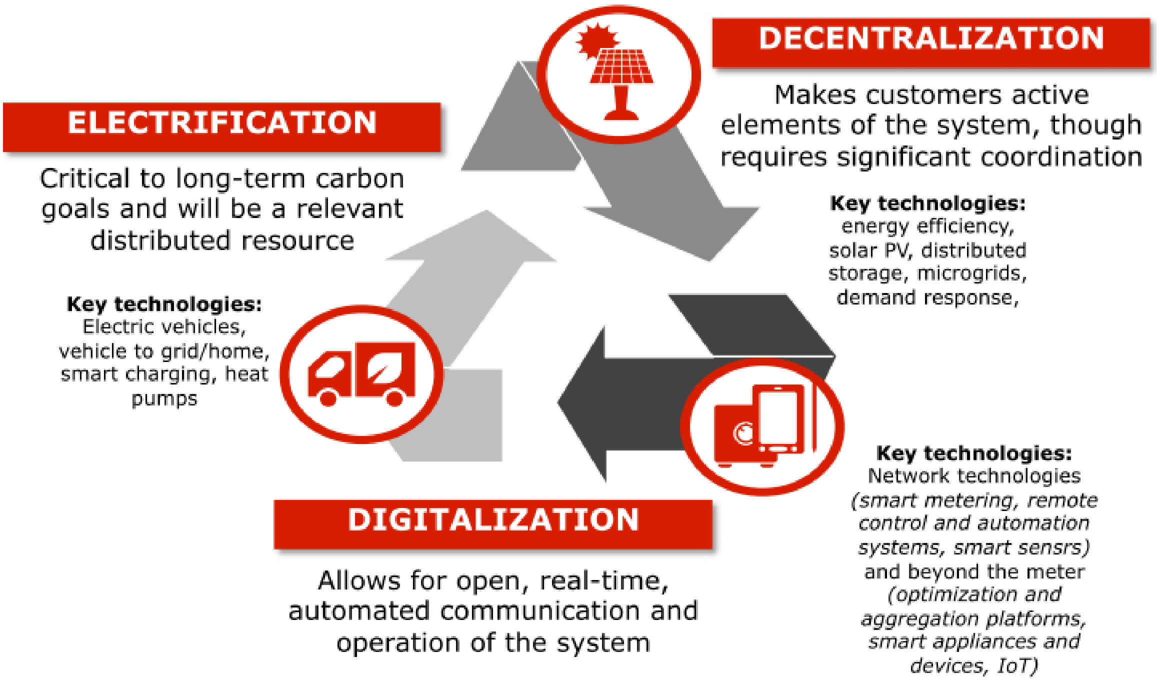


Figure 2 – Major grid trends [6]

These trends pave the way towards a system where traditional boundaries between producers, distributors and customers are blurred, increasing the complexity of system governance and posing many challenges to the distribution grid:

- Increasing presence of renewable power
- Increasing presence of Distributed Energy Resources (DER) RES, storage, PHEV
- Bi-directional flow of energy ("Prosumers")

(Increasing distributed energy resources require real-time management of bidirectional power flows - "Prosumers", since intermittent energy sources, such as wind and solar, must be counter-balanced by "smarter" grid and energy storage that may provide capacity to the grid when demand is peaking, reducing supply and demand mismatch)

- Shifting from centralized to decentralized generation and control architecture
- Automation of distribution management
- Situational awareness and grid predictability is becoming more critical
- New applications/services based on smart devices and more active network
- Smart devices/resources with distributed intelligence
- Coordinated decision making
- Big Data

Shifting from centralized to decentralized grid management, while maintaining grid stability and security, implies the need of real-time grid monitoring and new application/services gathering data from interconnected smart devices that replace or integrate traditional equipment, in order to improve the automation of distribution management operations.

2.2 GRID MANAGEMENT – CURRENT DSO OPERATIONS AND PROCESSES

Undoubtedly, the electric distribution system has been considerably affected by grid modernization. The "smart grid" has transformed the electric distribution systems from dated processes to electronic and computer-managed decision making with a high level of automation. The core of this transformation is the Distribution Management System (DMS), which is a set of integrated computer and communication systems whose purpose is to assist the Distribution System Operator (DSO), electrical engineers, and other electric utility technicians in monitoring and controlling the distribution system in an optimal way without compromising safety, stability or systems' protection [7][8][9][10].

The DMS can cover an entire distribution grid or just a subset of the whole system, such as a number of substations of the distribution grid. The DMS generally has full capability for the overall operation of the entire grid or part of the grid. Most of the today's DMS are designed to meet operational requirements for the automation and administration of traditional distribution grids. The fundamental characteristics of the traditional distribution systems are passive networks and radial configurations. These characteristics are the base for today's DMS planning and implementation; grid modelling, data structures, and advanced application algorithms are key features of a modern DMS. An ordinary DMS is generally consisted of several subsystems and software modules. Although the overall architecture of a DMS with these components may still work fine for a new distribution grid with a high penetration of DER and microgrids, the contents of these components may need to be extended or updated significantly by incorporating the impacts of the transition from passive to active networks in the distribution grids.

A typical Distribution System consists of a DMS, SCADA, GIS, AMR and ERP systems. These systems are presented below.

2.2.1 SCADA

A power transmission system transports the electric power from production to the loads by using transmission lines and distribution substations. Implementing a SCADA system for the power distribution not only reduces manual operation but also facilitates automatic operations with reduced disruptions offering a smoother and more reliable operation.

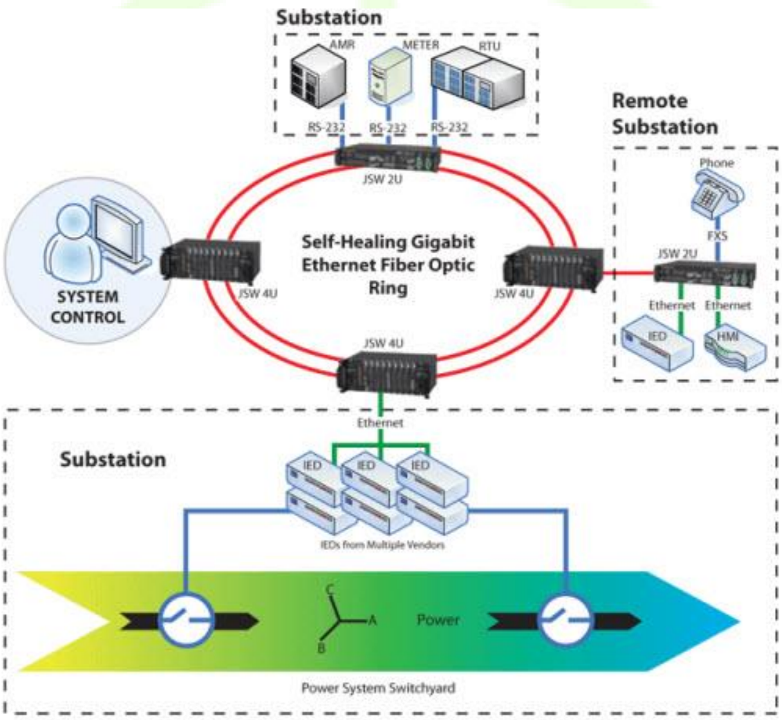


Figure 3 – SCADA system overview [11]

Figure 3 shows the structure of a SCADA in a power system, where it collects data from different electrical substations (even at remote locations) and correspondingly processes the data. Programmable logic controllers monitor substation components in real time and transmit data to a centralized SCADA system. If any failure of electrical power occur, SCADA detects the exact location of the fault, reducing the waiting time for calls from customers. SCADA immediately alarms system operators for identification, allowing faster system healing. Also in substations, SCADA automatically controls isolator switches and circuit breakers for exceeding parameter limits, thereby continuous inspection of parameters is performed without a line worker. Some of the functions of SCADA in power distribution system are:

- Improving power system efficiency by maintaining an appropriate range of power factor
- Reducing peak power demand
- Continuous monitoring, controlling of various electrical parameters and improvement of operation under both normal and unstable conditions
- Alarming operators by addressing the problem
- Historic data querying
- Response to customer service interruptions

The advantages of Implementing SCADA systems for Electrical Distribution are the following:

- Due to faster recognition of faults, equipment damage can be avoided
- Monitoring and control of distribution network can be performed remotely
- Saves work cost by eliminating manual operation
- Reduce outage time by generating alarms to quickly address problems
- Improves the constancy of service by restoring power after the occurrence of temporary faults
- Automatically improves the voltage profile due to power factor correction and VAR control
- Facilitates the view of historical data in various ways
- Reduces the labor cost by reducing the staff required for meter reading

The major components in a SCADA system are the following:

Remote Terminal Units (RTUs)

RTU is the main component in a SCADA system because it has a direct connection with various sensors, meters and actuators associated with a control environment.

RTUs are real-time programmable logic controllers (PLCs) which are responsible for properly converting remote station information to digital form, sending and receiving signals from a master unit to control process equipment through actuators and switchboxes.

Master Terminal Units (MTUs)

A central host server is called Master Terminal Unit, sometimes also called SCADA center. It communicates with several RTUs by executing reading and writing operations. In addition, it performs control, alarming, networking with other nodes, etc.

Communications System

The communication network transfers data between central host computer servers and field data interface devices and control units. The network link can be cable, radio, telephone, satellite or any combination of them.

Operator Workstations

These are the computer terminals presenting a Human Machine Interface software. These workstations are operator terminals that request and send the information to host client computer in order to monitor and remotely control the field parameters.

2.2.2 GEOGRAPHIC INFORMATION SYSTEM (GIS)

GIS is a powerful tool, which can be defined as a group of data, hardware, software and processes designed as a computer system for gathering, managing, mapping and analysing spatial data. GIS is one of the most important new technologies for fault analysis, optimization of networks, load forecasting and cost estimation. A GIS allows the utility engineer to design and focus on the real issues rather than trying to understand data or defining the problematic spot in a power grid [12].

Database, which plays a central role in the operation of planning, can be divided into two main data types: spatial data, that describe the location and the shape of geographic features, and spatial relationship of map features - attributes data known as descriptive information of the map features.

The two most frequently used GIS models of spatial data are raster and vector. Vector data are based on coordinates system where a geographic object is represented by points, lines and polygons. Vector data are more suitable for features that have discrete boundaries such as roads. Raster data consists of a matrix of cells (or pixels) organized into rows and columns (or a grid) where each cell contains a value representing information, such as temperature. Each set of cells constitute a layer, called coverage, and several thematic layers can logically constitute a complete database. The raster data model is the most suitable format for arithmetic operations between cells. A mathematical procedure called topology is used for representing spatial relationships among the objects. GIS software and hardware are used as tools for storing, analyzing, interpreting, and displaying geographical information.

2.2.3 AUTOMATIC METER READING (AMR)

The Automatic Meter Reading (AMR) and Meter Data Management (MDM) systems refer to equipment and applications that enable the provider to control remote smart meters, store their data and process it for pricing, troubleshooting, and analysis purposes. The AMR system can provide metering data and information about the consumer's energy profile and other elements that may be useful for different actors, such as DMS or other applications.

2.2.4 ENTERPRISE RESOURCE PLANNING (ERP)

An ERP is an IT system for automating business operations across different operating areas.

Thanks to the automatic interconnection of ERP subsystems, sharing of information is facilitated. This makes operational information, at least in terms of management issues, easily and quickly accessible to give a better insight into business operations and making them more secure to take strategic choices from the operators in the operation, organization and administration of an electricity distribution system.

The basic ERP subsystems commonly used are:

- Financial management
  It includes accounting, asset management, treasury planning, the implementation of the budget and other relevant economic functions business.
- Supply chain
  It includes material management and warehouse management, commissions, purchase budgets, orders, and so on.
- Project management
  Among other things, it includes managing the whole life cycle of projects (start, scheduling, execution, closing) as well as tracking it cost and budget.
- Sales Management
  It includes the charges for the use of grid and electricity from RES and support for various business sales processes.

* Human resources management
  It includes managing the organizational chart, employee file, disciplinary and, in general, the majority of HR-related processes (Human Resources).

2.2.5 DISTRIBUTION MANAGEMENT SYSTEM (DMS)

A DMS is one of the most important components for the modernization of today's distribution systems with automatic control and management. As a fully functional unit, a DMS may have dozens of individual applications [13][14].

As stated previously, most of the DMS in operation today are designed to meet the operational requirements for the automation and management of traditional distribution grids. The key common features of the traditional distribution grids are that they are large passive networks that are usually configured in a radial operation topology for distribution feeders. A typical DMS consists of several subsystems and major software modules, including a SCADA system, a GIS, a Data & Model Management (DMM) module, a set of advanced applications, and a User Interface (UI) environment. Figure 4 shows a high-level layout and structure of the subsystems and key components in a typical DMS.

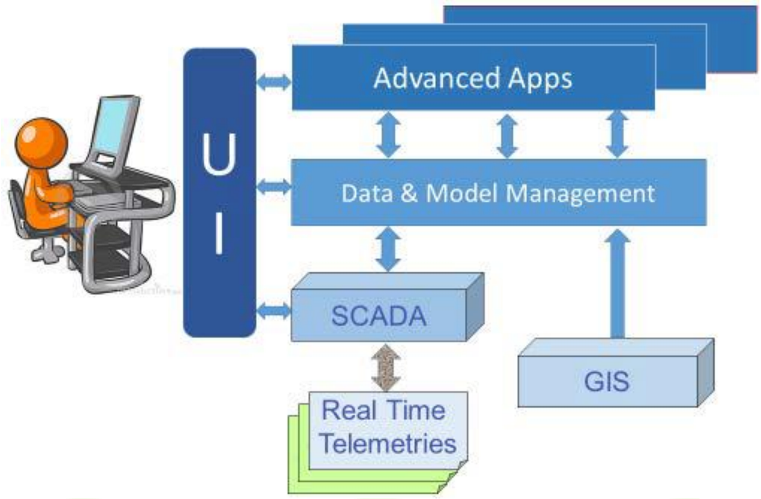


Figure 4 – Reference Layout and Structure of a DMS [14]

A DMS is fully responsible for the reliability of the overall system, power quality, grid economic operation (minimising energy losses), and all of the normal and emergency controls of the distribution system or subsystem, including maintaining an acceptable voltage profile. A DMS may operate in an integrated environment with other associated systems, such as advanced metering infrastructure (AMI) and demand response management system (DRMS). However, the other systems do not interfere with the DMS's tasks within the scope of the overall distribution grid operation assigned to the DMS.

A distribution system may be operated under a single DMS's monitoring and control span, or it may be partitioned into several geographically subsystems, with each subsystem having a dedicated DMS. A DMS may be assigned to control and manage a single distribution system, multiple systems, or multiple subsystems. However, a single system or a subsystem should be under only one DMS at a time, although it may have one or more backup DMS for fail-over.

The basic functionalities of a typical DMS in operation today include real-time monitoring and control through a SCADA system and individual advanced applications, such as:

* Topology processor (TP)
* On-line power flow (OLPF) Distribution power flow (DPF)
* Short-circuit analysis (SCA)

- State estimation (SE) / Load modelling/load estimation (LM/LE)
- Fault location, isolation, and service restoration (FLISR)
- Fault detection, isolation, and service restoration (FDIR)
- Restoration Switching Analysis (RSA) application
- Volt/VAR optimization (VVO) Optimal capacitor placement/ Optimal Voltage Regulator Placement (OCP/OVP)
- Optimal Network Reconfiguration (ONR)
- Contingency analysis (CA)
- Switch order management (SOM)
- Emergency load shedding (ELS)
- Short-term load forecasting (STLF) / Demand Management
- Relay protection coordination (RPC)
- Dispatcher training simulator (DTS)

The listed applications are the key advanced functions in a DMS and are generally designed to control and manage distribution grids in passive networks. They are all facing fundamental challenges from the high penetration of DER which makes the distribution grids no longer passive but highly active networks. In addition to integrating subsystems such as GIS and SCADA that provide overall system models and real-time data acquisition, respectively, a DMS also includes many advanced applications for various functionalities.

The basic functionalities and features of the individual applications in a typical DMS are presented below.

2.2.5.1 Topology Processor (TP)

Topology Processor (TP) is usually a background processor that accurately calculates the distribution network topology based on the static model of connectivity and the dynamic status of switching devices. It also depicts with colour the power supply circuit indicating the activation status of the grid, supplying paths, and so on. In case a non-intentional loop is being formed, TP can detect the loop and address with an alarm to system operators. If the topology of the system is determined, power flow direction is determined as well because of the radial configuration of the grid network. Moreover, the topology data are the basis of many other DMS applications like intelligent alarm processing, which is based on the topology structure. In some cases, a distribution grid may have intentional looped operation scenarios. TP is responsible for identifying the looped circuits and can highlighting them if requested from the operators. In general, the TP can perform the following functions:

- Locate each element of the distribution network (transformer, section) by name or ID
- Locate and mark supply paths through network elements
- Determine and highlight the activation status of network elements
- Locate and highlight network loops
- Locate and highlight all network elements for the downstream of a selected element
- Locate and highlight the neighbouring feeders of a selected feeder that can serve as an alternate supply for the feeder
- Colour individual feeders
- Colour by voltage level
- Colour line segments which voltage magnitudes exceeding specified thresholds
- Colour line segments with loading greater than specified level
- Locate and highlight portions of the distribution grid that are isolated from the utility's power grid and are being supplied by DER or microgrids.

In addition of requiring correct connectivity models, it is also essential to have accurate phase information in the connectivity model for TP to provide correct topology information and other advanced applications. This is because distribution networks generally operate in unbalanced conditions, including unbalanced networks (e.g. single-phase and two-phase laterals) and unbalanced power flow among the three phases. Incorrect phase information will lead to topology and power flow results that are completely wrong.

2.2.5.2 On-line Power Flow (OLPF) / Distribution power flow (DPF)

OLPF is one of the core applications in a DMS. It solves the three-phase unbalanced power flow of the distribution network. Power flow results from OLPF are used by many other DMS applications to set initial conditions and confirm desired performance or to show hypothetical impacts, such as in VVO, FLISR, and SOM.

The OLPF also provides the operators with the calculated values for each segment of the grid such as line current, node voltage and power flow values, and alerts the operators when abnormal conditions out on the feeders, such as low voltages or overloaded line sections may occur.

In solving power flow problems, the OLPF uses the distribution system model and load estimation (provided by load allocation and estimation functions) in its calculations. It may also use the available real-time status from the substation and feeder devices, alongside with the voltages and phase angles obtained from the EMS state estimator used by the transmission operator at the injection points (usually placed on a high-voltage transformer bus in distribution substations).

More detailed OLPF results include the calculated current and voltage magnitudes and phase angles, the real and reactive power flows and injections for the entire distribution system, and all the technical losses. All of the detailed results may be presented in various formats automatically or on demand on convenient graphical displays for viewing power flow summaries for a large area of the distribution system and/or viewing (on demand) the detailed results for the individual points or sections of the distribution system.

2.2.5.3 Short-Circuit Analysis (SCA)

SCA is an analysis tool in DMS that operates upon the operator’s request. It calculates the short-circuit current in a distribution grid for hypothetical fault types and pre-fault operation conditions to evaluate the possible impacts of the fault on the distribution grid. SCA results can be used to test the relay protection settings and operation, as well as the circuit breaker and fuse ratings, proposing more accurate relay settings or better feeder circuit configuration from the viewpoint of circuit protection.

The SCA function enables the operators to calculate the three-phase voltages and currents on the distribution system that could occur as a result of postulated fault conditions and pre-fault loading conditions. It can calculate and compare fault currents against switchgear current- breaking capabilities and device fault-current limits. It may also permit to identify estimated fault location using measured fault magnitude, pre-fault loading, and other information available at the time of the fault. The benefit is limiting (in combination with GIS) on one hand the area to be investigated following a permanent fault and on the other hand the time needed for restoration by optimizing (for example) the routing of on-site crews.

2.2.5.4 State Estimation (SE) / Load modelling/load estimation (LM/LE)

Load modelling/load estimation (LM/LE) is a very important base module in DMS. Dynamic LM/LE uses all the available information from the distribution network—including the user transformer capacities and customer monthly billings, if available, combined with the real-time measurements along the feeders to accurately estimate the distribution network loading, for both individual loads and aggregated bulk loads. The effectiveness of the entire DMS relies on the data accuracy provided by LM/LE. If the load models and the load values are not accurate enough, all the solution results from the DMS applications will be useless.

2.2.5.5 Fault Location, Isolation, and Service Restoration (FLISR)

FLISR is designed to improve distribution grid reliability. Based on real-time telemetries from the field RTUs or IEDs installed along the feeder line, it can detect a fault on a feeder section and can quickly isolate the faulted section by opening the nearby automatic switches. FLISR then restores power supply to the downstream sections by connecting to an alternative source. If a single alternative source lacks sufficient capacity to pick up all healthy feeder sections that are downstream of the faulted section, multiple alternative sources may be utilized to share the load, depending upon their available capacities. FLISR can significantly reduce the outage time, generally from several hours to less than a minute, considerably improving distribution system reliability and service quality, for example, in terms of the System Average Interruption Duration Index (SAIDI) because of reduced outage duration and the System Average Interruption Frequency Index (SAIFI) because some customers can be restored to service in less time than the threshold for permanent outages (usually 1 minute).

The main FLISR logic includes the following features:

- Automatic fault detecting
- Automatic determination of the approximate location of the fault (i.e., the faulted section of the feeder that is bounded by two or more feeder switches)
- Automatic isolation of the faulted section of the feeder
- Automatic restoration of services to as many customers as possible in less than 1 minute following the initial circuit breaker or recloser tripping.

The FLISR can analyze all available real-time information acquired from field devices to detect faults and other circuit conditions that require service restoration actions. All the control actions identified by FLISR are executed by issuing supervisory control commands to substation circuit breakers, reclosers, and various feeder switching devices (reclosers, load breakers, and section analysers that are equipped with supervisory control capabilities).

The FLISR function is normally only responsible for dealing with permanent faults occurring on the main three-phase portion of the feeder and those substation faults that cause the sustained loss of one or more feeders at the substation. Temporary faults that are cleared without sustained loss of service by standard automatic reclosing schemes are included in FLISR logic. FLISR function is not responsible for restoring service loss that occurs because of blown fuses on feeder laterals, ELS activities, or manual feeder tripping.

The FLISR generally considers all the possible ways to restore the maximum feasible load without creating such undesirable conditions. The service restoration strategies must assure that the FLISR:

- Does not cause undesirable electrical conditions on any distribution feeder,
- Restores electrical service to the maximum number of customers, and
- Requires the fewest number of switching actions.

2.2.5.6 Restoration Switching Analysis (RSA) application

RSA is an advanced application for improving reliability performance indices. This application can improve the assessment of all possible switching actions to isolate a permanent fault in order to restore power supply to customers as quickly as possible. The application analyses and informs the operator with the suggested switching actions, in order to select the best alternative, based on criteria such as number of customers restored, number of critical customers restored, and required number of switching operations. After the occurrence of a permanent fault, the application analyses all the possible switching actions and executes an unbalanced load flow to prevent the occurrence of possible overloaded lines and low-voltage violations if the necessary switching actions were performed. The operator receives a summary of the analysis, including a list of recommended switching actions. Similar to the fault-location application, the functionality uses the DMS model of the system but improves outage management reducing the CAIDI and the SAIDI. The RSA application is severally valuable during heavy loading and when the number of potential switching actions is high. Depending on the option selected, the application can be executed with the operator in the loop or in a closed-loop manner (fully automatic) without any interference from the operator. In closed-loop operation, the RSA application transmits control messages to distribution devices using communication networks such as SCADA or potentially AMI infrastructure. Such an automated isolation and restoration functionality approaches what many call the “self-healing” characteristic of a smart grid.

2.2.5.7 Volt/VAR Optimization (VVO)

VVO regulates the feeder voltage profile and VAR flow. It generally has the following three key objectives:

- Minimize network losses by switching the available capacitor banks.

- Obtain a desired voltage profile along the feeder circuit during normal and emergent operation conditions.
- Reduce peak loads through conservation voltage reduction (CVR) by controlling transformer tap positions in substations and voltage regulators on feeder sections.

Advanced multi-criteria optimization algorithms are utilized to optimally coordinate the controls of the capacitor banks, voltage regulators, and transformer tap positions to achieve these three key objectives.

The VVO function can operate either in closed-loop or advisory (open-loop) mode. In advisory mode, VVO provides advisory control actions that can be reviewed and then either approved by the dispatcher for execution or rejected. In closed-loop mode, VVO will automatically execute the optimal control actions without operator verification. The VVO function can run periodically at a user-adjustable interval, upon occurrence of a specified event (e.g., significant change in the distribution system such as significant load transfer or a topology change) or when requested by the user (on demand) manually. In addition to the real-time data from the field IEDs, VVO may also use the near-real-time voltage measurements from a small number of AMI meters if available. These voltage measurements can be continuously monitored by VVO to verify that voltage constraints are kept between limits at these locations.

2.2.5.8 Optimal Network Reconfiguration

ONR is designed to provide decisions' support of switch operation sequences to reconfigure the distribution feeder circuits from the existing state to the optimal one, in order to minimize network energy losses, maintaining desired feeder voltage profiles and balancing the loading condition among substation transformers, feeders, and the three phases. ONR can also be utilized to develop outage plans for feeder circuit maintenance or work in the field for service expansion. Common objectives of the ONR function are to:

- Minimize total electrical energy losses on the selected group of feeders over a specified time period
- Minimize the peak demand among the selected group of feeders over a specified time period
- Balance the load between the substation transformers or selected groups of feeders (i.e., transfer load from heavily loaded feeders to lightly loaded feeders), and
- Implement a weighted combination of the above.

The ONR function output is presented with a list of recommended switching actions and a switching plan to fulfil these actions, along with a summary of the expected benefits (e.g., amount of loss reduction).

2.2.5.9 Contingency analysis (CA)

Contingency analysis (CA) in the DMS is designed to analyze potential switching and fault scenarios that would negatively affect operational stability or electrical supply to customers. With the CA results, proactive or remedial actions can be taken by changing the operating conditions or network configuration to guarantee minimal number of customer outages and maximum network reliability. Switch order management (SOM) is a very important tool for system operators in real-time operation. Several of the DMS applications and the system operators will generate numerous switch plans that have to be well managed, verified, executed, or rejected. SOM provides advanced analysis and execution features to better manage all switch operations in the system.

2.2.5.10 Switch Order Management (SOM)

The SOM function is to assist system operators in preparing and executing switching procedures for various elements of the distribution system, including both substation and field devices (outside the substation fence). It can assist the user in generating switching orders that comply with applicable safety policies and work practices. It supports the creation, execution, display, modification, maintenance, and printing of switching orders containing lists of actions that are needed in order to perform the switching, such as opening/closing various types of switches, implementing cuts and jumpers, blocking, grounding, and tagging. It is also able to help in viewing a portion of the feeder being worked on in either geographic or schematic form that may be automatically created from the geographic view.

In addition to the computer-assisted switch order generation facility described above, the SOM can automatically generate switching orders, and the dispatcher can select the distribution system device or portion of the system to be isolated to work on. The defined switching orders may be executed in real-time mode or in study mode. The real-time executions will involve supervisory control commands, while study mode execution allows the dispatcher to check out the switching order's eventual impact on the distribution grid, including possible current and voltage violations, at a specified time and date using the OLPF function prior to actual execution. SOM can alert the dispatcher if any violations are detected during study mode execution of the switching order.

2.2.5.11 Emergency Load Shedding (ELS)

The ELS function can be executed in real time on request for the quick shedding of load in the distribution grid due to stability reasons. This function is usually synchronized with the load-shedding functions that are executed in the EMS (under frequency, under voltage load shedding). The objective of ELS is to minimize the manual effort that is required to shed a specified amount of load and restore the previously shed load when the initiating problem is corrected. The user is allowed to initiate the load shedding only for loads that are included in the user's assigned Area of Responsibility (AOR). When ELS is required, the user can activate the ELS function and enter the amount of load to be shed. The ELS will then determine which switching devices to operate in order to accomplish the load-shedding objective.

The loads that participate in the emergency load-shedding program, may be assigned different priorities corresponding to miscellaneous shedding strategies. The loads at the same priority level may be rotated dynamically for equal chance and duration of out of service, taking also into consideration historical data on service interruptions due to past events.

2.2.5.12 Short-Term Load Forecasting (STLF)

STLF in DMS is a function that can predict the distribution system load based on the historical load and the historical and forecasted weather data on an hourly basis for up to a 168-hour rolling forecast period. The STLF results should be available for viewing and outage planning and should also be used by other DMS application functions that require an estimate of expected peak loading in the near term, such as OLPF, FLISR, SOM, and ONR.

STLF in DMS usually provides the load forecast for the entire system or on a substation basis. The forecast load is then distributed to individual feeders or even individual consumer transformers based on certain allocation rules, such as using hourly or daily peaks or averages of the feeders or consumer transformers as the allocation factors.

2.2.5.13 Relay protection coordination (RPC)

Relay protection coordination (RPC) manages and verifies the relay settings of the distribution feeders under different operating conditions and network reconfigurations.

2.2.5.14 Dispatcher training simulator (DTS)

Dispatcher training simulator (DTS) role is to simulate the effects of normal and abnormal operating conditions and switching scenarios before they are applied to the real system. In distribution grid operation, DTS is a very important tool that can help the operators to evaluate the impacts of an operation plan in advance or simulate historical operation scenarios to obtain valuable training on the use of the DMS. DTS is also used to simulate conditions of system expansions.

2.2.5.15 Power Quality

PQ disturbances can range from high frequency impulses caused by lightning strikes, to long-term sustained overvoltages resulting from poor voltage regulation. The capabilities of the monitoring device will also influence the choice of which parameters to measure. The development of PQ monitoring requires first of all distinguishing between online and offline analyses. Online analysis is devoted to the incidents that need immediate attention (for example sags or interruptions). The online data analysis can be performed within the instrument itself or immediately upon collection of the information at a central processing location. In order to reduce the data overburden the event should be grouped in categories such as transient, interruption or voltage sag or swell. As exists the possibility of receiving several incident alarms at the same time, it could be necessary the use of some kind of “distribution scoreboard” algorithm that automatically classifies events in rank of importance. This could be done by the use of different criteria, e.g. maximal time duration, maximal magnitude variation or maximal energy variation.

On the other hand, the offline power quality analyses the information that usually has been included in a power quality report, for example:

- Statistics of the steady-state Variations (voltage level, harmonics, unbalance, or flicker).
- Statistics of the Event resulting from incidents (sags, short-interruptions, swells, or transients).
- Identification of the likely cause of the power disturbances.
- Characterization of the electromagnetic compatibility level of equipment and installation.
- Recommendations for cost-effective mitigation and maintenance solutions.

2.3 TODAY’S CHALLENGES: DSO HETEROGENEOUS SYSTEMS’ INTEGRATION - GREEK PARADIGM IN HEDNO (GREEK NATIONAL DSO)

One of the challenges that arise from the *digitalization* grid technology trend in grid described in section 2.1 is the integration of different systems, devices and data sources in order to allow devices across the grid to communicate and provide data useful for customers and for grid management and operation.

This section presents some suggestions for designing the interconnection and interoperability of the basic systems of the Greek National DSO (HEDNO) [15].

HEDNO, established in May 2012 after the spin-off of the Distribution segment of PPC S.A., is responsible for operating the Hellenic Electricity Distribution Network and, as such, responsible for the uninterruptible electricity supply of the entire country. Through the Medium and Low Voltage networks, HEDNO delivers electricity to 7.4 million customers, while the Company manages the High Voltage networks in Attiki and in the non-interconnected islands. In terms of number of consumers served, HEDNO is the fifth largest Distribution Company in EU [16].

The interconnection of an organization's or company's systems is a complex issue at both design and implementation level, with no off-the-shelf solutions, affected by the operational objectives for interoperability, by the technical constraints of the systems to be integrated, from economic and other factors that are structural to the organization or company. The aim of this paradigm is not the extensive and in-depth analysis of the aforementioned factors but, on the contrary, the investigation of this interconnection at a higher level. The proposed implementations are presented mainly in the context of their basic principle of operation, always in relation to the existing situation and the needs of HEDNO. In addition, the following analysis will be an initial approach to the interfaces issue. There are many outgoing issues related to the capabilities of the HEDNO systems (e.g. registration - reading data from databases, etc.), rendering the proposed solutions an "axis" to the future implementation but not binding and fully enforceable.

Large businesses and organizations, such as HEDNO, have large and complex systems to meet their demanding needs. These systems, as they are strategic investments and large-scale projects, are purchased and utilized over the long company's operating times and in the majority of cases by different manufacturers. For example, in the case of HEDNO, the HERMES (ERP/CRM) or ZEUS (Asset Management) systems are 20 years old; AMR started (partly) in 2007, while the ERP was implemented in 2014. These systems in most cases are required to communicate with another system in order to implement a certain operational function, such as the pricing of MV consumers where hourly load curves from the AMR system are sent to ARTEMIS (Billing System) and then, after processing, to HERMES. Over the years and with the addition of new or changing some older business functions, new interfaces between systems are required and have been developed. When the above functions and procedures are implemented in an unstructured and un-programmed way, it results in the creation of so-called "spaghetti" networks, i.e. networks that are based on point-to-point communication between systems such as the one shown in Figure 5.

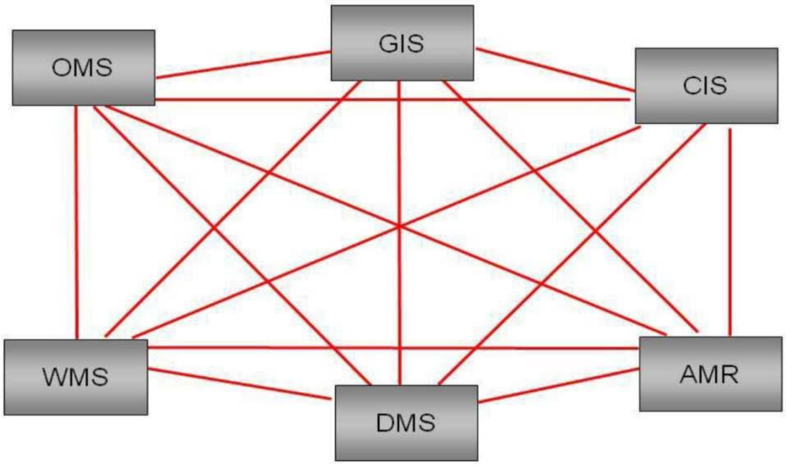


Figure 5 – Point to point network communication [15]

Such a “Spaghetti” Oriented Architecture, over time, leads to the following issues:

- Tight coupling between systems. This in practice means replacing or upgrading a system is a painful process as it greatly affects all the dependent systems.
- Minimal operational flexibility, as the redesign or the replacement of the implemented functions becomes very difficult and the organization or firm is therefore unable to adapt to possible future changes.
- The information is produced and processed more than once and stored at various points. This leads to additional processing burden and resources of the enterprise and creates difficulties in identifying primary production and information flow.

A DMS system is, in fact, a set of tools with different characteristics and different goals each, which in practice means that each one requires data from different systems. Considering that, the development, installation and operation of these tools is not necessarily at the same time or by a single contractor (due to technical, economic and other factors) and taking into account the fact that new tools may be required in the future in order for the organization to meet the new conditions, a design such as this is often attractive, but cannot be considered reliable and effective for the reasons outlined above. Therefore, in order to achieve the integration and interoperability of these heterogeneous systems to implement DMS applications, two implementations are proposed in [15]. These are:

1. Data integration using data warehouse.

2. Integration at application level using an enterprise service bus (ESB).

The solution can be based on consolidation at one of the two levels or a combination of these. These two implementations are presented next.

2.3.1 Data Integration

Data-level integration includes linking data to different sources and enabling users to have a single image and access to them. Consolidation at the data level is widespread in the field of scientific research (mainly medicine and biology) as well as for large organizations and businesses. In particular, in the business sector which is also involved in this paradigm, data integration is often implemented in terms of data warehouse or enterprise data warehouse.

A company's data warehouse is a central point where consistent data is stored that comes from various disparate sources of the company. It is a relational database consisting primarily of historical data, i.e. data for which the process that created them has already been completed. In this way, it separates the functions of the analysis from the executive into a business. Such a system is considered a key element of Business Intelligence and is used for data reporting and analysis.

A basic function that is required in a data warehouse is the so-called ETL (Extract-Transform-Load) which is responsible for:

- Exporting the data from different databases of the enterprise
- Transform the data into the appropriate format in order to be accepted from the data warehouse
- Loading data in the warehouse

These procedures are not necessarily sequential but can be performed in parallel when this is feasible. Quite often, the data needs to be processed before entering the data warehouse in order to meet the specifications that have been set. Often there is an intermediate area called the staging area. Figure 6 shows the basic structure of a data warehouse.

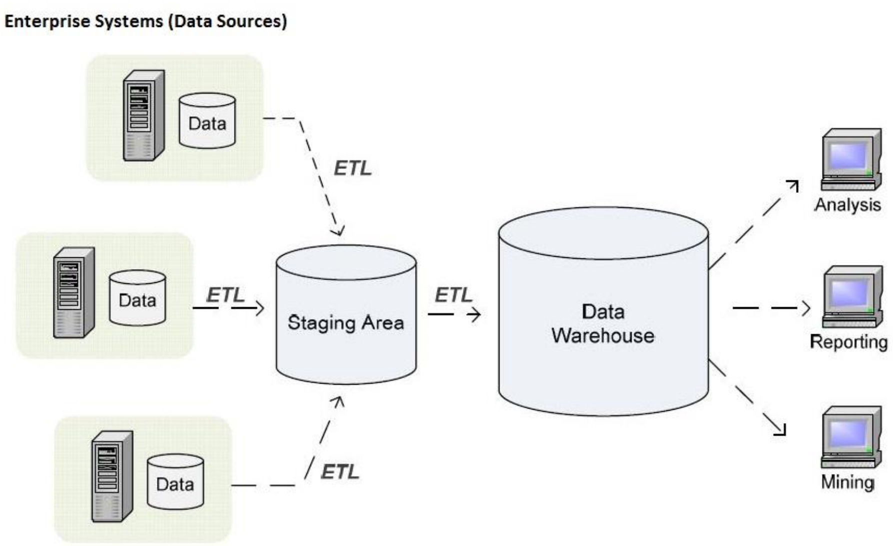


Figure 6 – Data warehouse structure [15]

Updating the data of a data warehouse can be done in two main ways. The first way, which is also the most common, is to schedule a renewal (e.g. daily or weekly) with a specific way (offline data warehouse) with batch operations. If the database only manages historical data then this is appropriate. In some cases, however, warehouse data is required to be updated in real-time or near real-time time. Thus, the second way of updating the data has emerged, namely updating it when it changes into the database of the source. This method, while it is necessary in some cases, is very demanding in terms of computing resources and often very laborious in its implementation.

One of the main advantages of implementing data warehousing is that data rather than being scattered across various systems in the organization, often resulting in the same information being stored more than once in different formats, is centralized at a central point where the search is less time-consuming and repeated registrations are avoided. However, the problem arises of the data form in the central basis. In fact, each system typically has its own model of describing and storing the information. On the central basis, it is obvious that a common information model should be applied to transform all the data coming from the heterogeneous systems.

Implementation of a Data Warehouse for the HEDNO systems

The primary objective of the integration of the HEDNO systems, as already mentioned, is the implementation of various DMS functions. The large number and range of these functions and therefore their definition and the requirements of the organization are decisive for the integration strategy. A basic separation between the functions is to determine whether they are performed in real time, near real time or historical data. For example, load flow can use any data category according to its purposes, while OMS only needs historical data. The proposed implementation using a data warehouse can support all data categories but is, as a rule, intended for historical data.

Figure 7 shows the basic idea of the proposed implementation:

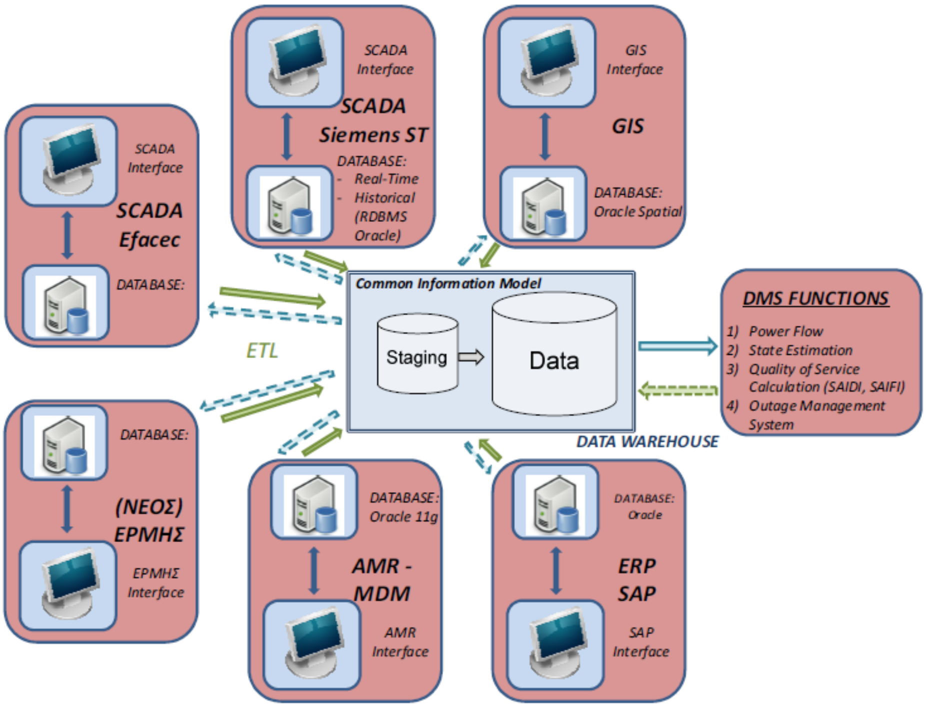


Figure 7 – Interconnection of various systems in HEDNO with Data warehouse [15]

According to this implementation, the organization has a central database whose data has a commonly identifiable information model. Each of the organization's systems, the data of which are useful for some DMS function, are associated with this database. For each system, the information to be extracted is predetermined. The ETL function is responsible for extracting the necessary data from each system, transforming them into the common information model and storing them into the data warehouse. Updating the central database is done periodically with batch operations (for a time that is deemed necessary and determined by the DMS function that is most frequently performed, e.g. once a day, week, etc.). The ETL function has a direction from the system to the central database and is part of a wider operation responsible for the proper storage and updating of data in the database, called Data Integration Service. From the central database, the various DMS functions derive the necessary information for their execution. The data transfer direction in this case is one-way, i.e. from the data warehouse to the system that performs the DMS functions.

In the previous Figure 7, the flow of information also shows an opposite direction (dashed line) than that described. The reason this line is interrupted is because its implementation is not absolutely necessary for the performance of DMS operations, and is often not feasible. First of all, reverse flow from the data warehouse to the systems may mean two things: either that the database of each system is updated or utilizes the warehouse data (for example, GIS is updated for the state of the switches and forms the colour of the lines) which is often unfeasible because the databases are locked, or that there is the possibility to query the data warehouse through the terminals of the peripherals systems, which is clearly easier to implement. Finally, the flow of information from the DMS to the data warehouse is possible using the ETL function and could also be useful depending on how the role of DMS functions is defined and who needs access to them.

Certainly, data warehouse will not be exclusively used for DMS functions, but may be the place where the information, at least the technique, is concentrated and easily accessible. For example, suppose there is a process where at the end of the month makes a report based on the necessary maintenance work. To make this happen, it implements a query at the database where it searches for the cell in which the date of the next (scheduled maintenance) is recorded. The resulting report is sent to the responsible department and begins the replacement process. The Asset Management System (ZEUS) monitors this process and, when completed, the database is updated with the (required) technical data of the transformer, new codes and new maintenance dates.

2.3.2 Application Integration

Integration at the level of operations involves the interconnection of the individual heterogeneous systems of the company, where each of them implements defined tasks, through their collaboration (either through messaging or data exchange), to implement the defined business processes. An implementation in this direction that has begun to spread widely in recent years is the Enterprise Service Bus (ESB).

ESB is a middleware architectural structure, i.e. software that provides broker services between different operating systems. Its main role is to provide integration and interoperability between applications implemented in heterogeneous systems, software platforms and communication protocols. In this way, the system of systems provides the opportunity for unified and coherent access to available information throughout the organization.

Generally, an ESB system has the following capabilities:

- Transport and transformation of available information across the whole enterprise.
- Intelligent routing of data according to the needs of each application.
- Monitoring and logging of events and messages between different services and applications.
- Record keeping of all service registry and managing the execution sequence based on defined business processes.
- Security in the communication transfer and management of messages and data.

The ESB channel favours each system's independency from the implementation and architecture of each other individual system. This is practically the case because the information transfer and the exchange of messages is done by using a commonly defined information model. At the entrance of each system, there is the appropriate interface that makes the conversion understandable by the local system. Because of this feature, ESB enables to replace each system with a new one without requiring all subsystems to be redesigned.

ESB is service-oriented and implements the principles of Service Oriented Architecture (SOA). This architecture uses services with strictly defined interfaces that eventually leverages the various processes of the enterprise by utilizing its resources (the integrated systems). These services depend to a very small extent on the form or status of other services (loosely coupled).

Using SOA and utilizing ESB as the backbone that unifies systems, various business functions (such as DMS) and business processes of a company can be implemented using the appropriate Interfaces. So, instead of communicating directly between interested subsystems, applications publish / subscribe their various messages through ESB. ESB undertakes rooting and mapping between concepts from individual systems (different protocols). The sender does not need to know the exact location of the receiver nor the structure of the information it uses, and data from a sender can also be received by several receivers. In this way, sending data and messaging becomes effective.

It is worth noting that the transferred data is divided into two main categories. The first concerns data and messages related to real-time events, alarms and other types of alerts requiring immediate response (such as SCADA data, OMS, etc.) and the second to data related to organizational resource management and general operational and management issues. Also, as shown in Figure 8, each system has its own interface with ESB (referred to as ESB adapter).

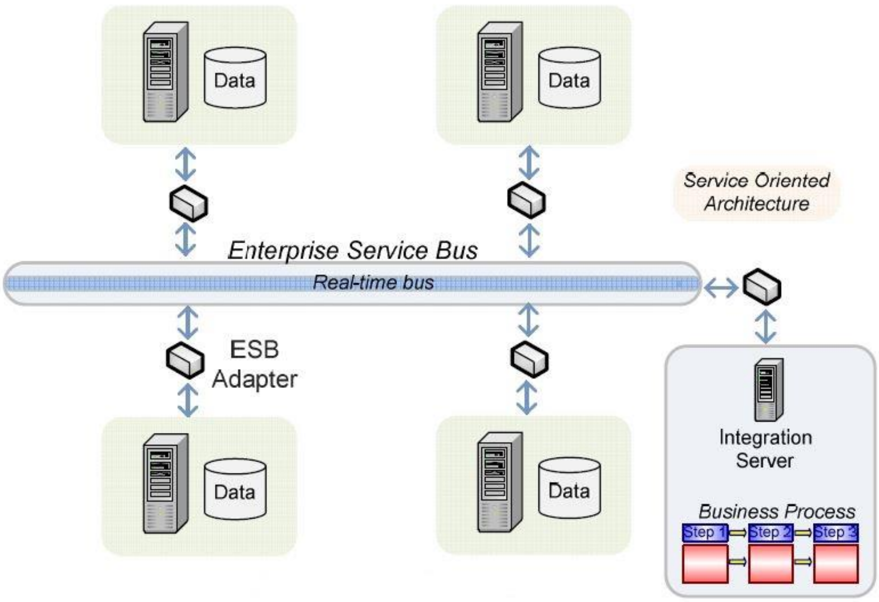


Figure 8 – Basic structure of ESB [15]

ESB is generally event-driven so it can handle real time or near real time events. However, it has limited capacity to transport and manage large quantity of bulk data (something that can do a data warehouse).

Implementation of ESB for the HEDNO systems

Implementation of the integration of the HEDNO systems using an Enterprise Service Bus is shown in Figure 9.

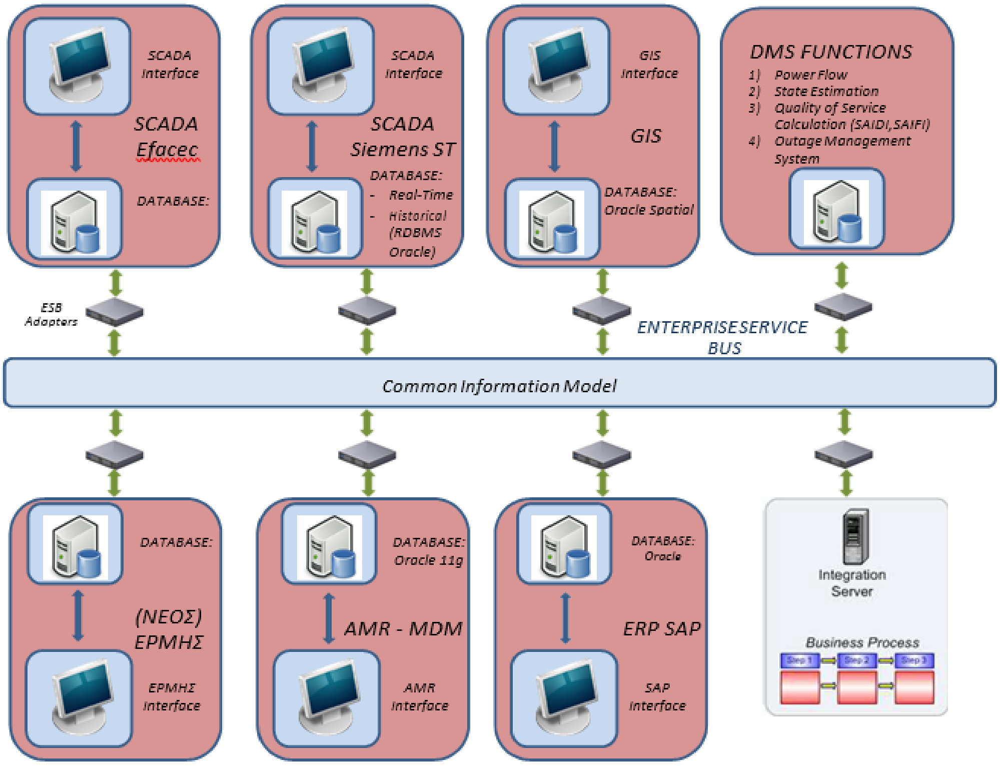


Figure 9 – Enterprise Service Bus – Common Information Model [15]

In this kind of implementation among individual systems and the system that performs DMS functions, each of them is treated as a distributed resource that provides specific services to implement a business process for the organization. Each of these systems may be a service client or a service provider. In order to control requests, routing messages and data, and coordinate the sequence of processes, the ESB is implemented by the integration server. Thus, for example, when a subsystem needs specific data for the implementation of a function, it appears as a service client and is addressed to ESB, which has a service repository with all the services available to the subsystems. ESB then requires the service to be performed by the appropriate service provider and returns the results, which it transfers to the service client. A similar process is also carried out for the exchange of messages.

The implementation of such a process in the case of the HEDNO systems is not entirely straightforward since the different systems do not have the appropriate interfaces for the implementation of these processes; on the other hand direct access to the functions of the various systems (for the design of the various services) is not always feasible due to ownership. In addition, in most cases direct access and processing of the database by external users is not allowed.

One way to implement the ESB in the current situation of HEDNO is as follows: For each system (which does not allow access to database) an external database is created that has the records that can be requested by a service. These data are transformed into the common information model used by ESB. The transformation will be carried out by the system that will handle the data of the external database and will have the mapping that will make the matching between the proprietary information model and the common standard model. In addition, the various services that will implement various processes on the database will be designed in this system. The interfaces of these services must be strict and clearly defined and independent from how the service itself is implemented. In this way, interoperability is achieved because the system that will request the execution of the service client will not need to know how it is implemented (by the service provider) to call it. In addition, even in the case of a system replacement, the Interfaces remain the same, and only the way of implementing the services and mapping between the information models changes.

3 DISTRIBUTED STORAGE IN THE SMART GRID

As already discussed in Section 2.1, smarter, decentralized and yet more connected electricity system could open new opportunities for services and businesses. Integrating and combining energy storage with RES generation could positively affect the management of the distribution grid, delivering benefits to grid stability and to DSO operations in two fundamental ways:

- **Energy Management,** decoupling RES generation from its instantaneous consumption (i.e. decoupling power supply and demand);
- **System Services**, supporting quality of services (e.g. power quality) and reliability of power supply.

A classic example of Energy management is **Load buffering**. It occurs when decentralised storage is installed as a facility to a RES generator connected to the MV/LV grid, making RES generator a more "manageable" energy source.

System services based on decentralised storage could include:

Anti-islanding Operation: Anti-islanding is in fact a protection operation. Since distribution networks generally have a weak mesh structure, when distribution assets fail, some areas of unbalance may occur, with quality or even safety problems in terms of voltage or frequency. Decentralised storage devices may be used to help in coping with this need when necessary.

Security Congestion Management: There are some situations in which commercial arrangements are not compatible with the security standards of distribution networks. In these situations, decentralised storage (and DER in general) can contribute for providing congestion management services.

Power Quality Management: Power or voltage quality is defined by the voltage level, frequency, wave form and balance among the three phases. Decentralised storage plus DER are expected to provide new system services that help DSOs to improve voltage quality. **Voltage control can be achieved** using *active power*, in this case storage will simply feed in additional power when voltage is too low and do the opposite (store energy) when voltage is too high. The power, the reaction time and the maximum periods of time for this type of control need to be carefully adapted to the specific situation. DC/AC converter in storage devices can also control their *reactive power* input. In case of voltage increase due to high reactive power load, this ability can be used to compensate and control the voltage. This kind of voltage control is only suitable for slow voltage control.

Reliability: The most typical example is the use of load shedding in case of an alert or emergency state of the system. In such cases, decentralised storage devices could help to avoid supply interruptions.

It is worth noting that all this kind services may be supported by RESCOs, combining RES generation and energy storage, as we will discuss in section 5.

3.1 STORAGE TECHNOLOGIES AND THEIR CHARACTERISTICS

There are several energy storage technologies that can be generally deployed and each of them has different characteristics such as capacity, energy, efficiency, lifetime and also cost.

Figure 10 gives an overview of the different storage technologies which can be separated in chemical, electrical, electrochemical mechanical and thermal systems.

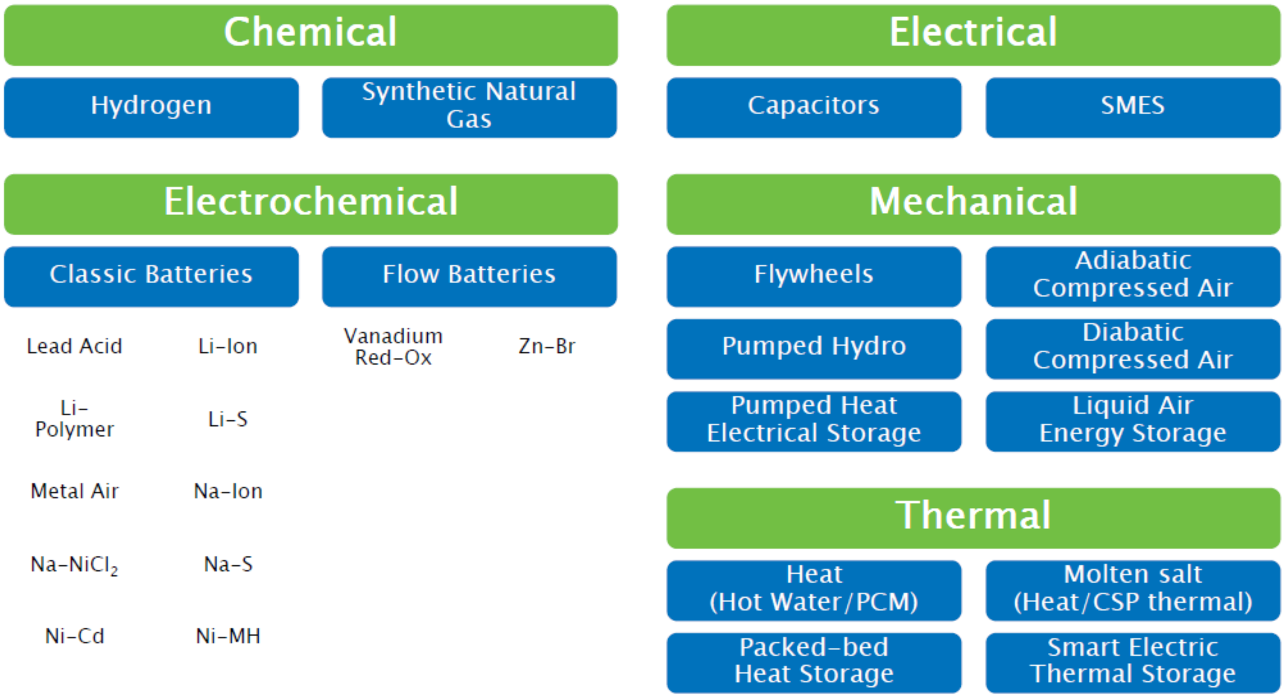


Figure 10 – Types of storage technologies [17]

Figure 11 illustrates the development of the global installations of energy storage systems according to the DOE Global Energy Storage Database [18]. It can be seen that in 2016 more than 160 GW of energy storage were installed. With 162.2 GW of rated power and more than 95% share Pumped Hydro Storage (PHS) - which has been deployed for several decades all over the world now - is the most-widely used technology. Although it is quite an old technology, the installed power of PHS is still growing by several GW each year.

Not only the maturity of this technology but also the simplicity and the fact that the installed power of each PHS station is often already in the GW range lead to these yearly increases. According to [19], 65 PHS stations with a rated power of >= 1 GW are operating today. The largest one by installed power is the Bath County Pumped Storage Station in the United States with a rated power of 3 GW. Besides, numerous stations exist with a rated power below 1 GW.

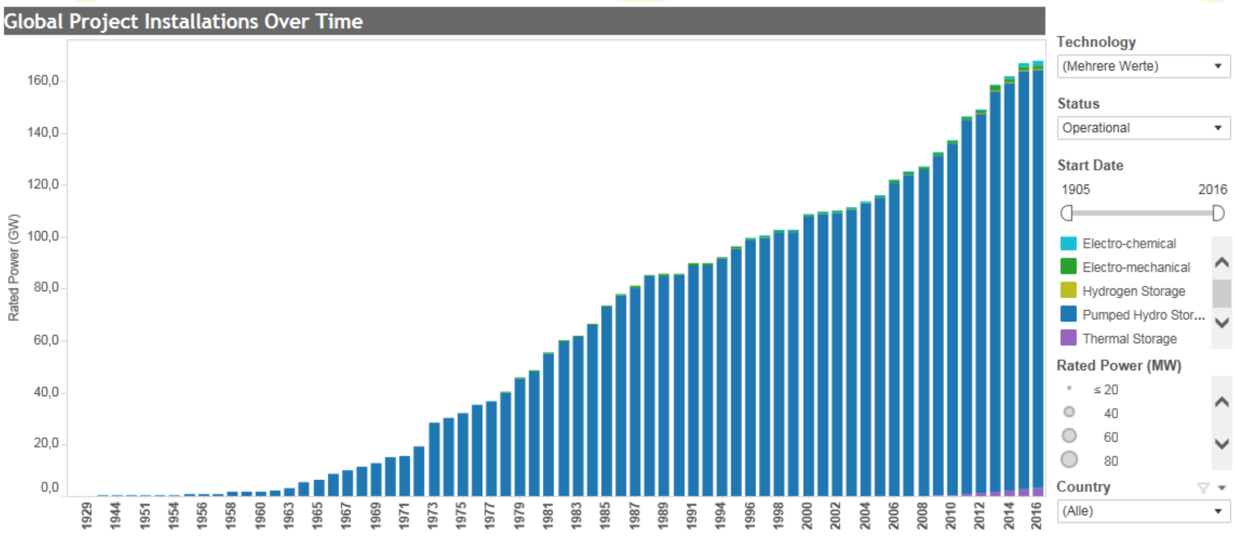


Figure 11 – Worldwide installed power of energy storage [18]

However, other storage technologies such as thermal and electrochemical storage are developing fast. In the last ten years, thermal storage has risen from 0.1 GW in 2007 to 3.2 GW in 2016. Electrochemical storage similarly increased from 0.1 GW to 1.6 GW, with years from 2013 onwards contributing the most [18].

The storage capacity and the duration of discharge for several technologies are illustrated in Figure 12.

PHS stations are usually designed for a discharge period of some hours. Since several infrastructural requirements (e.g. water reservoirs with height difference) need to be met, the locations for PHS installations are limited. Besides, since construction costs are relevant larger, units are normally built in order to reach positive economies of scales. PHS stations are usually used to cover peak demand (high energy prices) and are recharged in times of low demand (low energy prices) by pumping water to the upper reservoir. In the past, the energy for the pumping process came from traditional power plants such as coal, lignite or nuclear which could keep their power output stable and thus operate with a better efficiency. In recent years, however, this situation has changed, since renewable energies also cover peak demand. Since the profit relies on the delta (difference) between the high and the low energy prices, PHS is getting less attractive for operators.

Theoretically PHS can also be deployed on a small scale, e.g. on residential or district level. A technical solution for the integration of a PHS into a building could comprise a water tank on the top of a building. However, a study conducted by the Aero-Thermo-Mechanics Dept. (ATM), École Polytechnique and the Université Libre de Bruxelles (ULB) in Belgium has found that *"the economies of scale that render large PHS installations competitive are not present in small installations"* [20]. As a conclusion, the pumped-storage hydroelectricity does not seem to be an interesting option for use in buildings. The main disadvantage is the large volume of water necessary requiring infrastructure which is difficult to install in an urban area. The authors however point out that synergies with existing reservoirs could lower the costs significantly.

In contrast to PHS, thermal and electrochemical storage solutions are already commercially operated in a decentralized manner. In residential applications the capacity is usually of around a few kWh and the duration of discharge is ranging from hours to days. In Germany, for instance, the average size of solar battery storage systems is 6 kWh [21] and the average power capability of battery storage systems between 4 and 8 kWh is roughly 3 kW [22]. As the name indicates such systems store surplus of energy coming from the PV during daylight in order to cover the demand during the night.

Regarding thermal energy storage systems on domestic level, sensible heat storage systems are comparably inexpensive in comparison to competing with thermo-chemical-storage (TCS) or systems based on phase changing materials (PCM). The reason that sensible heat storage systems are comparably cheap is due to the fact that cheap solid or liquid media such as water can be used to store the energy. Another example are night storage heating devices which were primarily used in the 1970s when electricity was cheap in comparison to oil and gas. Due to a high penetration of renewables and enhanced control options this technology is discussed again nowadays and support peak shaving activities.

On a community/district level thermal and electrochemical energy storage systems can be placed as well. Depending on the number of households in a specific area, the capacity of such systems is usually around some kWh but both technologies can also be deployed on a larger MW scale. A prominent example is the Tesla 100 MW/129 MWh Powerpack System to be installed in Australia by the end of 2017 [23].

These facts and numbers illustrate that batteries are probably one of the most flexible storage technologies since they can be deployed in different locations, grid levels and sizes.

Electrical and electromechanical storage solutions such as capacitors and as Superconducting Magnetic Energy Storage (SMES) are usually discharged in a short time period from milliseconds to a few minutes. Since these systems are usually used for high-power applications, their storage capacity is relatively low and reaches a maximum of a few kWh.

Flywheel Energy Storage Systems are closing the gap between electrical, electromagnetic and electrochemical systems, since they feature discharge periods that range from seconds to several minutes and a storage capacity of a few MWh.

In addition to PHS, Compressed Air Energy Systems (CAES) can be used for daily based energy storage. Long-term or seasonal energy storage for a period of weeks or even months is covered by chemical Power-to-Gas systems. Here the power – usually coming from renewables – is used in order to produce methane, hydrogen or other synthetic natural gases. For the long-term-storage those gases are stored in large storage reservoirs such as caverns or aquifers with a storage capacity of several TWh.

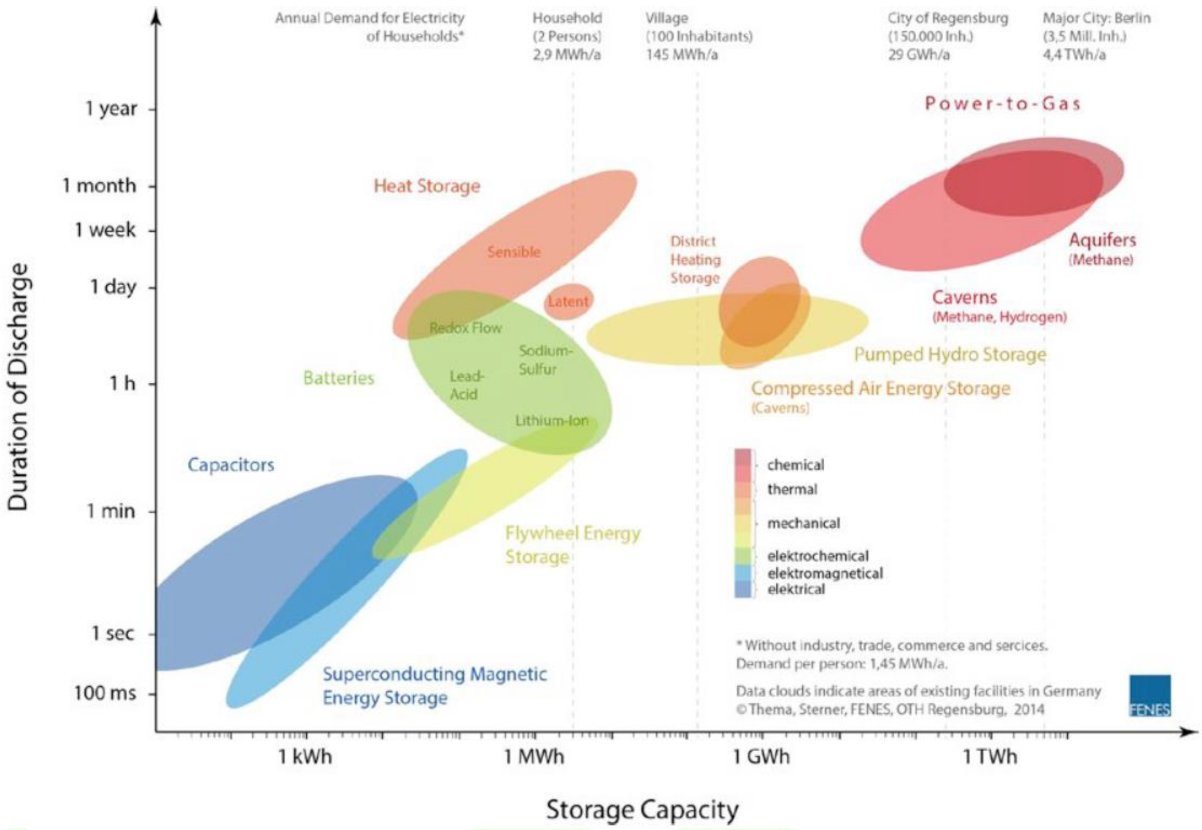


Figure 12 – Typical storage capacity and discharge duration for different storage technologies [24]

The storage capacity, the power capability or the duration of discharge are not the only important system characteristics. Also the efficiency, the lifetime cycle and the self-discharge, as well as the investment costs, are important characteristics that influence the cost per delivered kWh.

With a round-trip efficiency of up to 98% on cell level and 85-90% on system level (including power electronics), lithium-ion batteries are featuring one of the best efficiencies. In comparison PHS reach an average efficiency of 75-80%, in specific cases up to 85%. Other storage technologies such as CAES usually feature lower efficiencies. With less than 50% and in some cases even below 30% long term storage Power-to-Gas performs the worst in this category [25][26][22].

Larger storage facilities tend to have a longer lifetime. With a lifetime of up to 60 years PHS is second in this category. But also CAES and Power-to-Gas facilities can be operated from 30 for up to 40 years respectively. **The designed lifetime of a current battery storage system is 20 years**. Although some battery cell chemistries feature more than 10,000 cycles which would be enough for 40 years of operation (assuming 250 cycles per year as PV storage) the calendric lifetime needs to be considered as well. Electrical and electromagentical storage system such as Supercapacitors or SMES feature a lifetime of up to 100.000 cycles. Depending on the daily load - which can be several cycles by day - the lifetime can be derived [25][26][22].

PHS and CAES practically do not have any self-discharge, meaning that all the energy that is stored can be used at a later point in time. Short-term storage systems such as the Supercapacitors, the SMES and the Flywheels feature comparably high self-discharge rates. It hence makes sense to constantly operate these systems since the self-discharge within one cycle can be neglected. Modern electrochemical storage systems based on lithium ion or lead-acid feature almost no self-discharge.

Concerning costs, it can be said that today Energy Storage is still expensive. However, the costs for such systems have been decreasing dramatically in recent years and will continue to fall. Due to economies of scale larger storage units (PHS, CEAS, Power-to-Gas) often feature lower cost per kWh. However, because small-scale storage units are becoming more and more popular, economies of scale are being reaped for them as well. As an example, **between 2013 and 2016 the cost for solar battery storage system in the German market were reduced by 50 % and this trend is expected to continue.** In contrast for mature technologies such as PHS no major cost decrease is expected [21].

When combining the above mentioned features and considering typical load profiles, the levelized cost of storage (LCOS) can be calculated. **In 2015** the deployment of **Lithium Ion batteries resulted in LCOS of 310 – 830 €/MWh**. However, due to technological development and economies of scale it is **expected to drop to 100 – 210 €/MWh by the year 2030**. The LCOS for other battery technologies will be even slightly lower and thus be **competitive to already established energy storage technologies such as PHS** [25][26].

Due to their excellent cycle stability Flywheels are expected to have the lowest LCOS from all the energy storage technologies.

An overview and comparison of the presented storage technologies can be found in Table 1 below.

Storage technology	Type	Power [MW]	Capacity [MWh]	Storage period	Efficiency [%]	Cycles or Lifetime	Self-discharge [%]	Energy density [Wh/l]	Power density [W/l]	Response time	LCOS 2015 [€/MWh]	LCOS 2030 [€/MWh]
Supercapacitors	Electrical	0.01 - 1	< 0.1	sec - h	80 -95	10,000-100,000	20 - 40	10 - 20	40,000 – 120,000	msec	180 - 340	80 – 190
Superconducting Magnetic Energy Storage (SMES)	Electrical	0.1 - 1	< 0.1	sec - h	80 - 95	100,000	10 - 15	~ 6	~2,600	msec	n.a	n.a
Lithium Ion Battery	Electrochemical	0.002 - 100	0.002 - 130	min - day	85 - 95	1,300 – 10,000 20 years	0.1 – 0.3	200 -750	1,300 – 10,000	msec	310 - 820	100 - 210
Sodium Sulfur (NAS) Battery	Electrochemical	1 - 60	7 - 450	min - day	70 – 90	1,620 – 4,500	0.05 - 20	150 - 300	120 - 160	msec	240 - 320	60 - 80
Lead Acid Battery	Electrochemical	0.002 -30	0.002 - 30	min - day	65 - 90	160 – 1,060 6 – 40 years	0.1 – 0.3	50 - 80	90 - 700	msec	290 - 560	60 - 90
Redox/ Flow Battery	Electrochemical	< 7	< 10	min - day	60 - 85	1,510 – 14,000	0.2	20 -70	0.5 - 2	msec	280 - 770	100 - 320
Flywheels	Mechanical	0.001 -20	< 10	sec - h	70 - 95	20,000 - 100,000	1.3 - 100	20 - 80	5,000	msec	60 -90	30 - 35
Compressed Air Energy Storage (CAES)	Mechanical	2 - 300	14 - 2050	day	40 - 75	8,620 – 17,100 20 – 40 years	0	2 - 6	0.2 – 0.6	min	n.a	n.a
Pumped Hydro Storage (PHS)	Mechanical	100 – 3,000	< 19.000	day - month	63 - 85	12,800 – 33,000 30 – 60 years	0	0.2 – 2	0.1 – 0.2	sec - min	70 - 120	70 - 120
Hydrogen	Chemical	0.01 -100	varies	Week - month	25 - 45	5 – 30 years	0 - 4	2,7 at 1 bar	0.2 - 20	sec - min	310 - 420	130 – 230
Methane	Chemical	1 - 100	varies	Week - month	24 - 42	30 years	n.a	10 at 1 bar	n.a	sec - min	n.a	n.a
Synthetic Natural Gas	Chemical	1 – 100	varies	Week - month	25 - 50	30 years	Negligible	1,800 at 200 bar	0.2 - 2	sec - min	470 - 700	200 - 330
Sensible Storage - Water	Thermal	< 10	< 100	min - day	50 -90	5,000	n.a	< 60	n.a	sec - min	n.a	n.a
Phase Change Materials (PCM)	Thermal	< 10	< 10	min - day	75 – 90	5,000	n.a	< 120	n.a	sec - min	n.a	n.a
Thermochemical Storage (TCS)	Thermal	< 1	< 10	min - day	80 - 100	3,500	n.a	120 -250	n.a	sec - min	70 - 220	30 - 50

Table 1 – Characteristics of different energy storage technologies based on [25] [26] and own analysis

An important feature of most energy storage technologies is the ability to provide active and reactive power. By doing so not only the frequency of the grid can be stabilized but also the voltage quality can be supported. In different areas of the grid, voltage problems and overloads occur due to high amount of renewables installed. In these areas distributed energy storage systems can directly support the grid. Table 2 illustrates the grid management services that can be provided by energy storage systems and also states the requirements and the most promising technologies.

Service	Description	Discharge time	Best suitable storage technology
Intelligent self-consumption	Storage of self-generated energy during the day. Charging of the storage systems should be around peak production hours in order to relief the grid	Several hours	Decentralized batteries on domestic and residential level (Lead-Acid, Lithium-Ion)
Frequency support	Energy storage system provides power according to frequency deviations occurring in the grid. Usually some minimal system size for participation is required why small-scale systems need to be aggregated	Minutes to hours	Fast response + primary: batteries, flywheels, SMES, Supercaps (large-scale or aggregated), Secondary + Tertiary: PHS, batteries
Voltage support	Energy Storage system absorb active power in order to decrease the line current leading to lower voltage rises. Besides reactive power can influence the voltage profile positively.	Minutes to hours	Batteries, flywheels, SMES, Supercaps
Black start	In case of a blackout the power plants need restart power	Hours to dozens of hours	Batteries
Peak-shaving	Production or load peaks are chopped in order to relief the grid and prevent congestion. Depending on the grid level the named technologies can be used.	Minutes to hours	Thermal storage, PHS, batteries

Table 2 – Grid management services provided by energy storage systems

When it comes to grid management, the response time is important as well, especially when fluctuations need to be compensated fast. Electrical and **electromechanical storage systems as well as flywheels can react within ms. and thus almost immediately support the grid**. Large-scale mechanical and chemical systems however need several seconds or even minutes to start the operation process.

A more detailed description of these services and about characteristics of different energy storage systems can be found in the WiseGRID deliverable D6.1 [27].

3.2 POSITIONS FOR STORAGE DEVICES IN THE DISTRIBUTION GRID

An Energy Storage System (ESS) can be installed at three levels: Transmission level, Distribution Level and behind the meter. Due to the scope of the WiseGRID project, only the two last levels will be addressed. The services which can be provided by an ESS depends on the location where the ESS is installed, as can be seen in Figure 13

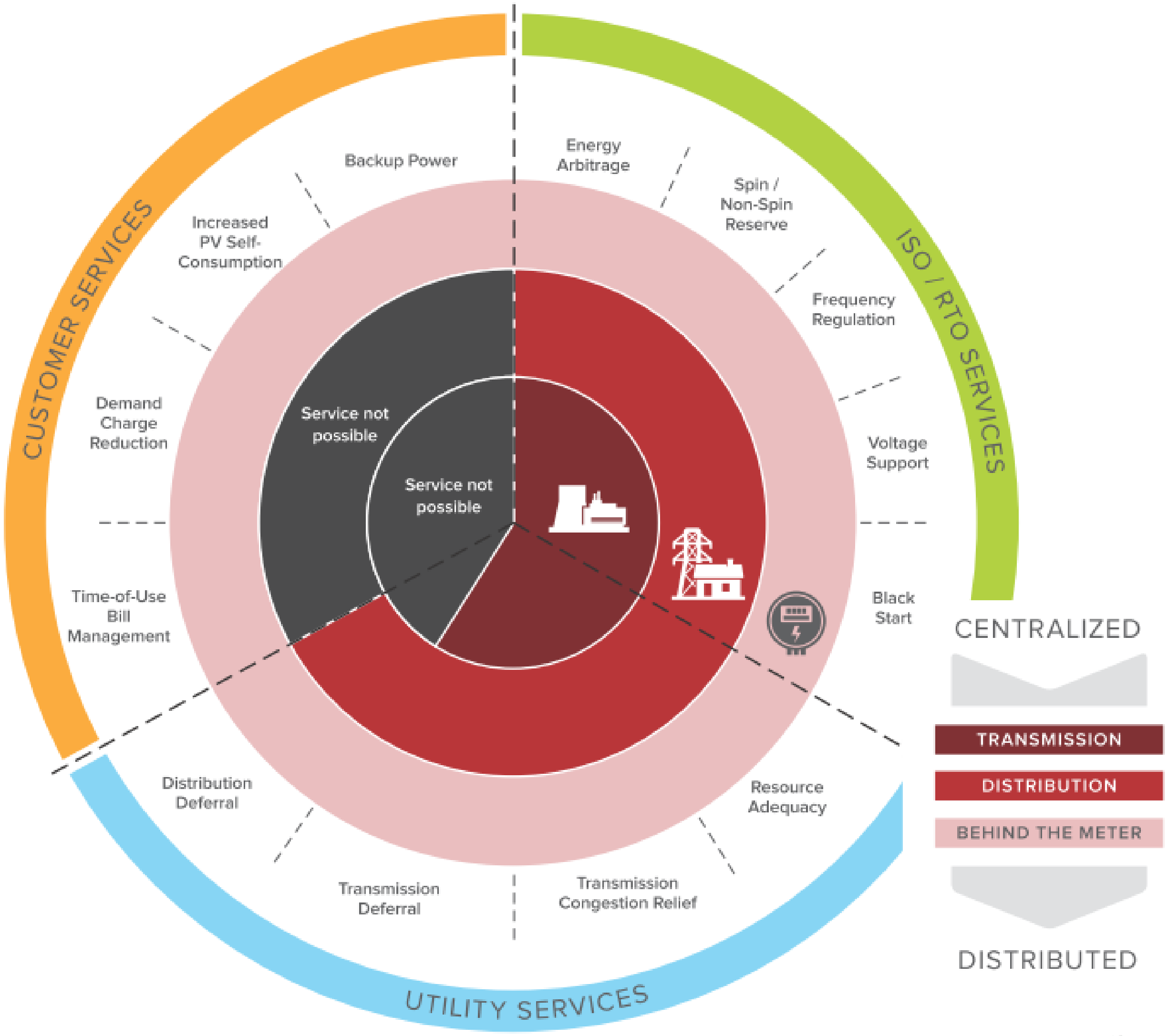


Figure 13 – Services that can be provided by ESS as a function of storage location [28].

As a definition, distribution level encompasses every location with voltage level over 4 kV to 69 kV. These locations include medium voltage distribution lines, distribution substations, and commercial or industrial customers. These customers must be connected to the distribution level grid by means of customer substations.

On the other hand, behind the meter locations refers to energy storage system installed on the customer's premises and on the customer's side of the utility meter. In this level, Electric Vehicles be included with smart point of charge, where intelligent charging can be shifted based on grid loads in accordance to the vehicle owner's needs and energy tariffs. In this point, an EV can be interpreted as a controlled electric load or a battery, in function of its state and need.

In order to get a better comprehension about the possible locations, the following scenarios will be commented:

A) Connection at the HV/MV substation

B) MV/MV Substation

C) Connection to a RES feeder in the MV grid

D) Connection at any point of the MV grid

E) Consumer/prosumer at MV

F) Connection at the MV/LV substation

G) Behind the meter

H) Connection at any point of the LV grid

3.2.1 Connection at the HV/MV substation

At HV/MV stations there is often room to install additional assets. If a DSO owns the station and site, it can install storage with little expenditure. This location is both near the HV grid (operated by a TSO) and the distributed generation in the MV grid, being hence a promising location.

In this location packs of batteries will be necessary to be used, which make up systems with several MWh of capacity, in order to be able to offer the services expected from them. Mainly, in these locations, ESSs offer ancillary services, beyond the simple energy storage. Its main use, however, can be divided in two categories: emergency services and contributions to the grid.

The emergency use, similar to household backup, allows some energy independence in case of breakdowns or unforeseen situations, acting both the interruption of supply, due to failure in the network, and operating in black start mode to reactivate large generation plants.

The battery packs can be used as spinning reserves in most cases. Spinning reserves are any energy resource which can provide power in less than ten minutes

On the other hand, the contributions to the network focus on the control of grid parameters, such as frequency or voltage control. In this case, the storage systems would inject energy to the network or store it according to the state in which the characteristics of the network would be found. In the same way, these units can be employed to slightly modulate the load curve of grid, avoiding the decompensation present in the current model of the distribution grid. This operation point is a kind of distribution, or transmission, deferral.

3.2.2 MV/MV Substation

Same contribution as at HV/MV Substation: to improve grid supply quality. Packs of energy storage systems can absorb grid fluctuations, making it more stable.

3.2.3 Connection to a RES feeder in the MV grid

Large RES - typically at least a few wind turbines or larger photovoltaic farms, are connected to the MV grid via dedicated cables. This location is a suitable place to install a pack of ESSs, since it allows the RES power plant to become more flexible and follow in a better way the demand curve. This objective is achieved by storing the energy surplus in low load hours and injecting energy to the grid when the current production is not enough to cover the existing demand.

3.2.4 Connection at any point of the MV grid

In the MV section decentralised storage devices can be installed via a new connection, using the existing connection of an end user or of a RES. No matter what the connection, storage devices can be used to improve voltage and power in the nearby area and in the downstream low voltage grid.

3.2.5 Consumer/prosumer at MV

Some large factories are connected directly at the MV distribution grid, due to the requirements of their processes. Large demand users, acting as either big consumers or big prosumers, are perfect situations to install energy storage systems, whose capacity depends on the load profile and power consumption.

These are especial prosumers, because they are able to produce vast quantities of energy and it can be a problem if the entire surplus is injected to the grid. In this way, a batteries pack can reduce this energy amount, avoiding having any grid infrastructure investment.

3.2.6 Connection at the MV/LV substation

At this level, a pack of energy storage system can operate in several modes. The most interesting of them are the option to work doing "energy arbitrage", decreasing consumption in the most expensive hours.

3.2.7 Behind the meter

The end users (i.e. prosumers) are one of the most interesting places to install an ESS. A prosumer can use many of the available services of a storage system. A typical way to use an ESS at this level, being the best example of "behind the meter" consumption, is for increasing self-consumption, working together with a PV installation, or to reduce their electricity bill by means of "Time-of-Use bill management" service. Among this kind of users, the consumers/prosumers can be aggregated into VPP or some kind of communities.

At this level, an energy storage system can provide many different uses. Therefore this option becomes the most interesting one, because it opens the market to several options.

3.2.8 Connection at any point of the LV grid

Location characteristics for decentralised storage systems connected to the LV grid are similar to those indicated for the MV grid.

3.3 BENEFITS OF DISTRIBUTED STORAGE FOR THE DISTRIBUTION GRID

3.3.1 System Services

3.3.1.1 Reactive power supply

The quality of the grid and the quality of the power distributed is an important challenge for Smart Grids. In Europe, energy is transported and distributed alternating current (AC), pulsing at a frequency of 50Hz. The other main parameter of the electric flux is the voltage (V), which, as the current (I), has a sinusoidal waveform. The product of current and voltage is giving the apparent power (S). This power has two components: active (P) and reactive power (Q).
When voltage and current pulse in phase (i.e. with peaks and valleys occurring simultaneously), as depicted in Figure 14, pure active power is obtained, which is always of positive sign. However, when the current flows through inductive (e.g. coils) or capacitive loads (e.g. capacitors) voltage will not be in phase with current any longer. Current and voltage will not be pulsing simultaneously and this situation causes the circulation of reactive power. When the shift is a quarter of period (90°), pure reactive power is obtained. All the other cases are a combination of active and reactive power. The degree of shift is usually measured by cos(φ) (also called power factor), where φ is the angular difference between the two waveforms of voltage and current.

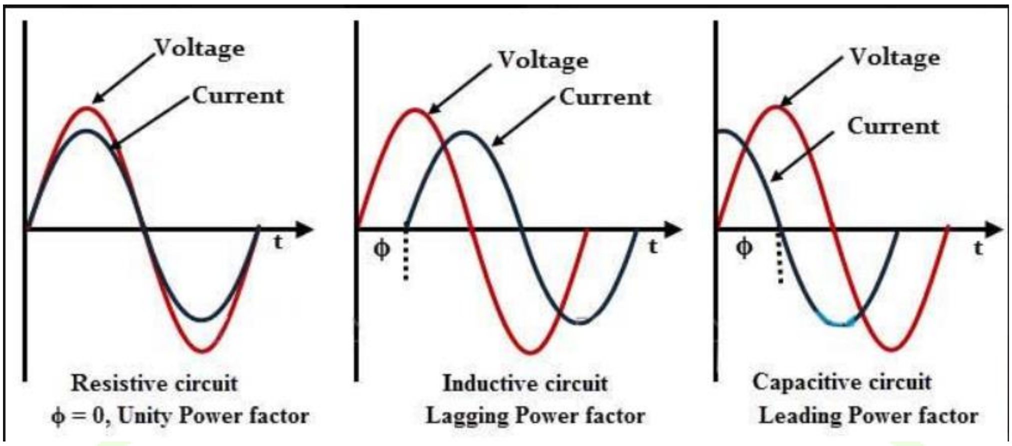


Figure 14 – Resistive, Inductive and Capacitive loads

The power diagram in Figure 15 defines the apparent power, reactive power and active power:

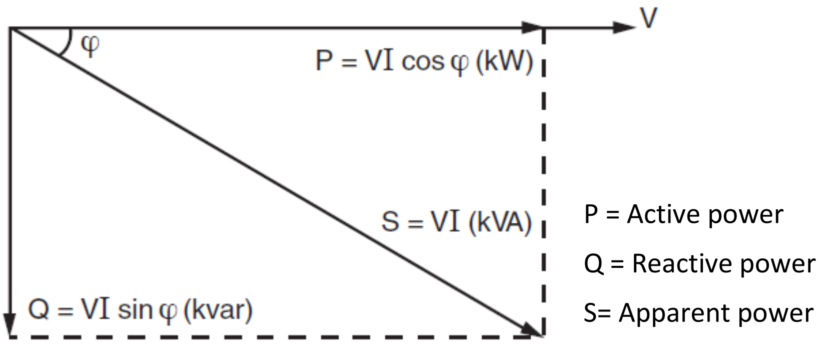


Figure 15 – Power diagram

Active power is the real power, it is power that can be used to perform work. Reactive power, on the other hand, is not able to produce useful work and it is consumed by motors, transformers and all electrical devices or assets that have some kind of coil to create an electromagnetic field. Reactive power just travels back and forth on the power grid, loading it and causing losses. Pure reactive power is oscillating between positive (produced by inductive loads) and negative (produced by capacitive loads) values. These two opposite signs can neutralize each other.

Most of the loads in the distribution grid have an inductive charge, and so require some reactive power. Depending on the kind of charge used, it will need a certain amount of reactive power [29] In order to quantify this amount of reactive power, two values can be used: the power factor (PF) or the tan (φ), defined as follows:

$$\tan(\varphi) = \frac{Q}{P}$$

$$PF = cos\ (\varphi) = \frac{P}{S}$$

The quantity of reactive power needed for an equipment will be measured using these values. Some basic equipment measures are presented, for instance, in Table 3:

Equipment		cos(φ)	tan (φ)
Induction motor	0% charge	0.17	5.80
	25% charge	0.55	1.52
	50% charge	0.73	0.94
	75% charge	0.80	0.75
	100% charge	0.85	0.62
Resistance oven		1	0
Dielectric heating oven		0.85	0.62
Welding machine		0.8 to 0.9	0.75 to 0.48
Arc welding machine		0.5	1.73
Light bulbs		1	0
Discharge lamp		0.4 to 0.6	2.29 to 1.33

Table 3 – Power factor values for basic equipment [29]

These different values show that the grid will have to provide reactive power to feed the final user. But, even if the reactive part does not consume any power, the transport of reactive power through the grid causes some losses in the distribution network. On top of that, this transport of reactive power is also leading to a voltage drop. For all these reasons, the DSO wants to limit the quantity of reactive power circulating on the grid [30]. Indeed, an excessive use of reactive power by final users can be taxed by the retailer.

On top of that, the transport of "lagging" reactive power (due to inductive load) through the lines will lead to a voltage drop and on the other hand to a raise of voltage in case of "leading" reactive power (due to capacity load). Managing reactive power in the grid can maintain the voltage through the transmission line. Moreover, it enables to fit the change in power on particular lines. Figure 16 shows the variation of voltage depending on the power and cos(φ). It can be seen that having leading reactive power enables the line to overcome with more power. The power change in the grid can be overcome by a change in cos(φ).

The generated and consumed reactive power should be balanced and then the voltage level will be within rated range. Any unbalance of reactive power will create voltage drops (if consumption is higher than generation) or voltage peaks (vice versa). Even the grid elements have their own reactive implication (due to reactance of the lines and transformers), the larger implication is from consumers and their *magnetisation needs*. If balance of reactive power is as *local* as possible, then there should be no need to transport reactive power and losses would be lower, while voltage levels would be in the admissible range.

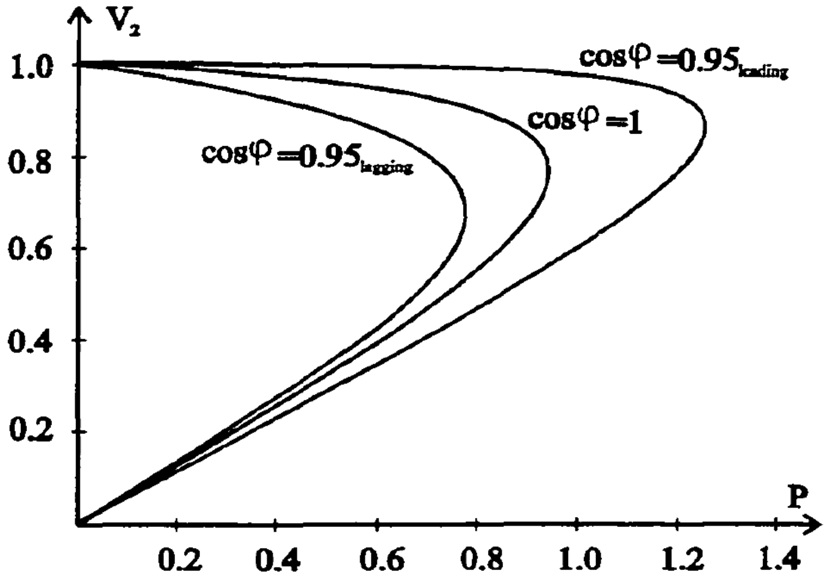


Figure 16 – Voltage on the line depending on power and cos (φ) [31]

A control of voltage on the grid can also be used to increase the number of DER on a particular section without extending the grid in voltage.

In practise, most of charges are inductive charge and, as a matter of fact, need a certain amount of reactive power. Since they are inductive loads, capacitive loads would be able to compensate the reactive power needed. Indeed, the reactive power supplied by the capacitive load will be compensated by the reactive power of the inductive load. In a way, the system is acting as if the inductive load has consumed the reactive power supplied by the capacitive load (see Figure 17)

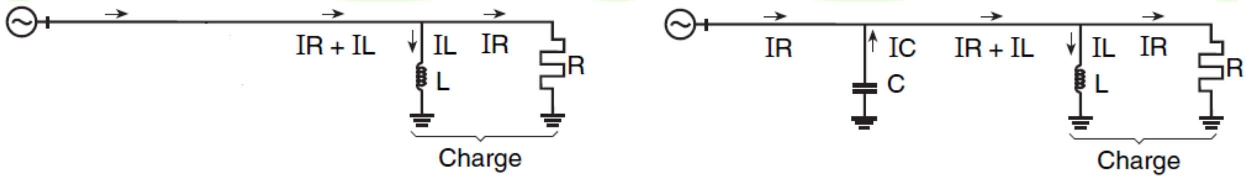


Figure 17 – Reactive power feeding on a basic charge [29]

In the example shown in Figure 17, the reactive power is fully compensated but in practice, it is not economic to react a cos(φ) of 1. The consumer would want to reach the specific value to not be taxed while the DSO would want the most economic value. This compensation of the cos(φ) will enable to limit the losses in the transmission lines.

The installation of a fixed capacitors' bank will fix the quantity of reactive power to be injected in the grid. If the variation of power is low, this can fit the requirements, but in many cases, the power variation will impose to adapt the reactive power injected in the grid. In that case, it is possible to put several capacitors in parallel, as shown in Figure 18.

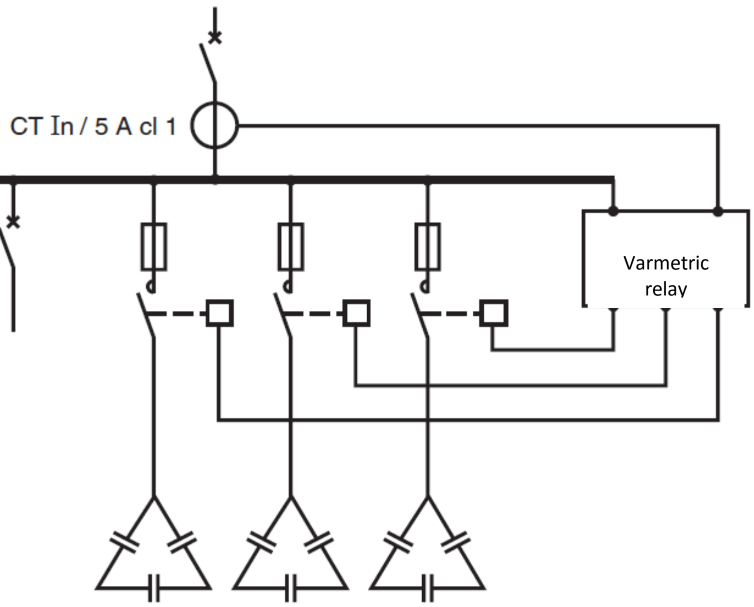


Figure 18 – Reactive power compensation with parallel capacitors [29]

Each step of capacitors is controlled by an electric switch. The varmetric relay is measuring the reactive power in the grid (and so the cos(φ) at the node of the installation) and command the different electric switch to reach a given value of cos(φ). It means that the reactive power given to the grid step by step. The tolerance of the overall system will depend on the size of this step. This enable a control of the reactive power in the grid by fixing the cos(φ) or the power factor wanted. This kind of installation can be integrated on the inverter of battery storage system and enable the storage system to compensate reactive power in the grid.

There are several solutions to produce reactive power. On the same principle showed in Figure 17 and Figure 18, is it possible to use battery of capacitors, as showed in Figure 19.

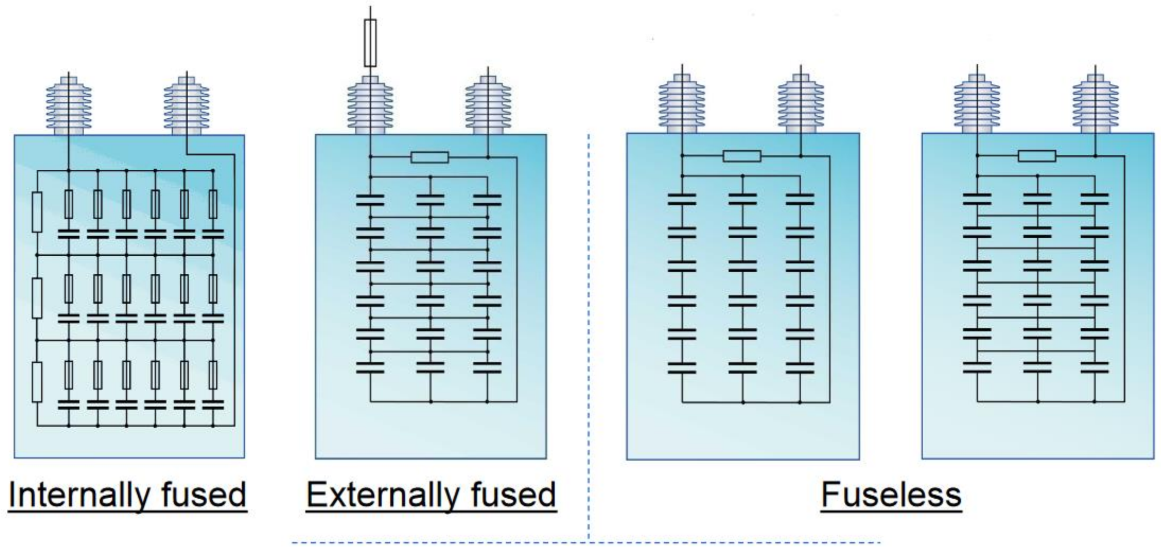


Figure 19: Different kind of battery of capacitors [32].

These devices do not provide any active power but only reactive power. The same kind of behaviour can be observed with some inverters for battery or solar panels. Here battery and solar panels are the same behaviour since it is seen as a DC source. The inverter, when charging and discharging the DC bus, is acting as a capacitive element and is providing reactive power. On this way of work, the inverter is not providing any active power neither but provide reactive power (see Figure 20)

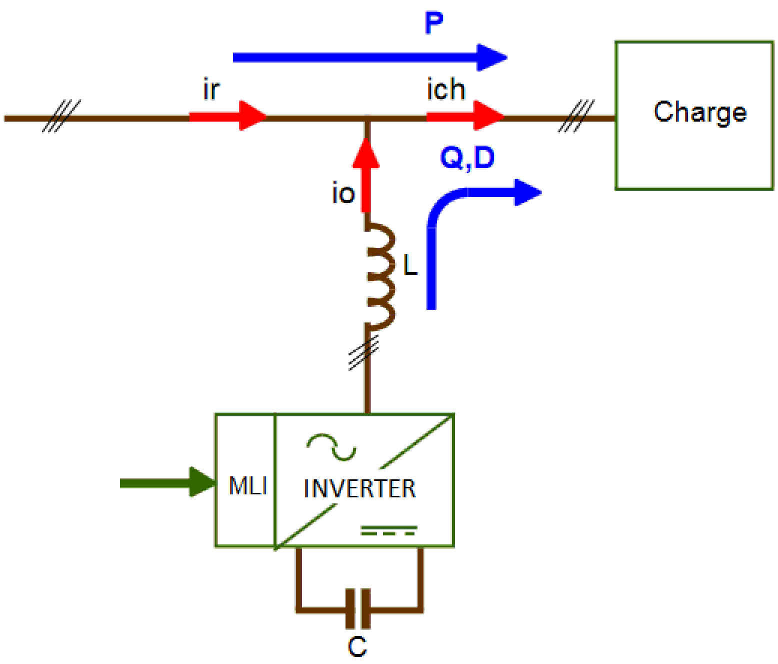


Figure 20: Inverter providing reactive power [30]

These two ways of reactive power compensation are not providing any active power to the grid. Nevertheless, battery storage system or PV solar panels are both energy provider to the grid. These energy resources coupled with an adapted inverter will be able to provide power with a chosen power factor. The selection of the power factor is determining the active power and reactive power. Obviously, this provision of reactive power is leading to a loss in active power as shown in Figure 21

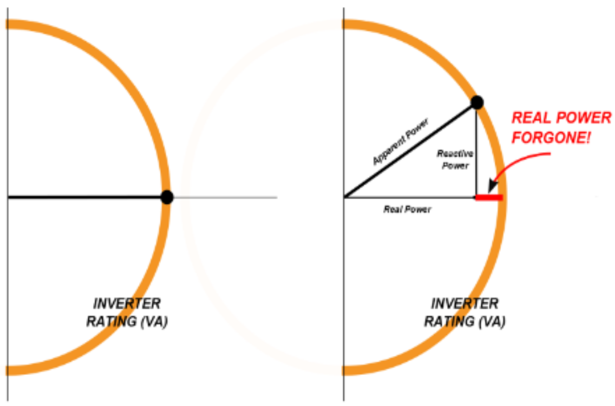


Figure 21: Real power loss from non-unity power factor [33]

3.3.2 Energy Management Services

On a conventional grid, energy production entails the transformation of natural resources into electrical energy. For example, a conventional gas turbine burns gas (or petrol) to produce electricity. The situation is not dissimilar for a nuclear power plant where fissile is transformed into electrical energy.

The natural resources can be seen as stored energy.

With the exception of biomass, hydropower and geothermal, RES energy production relies on energy flows like solar radiation, wind or water currents. Taking into account that the most utilized type of renewable energy are solar and wind, this implies that RES power production will depend on the energy flow and will not always be able to meet the power demand.

Today, conventional power production is modulated (adapted) to meet not just the variable power demand, but better the difference between the instantaneous power demand and the instantaneous RES produced power.

But in the case where there is only RES production, the grid has a real need of flexibility in the demand and the production.

3.3.2.1 PV smoothing

As previously stated, RES power production depends on energy flows. On some periods, production will be higher than demand.

For example, for a PV installation, production happens during day hours and depends directly on the power of solar irradiance received by the system. The power received by the system is shown in Figure 22:

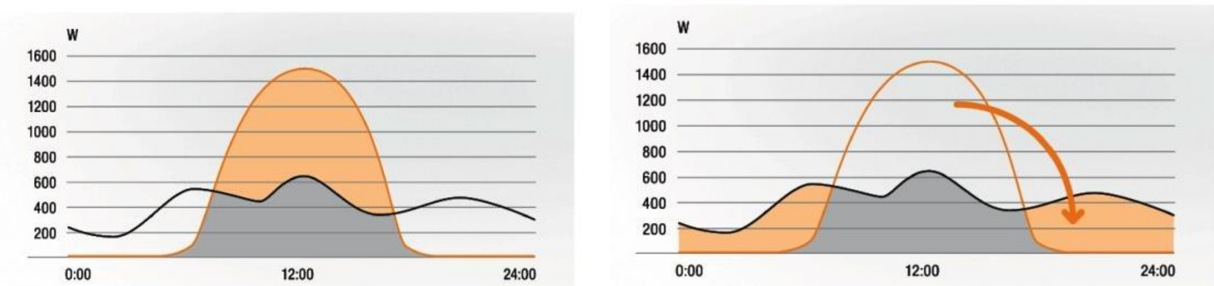


Figure 22 – Example of PV smoothing production [34]

During production surplus, batteries will be charged with the exceess of energy. When the primary energy flow becomes unavailable, batteries will take over and feed the power demand. This example is for solar energy, but an analogy can be shown for every RES, since it is dependent of the energy flow.

The combined system of RES plus storage may be seen as a single power unit by the grid, with more predictible energy production and the ability to provide some flexibility to the grid. In fact, such a system can provide power to the grid during longer periods of time. The whole system is then more reliable from the DSO point of view.The stored energy can be dispatched during peaks of consumption or when the DSO needs more extra power.

From another point of view, this service also avoid a voltage rise on the grid. In fact, when a RES is producing more power than the demand, this results in a voltage rise for the grid or curtailment of the production. Any control of the power produced by RES helps the DSO in controlling the voltage on the grid. In conclusion, the combined system of RES plus storage can offer more flexibility to the grid and reduce the amount of voltage control efforts to be performed on the grid and reduce curtailment.

By using storage services, DSOs could better control voltage profiles and currents in areas with a high number of intermittent sources of electricity. Storage can thus directly benefit grid users (e.g. solar panel owners) who would be able to feed-in more energy to the grid, as a result of an increased DG to accommodate capacity. The value of storage is determined by the avoided investments and maintenance costs incapacity and voltage control.

3.3.2.2 Peak shaving

The load profile of a day usually contains peaks of power demand.

The peak demand at midday can be e.g. shifted to a different time of the day, e.g. early afternoon, when prices are lower. Or the peak demand can be reduced through an alternative energy source e.g. electricity production with a diesel generator.

Peak shaving is a technique that is used to reduce electrical power consumption during periods of maximum demand on the power utility (See Figure 24). Thus saving substantial amounts of money due to peaking charges.

Peak shaving also helps the utility to provide maximum base load power without starting an expensive to operate peaking generator. In the long-term, peak shaving may help the utility to reduce investment in costly new power plants. The customers who install on-site generating equipment share in those savings, by receiving reduced power rates year round. (See Figure 23)

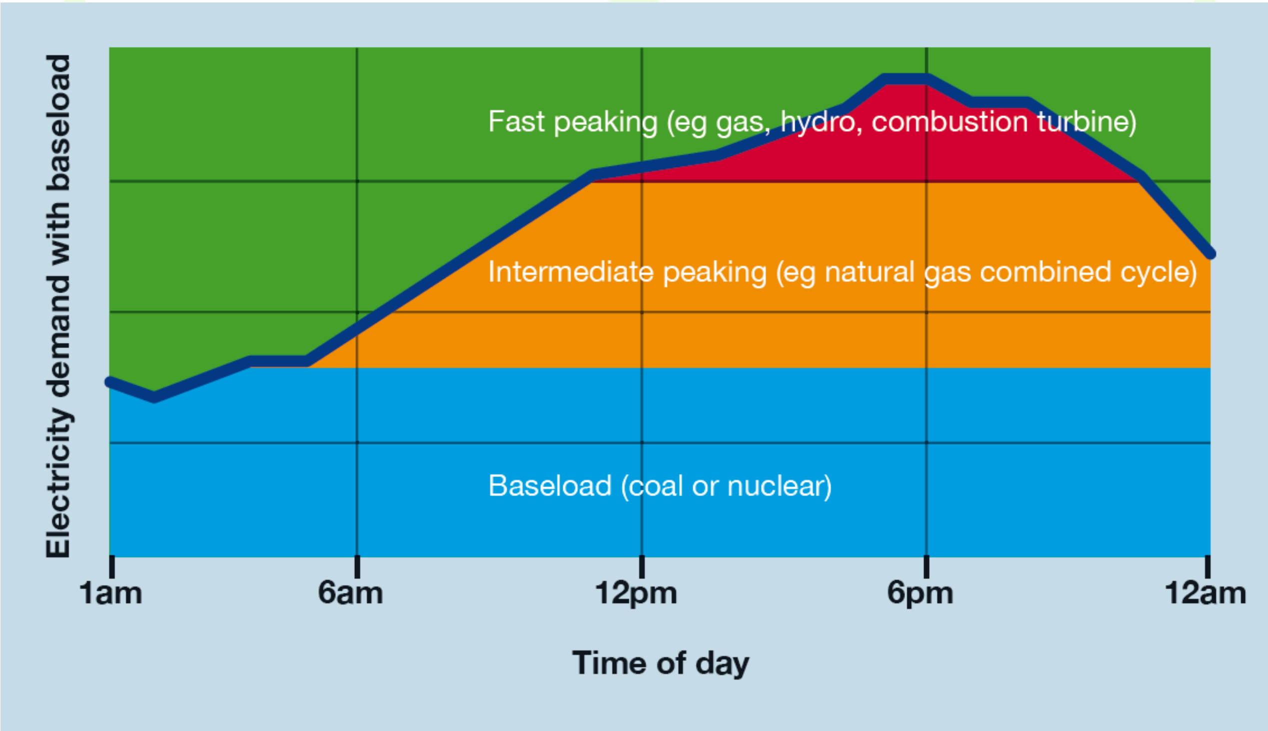


Figure 23 – Repartition of electricity production during the day [35]

From another point of view, if there is a fixed part on the electricity price based on the maximum power required, customers can save a substantial amount of money by using peak shaving (See Figure 24)

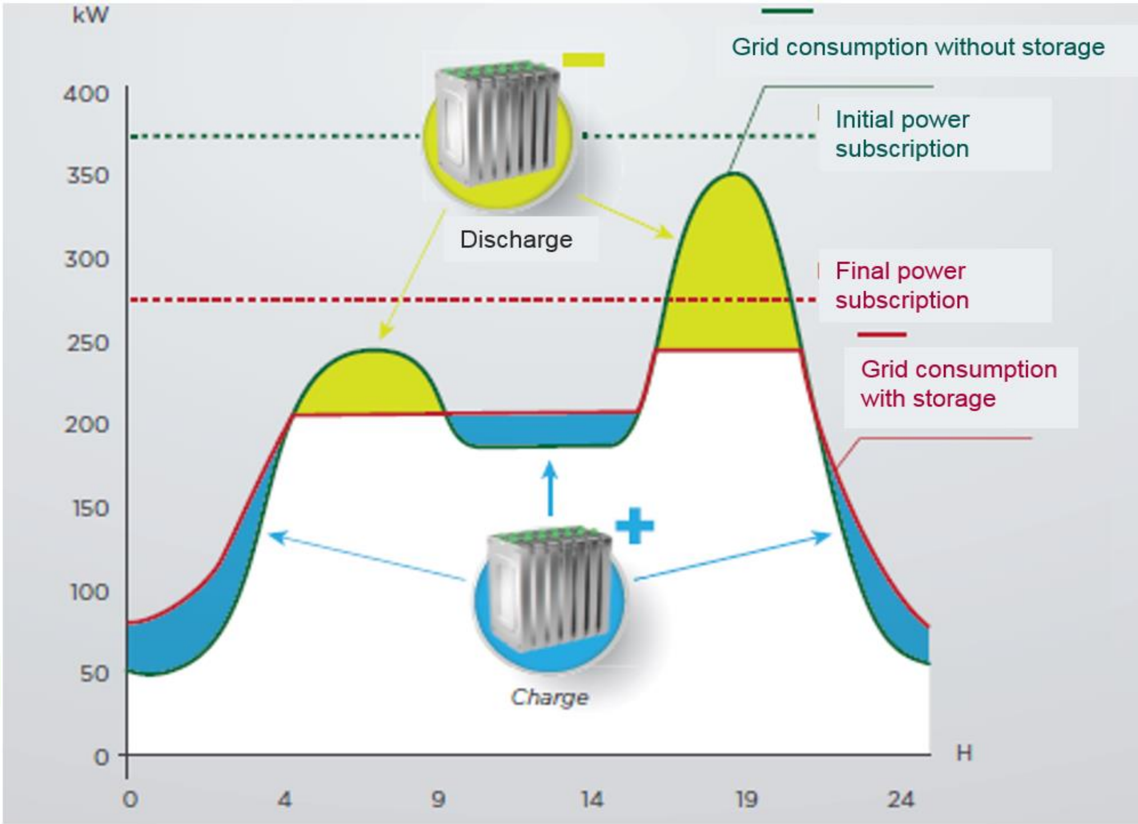


Figure 24 – Impact of Peak shaving on power subscription

Peak demand typically occurs around 7 PM in France, especially in winter [36], which is when non-industrial consumers typically demand the maximum power for family activities and heating.

Peak shaving can be seen as the contrary of the PV smoothing, the aim is to control the load and so to offer flexibility to the DSO. It also avoids voltage drop on the grid since it controls the power demand.

3.3.2.3 Redispatch

While PV smoothing and peak shaving are used to balance deviations of generation and consumptions over time, redispatch measures aim to do the same for spatial variations, i.e., they are used to avoid bottlenecks and to react in case of failure of some generator in their respective transmission grid area. Grid operator can face the overload of the transmission line in its grid area ("bottleneck"). Due to the fact of more and more distributed energy resources (DER), increase of international energy trading and at least in Germany nuclear phase-out, bottlenecks in the distribution and transmission grids will rise. Basically, the term dispatch designates the establishment of an operation plan for power plants through power plant operators. The term redispatch designates a temporary modification of this operation plan. More precisely, redispatch is defined as a measure which is activated by one or several system operators and which consists in altering the generation and/or load patterns within an area, in order to change the physical electric power flows in the trans-mission system and to relieve a physical congestion.If an overload in a line occurs at a certain point in the grid, power plants upstream may be instructed to reduce their feed-in, while power plants downstream will be instructed to increase their feed-in (re-dispatching). In this way a modification of the load flow is generated which counteracts the bottleneck and eliminates the overflow. This process is represented in Figure 25.

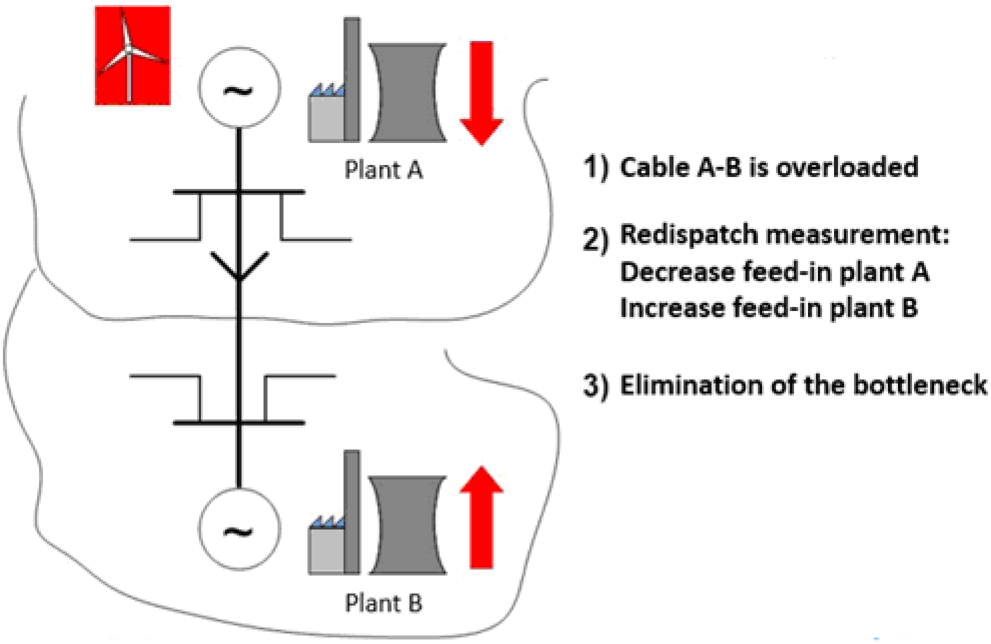


Figure 25 – Example of redispatch with unexpected wind power feed in [34]

Decentralized power production leads to complex grid situations. Therefore, local measures for grid services become more important. For example, multiple megawatts of flexibility may be needed at a network node on the distribution grid level. Redispatch measures could be used to provide the requested flexibility (generation or demand). Battery storage systems can be used instead, to avoid the increase / decrease feed in mechanism of the power plant. DSOs will then use contractual guaranteed flexibility, e. g. in the form of battery storage systems. The retrieval of the flexibility will be provided directly to the DSO by the respective grid user or supplier of the flexibility. The Battery operator can be the provider of this flexibility and would be under contract to realize the service needed by the DSO.

3.3.2.4 Deferral of investment

With increasing peak loads in the future, DSOs may decide that the traditional grid reinforcement approach is too costly (impacting on consumer network charges), and may decide to avoid or defer investment with the use of storage If the equipment price drops or can be shared with other services, energy storage can results as one of the most economic approaches to increase grid capacity up to 100% comparing with installing high voltage lines. This situation has for example been seen in the Massachusetts, where a Tesla storage system is planned to be build [37]. This storage will avoid the need of building an additional transmission. If storage avoids investments, the value of the storage equals the CAPEX and OPEX of the avoided reinforcement. If storage services enable the DSO to defer investments, the benefit of storage can be calculated as the avoided return on capital over the deferral duration.

4 INNOVATIVE DSO OPERATIONS: IMPROVING POWER QUALITY

4.1 IMPROVED CONTROL OF SELECTED GRID COMPONENTS

The connection of RES and DER in distribution networks (distributed generation) has created a challenge for distribution network operators (DNOs), to change their usual passive approach to an active one. This is due to the fact that the conventional distribution networks were designed on the basis of a traditional assumption of a unidirectional power flow. With the increasing connection of RES and DERs, the network has become more dynamic with bidirectional power flows and it is now known as an Active Distribution Networks (ADN).

An ADN is defined, therefore, as a distribution network with systems in place to control a combination of distributed energy resources comprising generators, storage and other actors.

The voltage variation ΔV across the line can be approximately represented by the following equation:

$$\Delta V = \frac{PR + QX}{V}$$

where,

ΔV indicates the voltage variation,

P and Q represent the active and reactive power output of DG,

X and R are the reactance and resistance of the line connecting to DG,

V is the rated voltage at the terminal of DG.

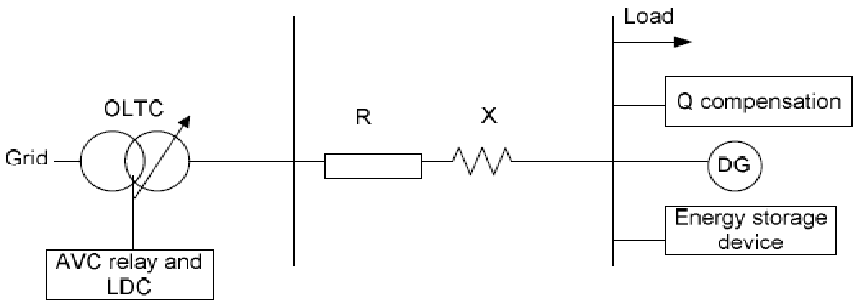


Figure 26 – Voltage Control

It is known that compared with the transmission line, the X/R ratio is relatively low in a distribution network. According to the equation above, any significant amount of power injected by RES or DER will result in voltage rise/drop on the distribution network, especially in a weak distribution feeder with high impedance.

Electric network management system is permanently under innovation. Traditionally, the network is operated with pre-set control strategies to meet the forecast load. In the future, in order to achieve more reliable and efficient performance, distribution systems will increasingly rely on technologies which actively shape the end-users response.

Therefore, network management systems would be operated in an automated feedback mode with feedback information from RES/DG, consumers and other distributed actors. Ideally, the network will be maintained completely active without pre-programmed operations.

In the context of the WiseGRID project, the actions of RESCO in case of a voltage problem/congestion or any other request by the DSO have been addressed, keeping voltage levels in acceptable boundaries with RES or DER implications, while reducing network losses and signalling possible network congestions. Table 4 lists the WiseGRID Use Cases addressing this issue.

HL-UC 1_PUC_3_Voltage support and congestion management
HL-UC 1_SUC_3.1_Provide local U control through P-Q flexibility of RES inverters (Centralized)
HL-UC 1_SUC_3.2_Provide local U control through P-Q flexibility of RES inverters (Decentralized)
HL-UC 1_SUC_3.3_Improve voltage symmetry between the phases

Table 4 – Voltage regulation related PUCs.

The methods will be both global and local as voltage, unlike frequency, is a zonal (local) parameter for power grids. This is an important activity that is likely performed on a permanent basis to keep the grid voltage stability within normal ranges. Centralised and Decentralised voltage control solutions shall be considered, as well as voltage symmetry between the phases.

The voltage variation would also depend on several factors including RES/DG size and location, and method of voltage regulation. In literature, extensive research has been undertaken to address this issue, and the following techniques have been successfully employed in a range of applications.

4.1.1 Centralised voltage control

Centralised voltage control (CVC) methods determine their control actions based on information about the whole distribution network and therefore data transfer among network nodes is required. Advanced CVC involves using advanced control systems which require inputs such as the status of the network, technical constraints and also market information on energy trades.

In the distribution networks the amount of RES and DER is in many cases limited by the voltage rise effect. Under usual practice, the voltage rise can be fixed using passive methods such as increasing the conductor size. Another approach could be the active voltage control methods as they can fix the voltage rise and this can decrease the connection costs of DER substantially [38]. Active voltage control and associated voltage control methods of different complexity and data transfer needs, have been largely proposed in publications. From the simplest methods based on local measurements only (e.g. control of RES or DER reactive power) moving further to coordinated voltage control (CVC) methods that use information about the whole distribution network before deciding most proper control actions, CVC methods are designed to determine their control actions based on simple rules or based on optimized algorithms [39]. Further on, the most suitable method shall be selected based on the configuration and structure of the distribution network, the available parts to participate in the control, the main and specific objectives of voltage control and also the available measurement data and communication channels.

Active voltage control methods considers the control of the various active resources located in the distribution network: the RES and DER; switch controlled capacitor banks and reactors; FACTS devices and OLTCs. Each of these may be controlled locally to support local voltage. Coordinated voltage control methods may further enhance the network hosting capacity compared to local control methods. The setting points of local controllers need to be optimized by using a centralized control method, in order to maximize network hosting capacity, minimize network losses, and minimize OLTC tap switching. This method can be realized as a control algorithm that can, for example, rely on a set of control rules or on a defined optimization function.

The active management of the distribution system making use of controller to coordinate the OLTC action together with the regulation of reactive power exchanges between DER plants and feeders is obviously one of the voltage control methods.

4.1.2 Decentralized voltage control

Decentralized voltage control (DVC) uses local information to independently control voltage at a particular bus where measurement, optimization and communication methods are usually limited. Different decentralized voltage control schemes have been developed to allow more RES and DER capacity to be connected. Decentralized control has one major advantage compared to centralized control, that is, it is able to provide voltage support by controlling locally its operation modes. Hence, reducing or eliminating the problem of faults in communication lines and slow response to rapid voltage variations. Another advantage is cost saving, since decentralized control is able to improve the power systems performance with limited need for large investments in communication systems.

4.1.3 Reactive Power Compensation.

Voltage variations caused by RES and DER can be fixed by allowing generators to modify their reactive power. Using synchronous generators, the control of reactive power is usually realized by an excitation system that consists of an AC or DC exciter, controller and voltage measurement components. Generators connected to the distribution grid are usually small rated and thus have limitations on control of voltage and reactive power. Usually other compensating devices are used (like reactors and capacitors) to ensure that the voltage level is within an acceptable range. These methods have some advantages in terms of efficiency, flexibility, reliability and scalability. A STATCOM, for instance, has the advantage of providing solution in fast response time, thus providing dynamic voltage control in the system.

A STATCOM is a flexible AC transmission system (FACTS) device, i.e. a voltage-source converter based device which converts a DC input voltage into an AC output voltage, compensating the reactive power of the system. The reactive output of a STATCOM is regulated to maintain the desired AC voltage at the bus where the STATCOM is connected. It can provide voltage control in either transmission or distribution systems with a fast and accurate control response. The function is similar to reactive power control of the generation, but the STATCOM provides a solution that is independent of the generator. Due to the fast response of a STATCOM, modern control strategies, such as linear quadratic regulator (LQR), can be provided for voltage control. The associated control methodologies can be applied on a STATCOM in a traditional radial feeder, but they can also be used in a network connected with multiple DGs.

Another solution is a SVC that is able to provide voltage control within very tight parameters, despite a widely varying load or contribution from RES and DG. The main disadvantage of these reactive power compensating devices is the relatively still high costs of the devices. SVCs and STATCOMs are more efficient and able to provide much better control on voltage profile when combined with fixed capacitor banks. Shunt capacitor banks are also another usual method for providing reactive power compensation in distribution systems. These devices consist of assemblies with a large number of capacitors that can be subsequently connected and/or disconnected from the system, using appropriate switches.

4.1.4 Power Factor-Voltage Control

Distribution network operators usually require to specific grid users (all RES and DER) that are connected to the distribution network to operate under power factor control (PFC) mode. The advantage of PFC mode is that it is less disruptive to the network devices, such as OLTCs. The overall operation would bring a balance of the reactive power for each specific zone. However, the disadvantage of this method comes from the certain limits of generation connected to the system, meaning that a further increase in the generation would still result in voltage rise. The new mode approached: Power Factor Control – Voltage Control (PFC-VC) method, combines the behaviour of the generator's operation in two modes, namely *constant power factor* and *voltage control* [40]. Under normal conditions where the measured voltage is within the admissible upper and lower limits, the generator will operate in *constant PFC mode*. However, at any circumstances where the voltage deviates above or below the admissible limits, the generator would switch into *the VC mode*, by varying the excitation of the automatic voltage regulator. In the PFC mode, the real power over reactive power ratio is kept constant, with the reactive power following the variation of real power. In the VC mode, the automatic voltage controller is activated to vary excitation and move the operating point within the bus voltage limit. Looking back to former problem related to islanding of RES and DER, this switch in case of islanding would be compulsory for the safety of the islanded area. This method is implemented with the knowledge of combining the advantages of automatic voltage regulator and PFC and is also named as automatic voltage/power factor control. On the other hand, the independent producers adopt PFC strategy as a means to avoid significant penalties due to excessive reactive power consumption.

4.1.5 On load tap changer (OLTCs)

The OLTC transformers are used between the multiple voltage levels to regulate and maintain the voltage which is supplied to consumers within admissible limits (within a specific range that fulfils consumer's needs). The OLTC mechanism is a transformer component controlled automatically by a relay that could increase or decrease voltage by changing the tap position of a transformer. When the secondary voltage detected (specifically the consumer voltage level) is no longer within the permitted dead-band, the relay issues a command to the tap changer mechanism to alter its tap position in order to restore the required voltage level. The OLTC transformer, coupled with its automatic voltage control relay, regulates the transformer output voltage to keep the voltage within limits. Important in this case is to consider that an OLTC procedure will not change the overall balance of the reactive power within the specified area. It will only force the reactive power to pass within a specific direction and thus would create a voltage increase on one transformer level and a voltage decrease to the other. That brings the main disadvantage of this scheme, that the operation of the tap changer is limited to its tapping capability and would fix a voltage level while possibly damaging the other voltage level as there would be no overall reactive power variation to affect the area. The measured voltage is shifted upwards or downwards depending on the power factor of transformer current and the direction of power flow to the DER and load.

4.1.6 Generation Curtailment

Voltage rise can be fixed by reducing the active power output of RES or DER. The disadvantage of this is obvious. The simplest method to implement generation curtailment is to disconnect the required number of generating units when the voltage exceeds its limits. For instance, if active power of RES or DER can be controlled by blade angle control of wind generators, disconnection is not required as long as the active power of DER can be controlled continuously. This can be a method to tackle the voltage rise problem as a last resort in case the PFC –VC control mode is not successful. This scheme would reduce some percentage of the power output when the voltage at the connection bus exceeds its admissible limits. In a similar way, the production of active power of low voltage photovoltaic generators is controlled by a specific control logic. For this purpose, a control named *Power Curtailment*, would adjust the active power generated according to the local node voltage to avoid any overvoltage at that node.

4.1.7 Energy storage

Energy storage solutions including pumped hydro storage, compressed air energy storage (CAES), hydrogen, lead acid batteries, lithium-ion batteries, super conducting magnetic energy storage (SMES), flywheel and capacitors are expected to be wide spread in RES and DER connected networks. Currently, energy storage technologies are at various stages of development and deployment. Pumped storage and lead acid batteries are the most widespread storage technology deployed on power systems, they are technically and commercially mature. Superconducting magnetic energy storage is technically possible but is not mature.

Energy storage devices have been recognized as environmentally benign means of modulating renewable generation and providing reserves. These devices use a power conversion system (PCS) to connect to the distribution system; they can source or sink both active and reactive power to compensate for voltage variations in the short or medium term. For longer durations of voltage problems, relevant energy storage capability is required.

Wind power generators have gained increased operational benefits and economic returns by combining with energy storage devices. Energy storage technologies can store the surplus during the periods when wind generation exceeds the demand and then be used to cover periods when the load is greater than the generation. Lund and Paatero in [41] demonstrated that approximately 1 MWh storage per MW of wind power is enough to reduce at least 10% of the local voltage rise in weak networks.

4.2 MANAGING NETWORK COMPONENTS

The electric distribution grid is changing faster and faster due to the grid's user dynamic attitude. Issues such as the consumer's new attitude, energy technology adoption, the Internet of Things, emission regulations, competition, renewable source integration and others are making existing systems and processes obsolete, requiring utilities to come up with new ideas for grid development and implicitly grid management. Transformers, feeders, substations, reactive compensation units (reactors and capacitors), resistors and other grid components are requiring higher accuracy monitoring tools and also a dynamic approach, so the grid as a whole can be better monitored and operating devices can easier and more efficiently be tuned for safety supply and getting closer to optimum performance conditions for the elements.

The usual approach of any utility to this problem is to design and install a complex DMS that would connect many parts of the grid to collect data, monitor and process them to best define safe and secure operating conditions.

A DMS is an IT system capable of collecting, organizing, displaying and analyzing real-time or very close to real-time electric distribution information. A DMS should also allow operators to plan and execute complex distribution system operations to increase system efficiency, optimize power flows, prevent overloads and finally avoid unplanned outages. A DMS can interface with other applications such as geographic information systems (GIS), outage management systems (OMS), and customer information systems (CIS) to create an integrated view of distribution operations. A Distribution Management System (DMS) is a collection of applications that monitor and control the entire distribution network efficiently and reliably, always available for extensions and updates. It acts as a decision support system to assist operators and field personnel in the monitoring and control of the electrical distribution system. As overall, the DMS will improve reliability and service quality by reducing outages, minimizing downtime and maintaining admissible voltage levels.

Technology is changing, energy industry is changing, and today's energy customers are changing bringing more actors in the area. We need to transform ourselves by designing a new-generation network that meets the evolving needs of the customers and at the same time delivers safe, reliable but also affordable electricity.

Distributed energy resources would mean energy efficiency, demand response, renewable energy generation, energy storage and electric vehicles and would play a key role in these industry trends. We are moving towards a future where distributed resources are integrated in the distribution network at unprecedented levels. The grid of tomorrow will look very different from the yesterday grid. Power will come from multiple sources and flow in several directions, looking permanently to be more ecological as carbon emissions need to decrease exponentially. However, the intermittent and unpredictable character of renewable generators creates quality, balancing and voltage problems. The ability to adequately protect against system events can be compromised, and maintaining customer reliability would require more attention [42].

4.2.1 Improved monitoring

To maintain a secure and reliable network, utilities must increase visibility of the distribution system. They need to collect more data, more frequently, in a variety of points that communicate the status and the performance of the assets, allowing a timely visibility of network issues. This is true both for real-time operations and for long-term system planning. Currently real-time monitoring practices must extend beyond the transformer circuit breaker to strategic locations of the circuit, including the main infrastructure and major DER facilities that are connected to the grid, to facilitate on-line decisions for using such resources for grid security improvement. As more devices are connected to the network, the complexity continue to increase. As a consequence a trend toward "Big Data", processing of large amounts of information will be necessary to assess the state of an increasingly complex distribution network.

The ability to detect problems directly supports security, including identification of virtual or physical operation of the distribution system and any asset performance or network conditions that could endanger the personnel. Real-time observability provides useful information to assess interruptions and maximize service re-establishment faster than ever possible.

Early detection of grid problems gives more time to respond before these weaknesses extend to greater security or reliability issues. We need improvement in elasticity, improving visibility under steady state and transient conditions. Ultimately, additional data increases flexibility to support more future scenarios.

More data improves the ability to operate, plan and maintain today's grids and meet the data needs of a highly distributed network.

Under such circumstances, a DMS would facilitate **Monitoring**:

- Active power
- Power Factor / Reactive Power
- Currents and Voltages
- Harmonics
- Neutral Current
- Voltage or Current unbalance
- Frequency
- Voltage sags & swells (due to load fluctuation – e.g. motor starting, power up of transformer or capacitor banks, lightning...)
- Disturbances, Transients…

In order to **Avoid**:

- Overloads and Congestions
- Increased losses in cables & transformers
- Equipment failure or reduced life time due to overheating (transformers, capacitors, motors, VSD’s, neutral cables…) & vibrations (motors)
- Untimely Circuit Breakers tripping or extended tripping
- Process disturbance (sensitive equipment: relays, VSD’s, PLC ’s, motor speed instability...)
- Perturbation of communications

Looking forward, we can evaluate that Desired Enhanced Monitoring Capabilities would be the ones described next.

4.2.1.1 Real Time Situational Awareness

An important step to modernization is visibility of all steady state grid conditions that may need to be addressed, including criteria violations, equipment failures, customer outages, cybersecurity, etc. Visibility by itself is not sufficient; recognition of issues requiring attention is the critical second half, and for this, hardware components that gather data from the field must be combined with software tools to analyze this data simultaneously. Real-time situational awareness would directly address the challenge we face with bi-directional power flows and minimal or delayed visibility of the distribution system beyond the substation breaker.

4.2.1.2 Power Quality (PQ) Awareness

Operators and planning staff also require visibility to transient grid conditions affecting power quality for customers. PQ awareness differs from real-time situational awareness because of different types of grid conditions not previously monitored on a regular basis. With the potential ubiquity of power electronics interconnected to the grid, new PQ conditions that have never resulted into issues are expected to materialize.

Having this capability addresses technical challenges associated with more and more power electronics connected to the distribution grid.

4.2.1.3 Distribution Load Flow Analysis

Distribution load flow analysis provides a visual load flow tool that assesses all the points on the distribution grid for criteria violations in real time. This tool would respond to criteria violations by providing recommended options for mitigation to system operators. It enhances and expands situational awareness by automatically identifying all criteria violations for distribution system operators. A complement to real time situational awareness, it allows to assess considerably more field telemetry, and optimizes usage of available assets on the distribution grid. It would also provide to system planners a simplified means to analyze impacts of grid changes and third-party interconnections.

4.2.1.4 Automation of Circuit Reconfiguration

Operations engineering needs automatic notification of permanent circuit reconfigurations to review protection settings. More frequent and timely review of protection settings will become increasingly important as distribution topology changes, including more fault contributing sources. Automating certain steps of this process will help to overcome the challenges tied to a more frequent review.

4.2.1.5 Self-Healing

Large amount of data combined with significant increase of data processing are helping the grid operators to rely more and more on the IT aid. Nowadays tendencies are towards solutions based on a “self-healing strategy”, to be achieved by “artificial intelligence” means. The system would be allowed to decide switches that further will become “lessons learned”, but taking the risk to create another outages meantime. The learning process is complex and needs deep knowledge and expertise. The “artificial intelligence” for self-healing algorithms can be based on tables of rules to be used and combined in several events in the grid for fault isolation and reconfiguration of the network, or by autonomous learning of an AI system running offline on mathematical and topological simulation models of the grid network combined with real time data. This manner allows for the AI system to discover and refine its own rules for healing the network. Deep neural networks can be used for such algorithms.

This functionality is strongly connected to *fault detection, isolation and service restoration.* For this, fault indicators need to contain wireless communications capability to assist in fault detection, isolation, and restoration. Such devices can also be leveraged to provide real time telemetry to support operations’ situational awareness.

4.3 NEW TECHNIQUES BASED ON REAL TIME METERING DATA FROM USM

The latest technological developments are challenging for finding new solutions to mitigate the massive integration of renewable-based electricity generation in the electrical networks and to support new and dynamic energy and ancillary services markets. One challenge is, for instance, the massive (small) PV roof-based installations, which demand a solution to solve observability in such sites. Smart meters are becoming ubiquitous equipment in the low voltage grid, enabled by the decision made in many countries to support massive deployments. The smart meter is the only equipment mandatory to be mounted when supplying a grid connected user, as it primarily has the function to measure delivered and/or produced energy on its common coupling point with the network, as a technical and legal support for billing. Active distribution networks need new functionalities to cope with bidirectional energy flows on the grid, and many smart grid requirements need to be implemented in the near future. However, there is no real coupling between smart meter systems and smart grids, as there is not yet a synergy using the opportunity of the high deployment level in smart metering. Currently, our approach to managing the smart metering and smart grid orchestration proposes a new general design based on an unbundled smart meter (USM) concept, labelled as a next generation meter with a design from scratch accommodating both SMM and SMX, and having the name SLAM (Smart Low cost Advanced Meter). SLAM is intended to be deployed everywhere at the prosumer's interface to the grid is, as it is usually now, the case with standard meters. Furthermore, rich data acquired by the SLAM will be used to demonstrate the potential of providing real-time data for improving DSO operations. The information sent to the DSO is only non-sensitive data from a privacy perspective, and is therefore able to be applied everywhere in the grid, down to the end-customer level, where a citizen's personal data protection is an important aspect.

Today, electricity grids face multiple challenges due to high renewable penetration and to the dynamic evolution of the markets of energy and energy services. Some of the challenges related to renewables are: the stochastic behaviour of renewable energy production, the possible change of power flow direction in the distribution networks (initially designed to have only one-way power flow and a passive/loads only behaviour) and the temporal mismatch between production and load. These challenges are being widely considered in the scientific community and have been treated in many papers (e.g., [43],[44],[45]). Smart metering (SM) is the new technical solution for evolving markets and the smart grid is the new paradigm where the power network and its generic prosumers are highly linked by information and communication technologies (ICT) solutions, expecting to improve the overall network functionality. But at producer or consumer level, high levels of smart metering deployment still do not support the emerging smart grid functionalities.

Both smart metering and smart grids must also face cyber-security threats. Security aspects related to smart meters deployment have been analysed from different perspectives, e.g., by the authors of [46],[47].

Today, the state-of-the-art smart meters are characterized by complex functionalities:

- Active and reactive energy measurement with metrology certification, such that they can be used for official billing purposes (meters without such certification are not legally enforced to provide information valid for invoicing).
- Complex tariff implementations.
- Design based on communication with the most important actor, which is managing the billing data: the DSO (distribution system operator)—as market facilitator in most EU countries, or the independent central hub—as third party market facilitator [48].
- The communication path is implemented in most cases through the PLC (power line carrier, considered to bring no or very low operational losses) and in some cases through GPRS (general packet radio service)/3G.
- Usual protocols for the data readout from smart meters are specialized for AMR/AMI (automatic meter reading/advanced metering infrastructure) data collection, e.g., DLMS/COSEM (device language message specification/companion specification for energy metering) protocol and its associated data model.
- Smart meters are able to provide, on request, instrumentation measurements at high reporting rates, between 1 and 10 s, as a possible support for SCADA (supervisory control and data acquisition) functionalities. This instrumentation data (e.g., voltage u, current i, active power p, reactive power q) is still not used at its full potential, for various reasons: the communication path is too slow (valid especially for PLC communication), protocol is not appropriate for SCADA, etc.;
- Load profiles (LP) of energy, instrumentation and of other data can be stored for medium to long periods, such as one month to several months, depending on the selected time period for LPs memorization; usually for LP periods of 15 minutes between consecutive records, the LP time depth is more than one month.
- Some electrical energy smart meters have functionalities to collect data from other local meters: gas, water or heat meters; this architecture enables multi-utility/multi-service smart metering [49], allowing improvements in energy and market efficiency.

- A small number of electrical energy smart meters have a local interface to communicate with local devices, thus enabling different services for final users.
- A small number of electrical energy smart meters have a local interface to communicate with end-users [50], thus enabling energy awareness and supporting different services for final users.

The Smart Low-cost Advanced Meter (SLAM), developed within NOBEL GRID project [51], implements in an enhanced way all these functionalities and much more:

- Complex tariffication is helped also by a nearly real-time possibility of communication with the supplier or with the spot market, thus allowing to take advantage of real-time opportunities such as small or negative prices due to temporary excess of RES energy (curtailment in the case of excess energy may be avoided if additional RES production is paired with additional consumption, if possible).
- The SLAM communication is simultaneously multi-user and multi-protocol, which allows that all energy actors can access the metering data;
- A powerful role-based access control (RBAC) functionality allows that each actor is accessing the data with his particular rights, based on its role in providing services; for instance, DSO has access at non-private real-time data such as voltage level, but not to the real-time active power, which can disclose private activity; an ESCO or aggregator can have access to more fine-grained data if their service requires it and if a specific data protection contract has been signed between the parts.
- Smart Grid is helped with real-time data down to one second reporting time, which gives similar or better performance compared with traditional SCADA, while the measurements accuracy is in most cases superior.
- To allow this flexibility of communication, IP-based communication is used on public networks, such as internet, which gives easy access directly to the meter data; it means that today PLC is not a choice, as it is not publicly available (but only to DSO) and does not have enough dynamics to allow real-time exchange of data for all the meters (only very few and selected meters in a LV metering pool may have a certain real-time behaviour).
- Cyber security is high, based on multiple VPN pathways, a different one for each type of actors; this allows a high level of security for the transmission of data; additional improvements of data security may be possible by extending the security level with Physical Unclonable Function (PUF), which is developed in [52].
- The meter allows different types of local interface in order to communicate with local devices, thus enabling different services such as demand response. Different communication means can become operational by adding e.g. through the USB a radio dongle to interact with loads / intelligent white appliances through Wi-Fi or ZigBee); the interoperability is enabled by a specific driver (or agent) in SMX, which can be added during the runtime, and not only during the initial deployment.
    - The meter has a local interface to communicate with end-users, which can access it through a web browser on the smartphone, tablet, laptop or stationary PC; energy awareness is highly boosted and allows important savings based on the real-time monitoring.
- The fine granularity in voltage measurement (each second) allows to monitor voltage level quality, as part of a more complex PQ measurement support.
- SLAM supports measurements of voltage harmonics up to the 42^{nd} harmonic, being able to monitor and assess the pollution of the grid with the harmonics at the level of all meters. Complex IEC-based measurements can be done with specific and expensive equipment only in special situations when there is a specific request or for grid analysis.

- SLAM allows to run on the SMX side different software agents which allow new functionalities such as local renewables and storage support for the upcoming prosumers as well as a better accommodation of home EV charging,

- SLAM is unleashing and improving all businesses which need energy measurement over different time periods (slots) from each hour down to each minute. It is also improving functionalities for smartening the grid, as it is able to provide real-time grid data to actors such as DSO and aggregators, in order to improve different specific functionalities. The high reporting rate, down to each second, is competing with the classic RTU, while this comes with smart meter needed for billing purposes.
- The data security is a killing factor for smart grids, meaning that if it is not well implemented, the smart grid functionality should be not implemented as well. With high data-security based equipment such as SLAM, the real-time data as well as the energy records used for billing energies and energy services become trustful and allow both high security and enhanced privacy by design.

4.4 AUTOMATED NETWORK FAULT LOCATION, ISOLATION, RESTORATION AND RECONFIGURATION (SELF-HEALING)

One of the key features of smart grids is the reliability and efficiency improvement obtained by automatically anticipating and responding to system disturbances. In order to reach the status of intelligent network at the level of the distribution system, different automation technologies have been applied in the areas of measurement, protection and control.

In this regard, it is known that for a system to be highly reliable and fault tolerant, in addition to multiple redundant paths, it is paramount to have smart strategies such as Fault Detection, Isolation and Reconfiguration (FDIR) to manage redundancy. This technology has become an important part of today's networks in order to automatically determine the best way to configure a feeder to first isolate the fault and then restore the largest number of customers possible [53].

However, the existence of FDIR in current networked distribution systems is normally limited to local protection schemes, which usually do not communicate with each other. Thus, in order to selectively convert existing networked distribution systems into smart distribution systems, it is necessary to add advanced FDIR mechanisms and other smart control concepts. The methods used shall also replicate transmission system concepts that use system restoration logic to automatically restore the distribution system [53].

In recent years, utilities have deployed switching devices in feeders, such as restorers and switches with Intelligent Electronic Devices (IEDs) for protection and control applications. The automated capabilities of IEDs, such as measurement, monitoring, control and communications, enable to implement automated fault identification, isolation, and energy restoration. As a result, the power outage duration and system reliability can be significantly improved [54].

Based on the information provided by the IEDs, the automated identification of faults and their isolation is relatively easy to achieve, although in the current and future scenarios with high penetration of DER the existence of bidirectional power flows has added complexity to this task, requiring the use of specific devices such as bidirectional Fault-Pass Indicators (FPIs). In contrast, automated power restoration is a difficult task, and large research efforts are focused on carrying out this functionality considering the constraints of operation, load balancing, and other practical considerations [54].

Although many of the proposed automated energy restoration techniques and strategies are intended to provide a real-time solution, most of them are only suitable for planning analysis or developed to be executed at the Distribution Control Centres to support the system operators in making the right decisions [54].

Depending on the characteristics of the distribution network, the number, location and capacities of the automated devices, different operating procedures/schemes can be implemented for fault detection, isolation and automated energy restoration.

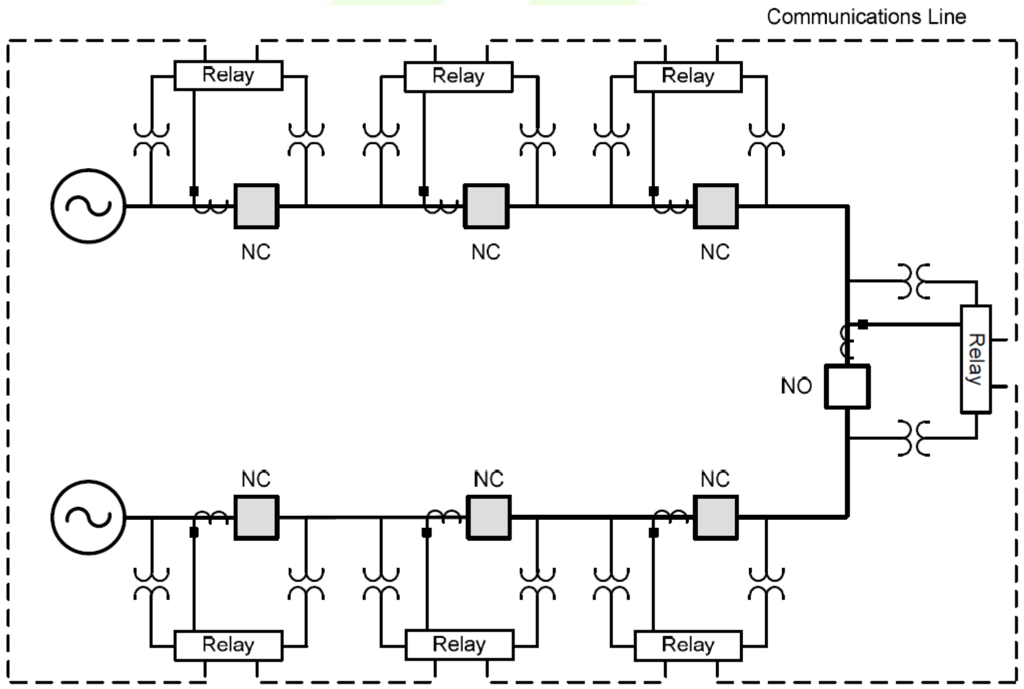
4.4.1 Schemes in single loop networks

The wide area control used today in distribution networks employs strategies that reconfigure the network in response to changes in power system conditions. Automatically reconfiguring a distribution network in response to fault conditions can greatly improve the reliability of the electrical service, reducing interruption times from hours to seconds.

Engineers have designed loop schemes that are very effective for well-defined networks. These schemes work without any communication, monitoring the voltage at each switch to detect faults and restore loads. Implementations may vary, but usually they are applied to two radial feeders separated by a normally open switch (NOP). These schemes rely on time-coordinated switching operations to isolate missing line sections and restore service to sections without fail. These schemes generally operate to restore the load in one or two minutes, which dramatically improves the time required to manually restore the system [55].

This type of scheme benefits from the high-speed processing of input and output signals, as well as its independence from communications systems. The drawback is that control decisions are based on local measures. Local field devices have very little knowledge of the situation of the rest of the distribution network.

The addition of communication capabilities provides the possibility to further reduce the restoration time in what is called Automated Loop Restore Schemes (ALRS). Utilities have implemented schemes using protection-oriented communication technologies to clear faults and restore the load in less than a second, and in some cases, in only a few cycles. Each switch sends a small set of status data to adjacent high-speed network switches (see Figure 27). The use of communications not only reduces restoration times, but also reduces the effects on customers who still have service. A non-communications restoration scheme has the potential to cause a voltage gap in clients that are not affected by the initial failure.



NO: Normally Open

NC: Normally Closed

Figure 27 – Single loop scheme with *peer-to-peer* communications

4.4.2 Schemes in distribution networks with complex topologies

The schemes mentioned above are normally applied to networks with two feeders. The possible topologies in these networks are few and therefore the logic required is limited. Wide Area Control systems that manage larger feeder groups with more complex topologies (see Figure 28) usually require more information that must be shared through communication channels.

A centralized controller is usually used to collect data and to provide wide area control functions for a group of feeders. It is often convenient to locate the controller in a substation associated with one of the automated feeders, although the controller could be located anywhere, as long as the necessary communication channels are available.

The controller monitors network topology, feeder load, voltage levels, and any valuable information over the network. The controller provides system-oriented control decisions to achieve the interdependent control objectives mentioned above.

The functions in the Control Centre are improved, as more monitoring of the entire distribution network is available. Usually, the implementation of the functions in the Control Centre benefits from greater computing capabilities, due to its centralized nature and safer environment. Systems in the Control Centre also often include sophisticated software applications related to optimal load flow, asset management programs and economic aspects [55].

Distributed or decentralized control schemes based on for example multi-agent architectures, with peer-to-peer communication capabilities similar to simple networks, are also possible, but the management of a multi-agent architecture to contemplate global interdependent control objectives is far more complex.

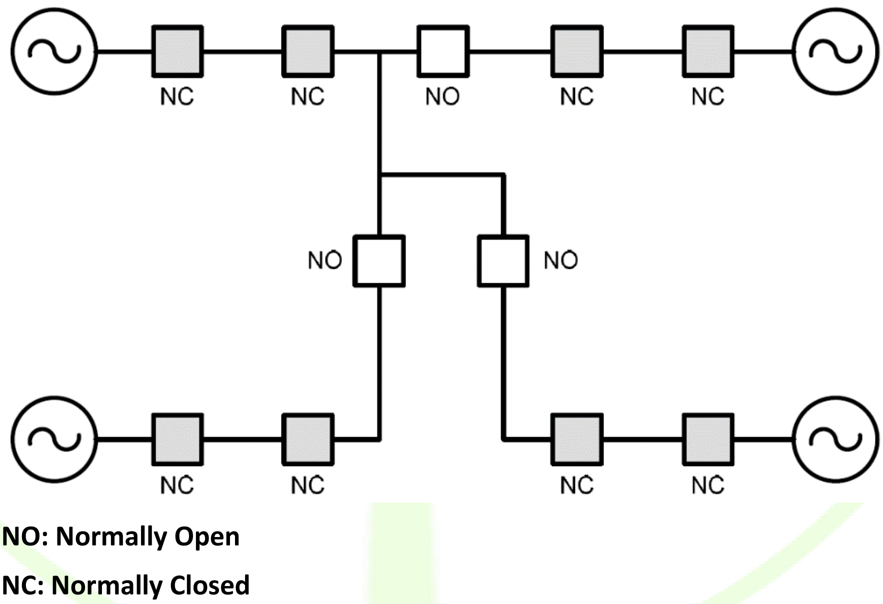


Figure 28 – Distribution network with multiple feeders

4.4.3 Importance of ESS on Network Restoration

The Energy Storage Systems (ESS), as well as the distributed generation may play an essential role in the network restoration procedure, at least in a first phase. These resources can be considered as *black start* resources since, after a grid-wide outage, they must be able to start up without power from the grid and must be able to operate in standby mode, while disconnected from the grid, until they are called upon. In most cases, the black start service is provided by specially equipped generators (i.e., fitted with batteries and/or diesel generators providing the required starting power). However, most storage types are well-suited to serve as black start resources because, unlike most generators, they do not need such an equipment, and storage does not have to operate while awaiting dispatch. So, black-start capacity of ESS is of great interest, since it would enable temporarily the reconnection and service restoration to the network and its consumers in an easier way without depending on the main grid.

The feasibility of using ESS to enable black-start operation has already been demonstrated in some studies [56] [57]. Not only the ESS can have black-start capabilities, but can also enable other DG units and other storage capacity to perform black-start actions as well, like PV and wind generation, among others.

There are several proposed algorithms for black-start operation in the literature, which can be gathered in two main categories: The parallel (also called Bottom-up) restoration strategies, and the serial (also called Top-down) restoration strategies. In a parallel restoration strategy, as the sources with black-start capability are started, the subsystems are built up, and they are connected to the grid through the synchronization devices. The parallel restoration strategy has the characteristics of short recovery time, complexity of the control system, necessity of pre-synchronization and the existence of several subsystems at the initial stage of black-start [56]. In a serial restoration strategy, the main power supply establishes the stable voltage and frequency, and the other sources start under the reference voltage and frequency. The serial restoration strategy has the characteristics of longer recovery time than the parallel strategy, and simple control structure [56].

5 AN EXTENDED ROLE FOR RESCOS IN SMARTENING THE GRID

5.1 THE RESCO CONCEPT

RESCO – Renewable Energy Service COmpanies – appear in scene with a feasible business model that will encourage the broad adoption of distributed RES and storage, facilitating the transition of energy end-users from passive consumers to prosumers with more active participation, and promoting the increase of green sources in the energy share. The main purpose of RESCOs is providing RES services (usually photovoltaic, wind power or micro-hydro) to end-users (both households and businesses) that do not own nor wish to maintain the necessary equipment. A natural extension of this business involves providing batteries as well as supporting the operation of the RES equipment. In this way, RESCO could play a role in grid balancing, offering advanced service to the distribution grid.

The main difference between a RESCO and a RES/battery equipment supplier is its involvement in the overall lifetime of the installed assets. A RESCO will typically deploy the RES project and then monetize the energy produced in contrast to a system integrator, who will only be involved in the execution and implementation of the installation project [58]. RESCOs are expected to operate on a model in which they partner with investors to own the assets (solar panels, domestic wind turbines, batteries…) using long term funds, generating power, distributing it and collecting revenues from their customers [58].

So far, RESCOs have been very important in the expansion of rural electrification projects around the world because [58]:

- Low income rural households can use electricity without having to invest in RES, something that they would not normally be able to afford due to the high initial cost.
- Equipment and components are properly maintained and replaced by the RESCO, so the service is not interrupted.
- Equipment is owned by a company that directly or indirectly represents the domestic users (that are in fact beneficiaries of the funding).

The final goal has deep environmental impact, since RESCO business model improves the share of renewable distributed resources by encouraging the wide adoption of these technologies.

In the WiseGRID framework, three potential scenarios related to RESCOs business model are envisaged, involving three different types of relationships with their customers:

- S1 - In the first scenario, the RESCO pays a fee to its customers for being allowed to use their premises (e.g. for installing PVs on their roof), to install and maintain the RES assets, and to trades with all the produced energy.
- S2 - In the second scenario, the RESCO provides to customers the supply of energy coming from RES owned by the RESCO (i.e. allowing its customers to self-consume the produced energy) and trades with the production surplus. Customers under this contractual relationship should pay a fee to the RESCO to cover the provided energy – at prices lower than the ones of the retail market – and the maintenance of the equipment.
- S3 - In the third scenario, the RESCO provides to customers the installation of RES equipment (e.g. PV panels and batteries) which are still owned and maintained by the RESCO but fully exploited by the end customers. This third scenario describes basically a RES renting business model.

5.1.1 RESCO profitability overview

This section provides a small economic analysis of the business model of RESCOs. In order to perform this market overview, we focus on the PV market, as it is likely to be one of the most common scenarios of the RESCO business model.

As shown hereafter in Figure 29, the Cost per Wp (watts peak) installed in the residential sector, is less every year. So the PV residential systems will be more and more profitable in the next years.

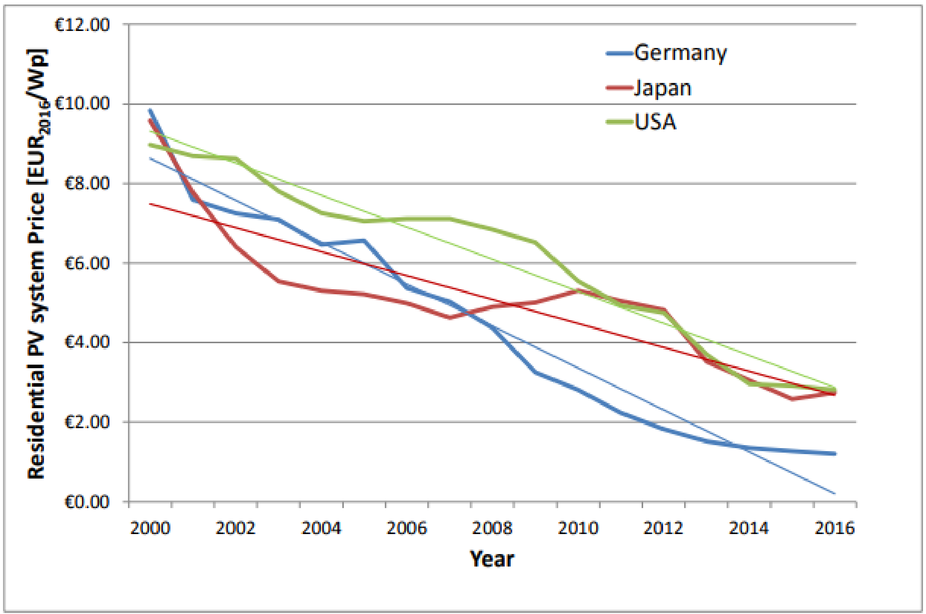


Figure 29 – Residential PV system price development over the last decade [59]

This scenario is so profitable for RESCOs because one of their main business costs are the required systems and they will become cheaper year after year.

Specifically in Europe, the average price of a residential system is 1.21€/Wp. Adding a surcharge of EUR 0.14/Wp for fees, permits, insurance… an installed PV system costs EUR 1 350/kWp without financing and VAT [59].

The average European residential electricity price given by Eurostat for the second semester of 2015 was

0.211€/kWh, including fixed charges [60].

A detailed sensitivity analysis is done hereafter to provide a simple illustration of the competitiveness of small PV systems for residential applications (assuming a system price of 1400 EUR/kWp +20% VAT, 2% operation & maintenance costs, an annual generation of 1000 kWh/kWp/ and an installed and a financial investment period of 20 years, the LCOE is 0.162€/kWh. All these assumptions are shown in Figure 30).

Item	Cost	Contributions to LCOE				LCOE
		Item	20% VAT	Capital for ROI 5%	O&M 2%	Total
	[EUR/kWp]	[EURct/kWh]	[EURct/kWh	[EURct/kWh]	[EURct/kWh]	[EURct/kWh]
PV Module	560	2.80	0.56	1.78	1.34	6.48
Inverter	140	0.70	0.14	0.44	0.34	1.62
Balance of Systems	270	1.35	0.27	0.86	0.64	3.12
Engineering Procurement & Construction	300	1.50	0.30	0.95	0.72	3.47
Other (fees, permitting, Insurance.)	130	0.65	0.13	0.41	0.31	1.50
Total	1,400	7.00	1.40	4.44	3.36	16.20

Figure 30 – LCOE of PV generated electricity for residential systems [61]

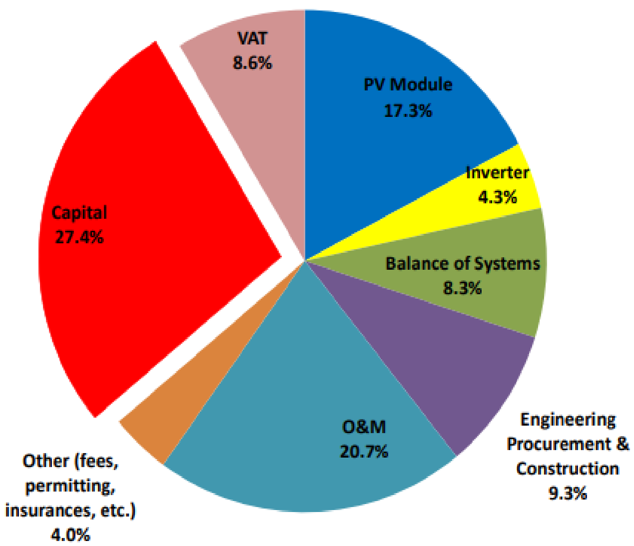


Figure 31 – LCOE cost breakdown for a residential system [61]

This data is a European average. It is obvious that, as in the countries located in the South of Europe the solar irradiation is higher, the same PV Module (17.3% of the PV residential system, as showed in Figure 31) provides more energy in a Southern country than in a Northern country, therefore, the LCOE will be lower (more profitable).

In the case of a PV system that produces as much electricity as the customer uses over a year, the actual consumption during the time of generation is in general about 25 %-30 % of the daily production (talking about on the residential sector; in commercial buildings it can be even more) [59].

Taking into account all this data, it is possible to provide a general overview of the RESCO market concept regarding the three (3) business models described above (taking into account the data here before detailed).

5.1.1.1 Scenario 1

The RESCO pays a fee to end users using their premises (e.g. for installing PVs on their roof), installs and maintains the RES assets and markets all produced energy.

Yearly production (kWh/kWp)	Electricity cost (€/kWh)	Yearly Revenues (€/kWp)	LCOE (€/kWh)	Yearly costs (€/kWp)	Yearly benefits (€/kWp)
1000	0.211	211	0.162	162	49

Table 5 – Scenario 1 economic analysis.

Table 5 shows that, if the RESCO pays a fee to the end user **lower than 49€ per kWp** installed per year, it will obtain economic profit.

5.1.1.2 Scenario 2

The RESCO provides to customers the supply of energy coming from RES owned by the RESCO (i.e. allowing self-consumption) and markets the production surplus. In addition, the end user should pay a fee to the RESCO.

In order to perform this analysis, it is noteworthy to mention again that the actual consumption during the time of generation is in general about 25 %-30 % in the residential sector. So we have assumed a volume of 70% of marketed energy. In Table 6 is not shown the tax that the end user should pay to the RESCO.

Yearly production (kWh/kWp)	Marketed energy (%)	Electricity cost (€/kWh)	Yearly Revenues (€/kWp)	LCOE (€/kWh)	Yearly costs (€/kWp)	Yearly benefits (€/kWp)
1000	70	0.211	147.7	0.162	162	-14.3

Table 6 – Scenario 2 economic analysis.

As we can see in Table 6, the tax coming from the end user is completely necessary. In order to perform coherence between these first 2 scenarios and make that the RESCO obtain the same benefits, the tax from the RESCO to the user (and in the second scenario from the user to the RESCO) should be **31,65€/kWp** per year. Thus the yearly benefit of the RESCO will be **17,35€/kWp** per year as shown in Table 7**.**

Yearly production (kWh/kWp)	Marketed energy (%)	Electricity cost (€/kWh)	Yearly tax from the user (€/kWp)	Yearly Revenues (€/kWp)	LCOE (€/kWh)	Yearly Costs (€/kWp)	Yearly benefits (€/kWp)
1000	70	0.211	31.65	179.35	0.162	162	17.35

Table 7 – Scenario 2 economic analysis with user's tax.

5.1.1.3 Scenario 3

The RESCO provides to customers the installation of RES equipment (e.g. PV panels and batteries) which are owned and maintained by the RESCO but fully exploited by the end customers (renting business model).

Yearly production (kWh/kWp)	LCOE (€/kWp)	Yearly Costs (€/kWp)
1000	0.162	162

Table 8 – Scenario 3 economic analysis.

Regarding Table 8, if we want to maintain the coherence among the three business models (and obtain

17,35€/kWp), the end user should pay **179,35€/kWp** per year to the RESCO.

It is worth to remark that this analysis has been done without taking into account batteries (because they are only envisaged in scenario 3 and would have been difficult the comparison among the 3 scenarios). In addition, all the statistics provided do not take into account batteries.

As mentioned before, this is an analysis based on European average data so the information provided here is only a reference for the viability of the RESCO scenarios proposed within WiseGRID.

5.2 RESCO ORGANIZATION PROCESSES

In order to support the scenarios described above, RESCOs will need to implement different processes. The following subsections describe and analyse each of these processes.

5.2.1 Manage contracts with customers

The most basic process of the RESCO organisation is handling the portfolio of customers. This implies the following operations:

- Registration, management and cease of customers: includes the management of any data required by the RESCO from its customers: name, address, contact information, bank details…
- Contracts associated to a customer: a customer may have several contracts, each of them linked to a particular dwelling (supply point). Contracts may include information such as period of validity, supply point, references of installed assets and contract type (accordingly to the three scenarios S1, S2 and S3)

An important remark is that the type of contract has implications on the point where the equipment shall be installed, and where the energy measurements need to be taken:

- S1: under this contract type, the RESCO trades the whole production of the assets installed in customer premises. It is therefore necessary to measure this production directly from the connection point of the assets – i.e. measurements cannot be affected anyway by the customer’s consumption. In order to cover this assumption and simplify the billing process, it would be necessary that the RESCO contracts a different supply point with the DSO, where all the assets and the corresponding smart meters are connected
- S2: under this contract type, the customer is allowed to self-consume energy and the RESCO trades the production surplus. Two kind of measurements are therefore needed:
    - Production surplus: can be obtained directly from the information provided by the smart meter located at the supply point of the customer. This information is usually retrieved by the DSO, and provided to the customer. Any energy produced at the supply point is property of the RESCO
    - Self-consumed energy: if the contract stipulates a price for the self-consumed energy, it will be necessary to install an additional smart meter to retrieve the whole production data. Self-consumption can be measured by comparing this data with the metering information at the supply point
- S3: under this scenario, the contract basically includes a fee for the renting of the assets, and no metering information is needed

5.2.2 Manage portfolio of installed assets

As already introduced in the previous section, each contract will be linked to a set of installed assets (RES or batteries). The RESCO needs to keep track of the characteristics and status of this portfolio of assets, which involves:

- Monitoring problems: problems may be registered either manually (e.g. notified by customers' calls) or automatically (if the RESCO support system is integrated with assets capable of automatically send alerts or provide status updates). In addition, metering data analysis may also reveal misbehaviours of the installed assets. Feasible techniques to detect misbehaviour on data may include control charts, business rules engines or even machine learning techniques.
- Managing maintenance: RESCO is responsible for the maintenance of the installed assets, and an optimum performance of the assets directly affects the economic revenues of the company. It is therefore important to plan and monitor regular maintenance tasks, as well as react to problems as fast as possible. Integral Maintenance Management tools can help RESCOs to achieve these objectives. A maintenance management system is an ICT system with the purpose of automating the registration and information distribution processes relative to system incidents, supporting management related to human resources, asset inventory, preventive maintenance planning and management and corrective maintenance management among others. Furthermore, a formal maintenance procedure can be economically beneficial to RESCOs, since by knowing the installation date of the assets and their nominal service life, an amortization table per asset can be constructed, thus allowing future planning of replacement. Advanced analysis of metering data against asset life-corrected nominal values of the assets may also help triggering alerts on misbehaving assets.

5.2.3 Manage energy flows

One of the main purposes of the RESCO to obtain economic profit is marketing the production of its assets. Since customer contracts define the ownership of the produced energy, these details will directly influence the energy flows management process of the RESCO. As described before, basically two types of contracts involving energy flows information are foreseen:

- Self-consumption contracts: RES assets provide energy behind the supply point meter, since customers are freely allowed to self-consume the generation. Minimum information required by the RESCO is therefore the metering information of smart meters located at the supply point in order to measure the production surplus that is delivered into the grid, which is the part of the production owned by the RESCO. Since this data is, in principle, collected by DSOs, RESCO will need to sign a contract in which the customer authorizes access to this information. In those cases where the RESCO also bills the self-consumed energy, RESCO will also need to quantize the self-consumption. It will be therefore necessary an additional metering point of the net RES assets production.
- Customers renting their private space to the RESCO: In these cases, the whole production is property of the RESCO. The simplest way to handle those cases is contracting a new supply point with the DSO – directly bound to the RESCO -, where RES assets will inject the production in the LV grid. The smart meter located at that supply point will provide all the necessary information.

A particular case is when the RESCO is installing batteries in customer premises. In this case, the RESCO will be able to offer to its customers those services that are usually provided by ESCOs to large facilities (i.e. peak-shaving, self-consumption, cost minimization…). Batteries on its own can help customers to lower their energy bills, either by reducing demand peaks (by providing power so those peaks are not entirely supported from external supply), or by reserving energy from low-price periods and delivering it as necessary during high-price periods (an integration with a control system optimized fed with tariff prices and capable of adapting battery set points in real time is deemed necessary). When integrated with RES assets, a similar operation can lead to increased self-consumption (and therefore, to reduce the energy bill).

5.2.4 Manage economic flows

Another important process for RESCO organizations is the management of the economic flows. Accordingly to the operations of the RESCO and to the types of contracts defined so far, the following economic flows are identified:

- Investment-related economic flows
    - Investment per installation/customer: RESCO needs to keep track of the investment performed per installation, in order to segment its customers and identify the best commercial strategies to deal with them
    - Assets lifecycle: RESCO needs to keep track of all the costs associated to the maintenance of the installed assets, as well as planning the replacement of the assets at the end of their service life
- Non-energy-related economic flows
    - RESCO renting assets to customers (fixed fee paid by customer)
    - RESCO renting premises from customers for assets deployment (fixed fee paid by the RESCO)
- Energy-related economic flows
    - Billing of self-consumed energy (sold by RESCO to its customers)
    - Billing of energy delivered into the LV grid (sold by RESCO at the wholesale market). At this particular point, a high potential synergy with the VPP aggregators exists, since they both share common objectives and manage similar asset portfolios.

A Decision Support System for RESCOs will need to monitor a number of economic KPIs to help RESCOs identify their best investment options. Some of those KPIs may include, for instance:

- Production per asset type per geographical area: decision support to help the RESCO identifying benefits in promoting certain types of RES at particular geographical areas
- Investment vs Profit per contract, including the Return On Investment: this KPI can help RESCOs to identify the profile of potential beneficial customers
- Investigate beneficial changes in contracts: estimate and compare application of different types of contracts to the same customer, in order to proactively identify and propose changes leading to win-win situation both to the RESCO and its customers

5.2.5 RES production forecasting

Marketing the production of the installed RES is at the core of the business of RESCOs. It is fundamental that the organization is able not only to monitor, but also to estimate the production of its assets in order to facilitate its participation in the wholesale market and the optimal management of its assets.

5.2.6 Market participation

Related with the previous point, tools used by RESCOs shall facilitate the management of all information required by them to sell energy in the wholesale market. This information mainly includes production estimations and real-time monitoring, assistance to calculation of proper offered prices, and management of accepted bids and imposed limits to the generation.

5.2.7 Provision of services to DSO

Due to their ability to monitor and control remarkable amounts of distributed RES, RESCOs are in position to deliver ancillary services to the DSO to collaborate to the stability of the grid. The main service that may be delivered is the flexibility inherent to the RES units and the batteries managed by the RESCO, which may help to accommodate local production to local demand, thus minimizing the power flows managed by the substations owned by DSO, the loses in the lines and the related voltage drop problems. Additional services may include voltage support by smart configuration of the inverters attached to the different RES assets.

5.3 RESCO RELATED USE CASES AND KPIS

In order to deal with the above-mentioned scenarios, one PUC (and its respective SUCs) has been defined in the scope of the WiseGRID project, in order to support the integration of RESCOs in the project:

HL-UC 1_PUC_5_Promote RES via RESCO companies
HL-UC 1_SUC_5.1_RESCO asset inventory, control and maintenance
HL-UC 1_SUC_5.2_Monitor domestic RES production
HL-UC 1_SUC_5.3_Monitor domestic clients consumption
HL-UC 1_SUC_5.4_Manage energy selling
HL-UC 1_SUC_5.5_Energy cost management

Table 9 – RESCO related PUCs.

In order to evaluate the impact of RESCOs in the smart grid environment, 3 KPIs have been defined:

KPI ID	KPI name
1	Increased RES and DER hosting capacity
26	Energy generation capability per investment ratio
46	Self-consumption ratio

Table 10 – RESCO related KPIs

5.4 RESCO ADVANCED FUNCTIONALITIES FOR SMARTENING THE GRID

In light of what is written in the scope of the document, this section is aimed to envisage possible innovative roles for RESCOs to smartening the grid.

The European Strategic Energy Technology (SET) Plan includes some issues to be achieved for improving the energy system in Europe taking into consideration its current transformation [62]:

- The growing share of renewable and decentralized generation,
- The progressive increase in energy efficiency along the whole energy value chain,
- The increasing need for flexibility in the energy system,
- The emergence of the consumer as an active player in the energy system,
- The appearance of new network users (e.g. prosumers)

Thus, the energy system challenges in the SET for supporting these transformations focuses on aspects such as the active consumer, the energy efficiency, the optimization of the energy system and the improvement of the energy supply resources.

In the first one, the EC considers that active consumers must be placed at the centre of the energy system. Therefore, new tools and services like RESCO must provide information to the consumers, improving their perception of their active engagement in the energy system. In this way, demand management techniques for adapting demand and generation will be motivated by a better understanding of their new role, rights, obligations and opportunities.

Concerning the optimization of the system, one of the issues to be promoted refers to improve the flexibility of the energy system by contribution from all the possible energy sources, such as flexible generation (including renewable resources) or cross-energy vector coordination (tools that allows the transportation and/or storage of energy is called energy vector). The RESCO must support these flexibility solutions to have the possibility to be part of new energy markets related to new smart grids services.

Concerning smart grids technologies, the International Energy Agency (IEA) in [63], includes the following categories:

- Advanced metering infrastructure (AMI).
- Distributed energy resources (DERs) categorized into distributed generation (DG), demand response (DR) and storage.
- Customer-side systems, such as home of building energy management systems (HEMS/BEMS), control-centre systems, distribution automation or assets management.
- Cross - cutting technologies, mainly Information and communications technology (ICT) and security and privacy applications.

Taking into consideration these smart grids technologies, IEA includes in the [63], the main products resulting from smart grids (see Figure 32).

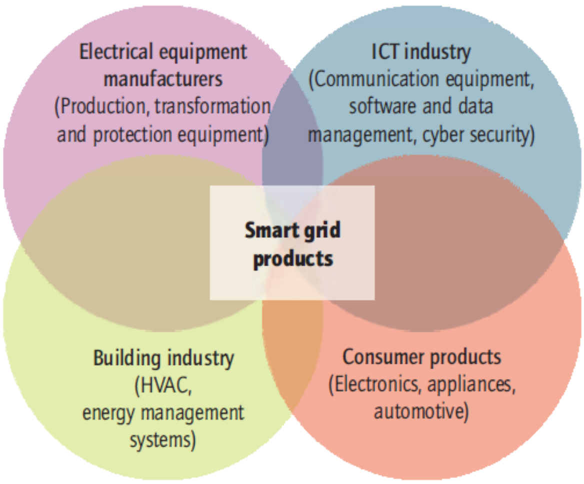


Figure 32 – Smart grid product providers [63]

As mentioned in previous sections, the RESCO will collect and centralize information from small and medium size RES equipment (e.g. PV panels and batteries) that have no visibility by the DSO individually, but which together have a considerable impact in the stability of the network.

In addition, the RESCO will manage equipment from different owners. This characteristic will allow RESCO to share its resources (e.g. storage sharing) and to schedule a more optimal energy flow than the one that will achieve a smaller infrastructure.

These two items will allow the RESCO to contribute to the grid stability by means of managing its energy resources in a proper way and ensure visibility to the DSO (if it is required). Thus, a central challenge for a RESCO will be the proper management of the RES services.

Production uncertainty is typical of the RES that the RESCO will extensively deploy (e.g. photovoltaic, wind power). Having incorrect input information can lead to wrong decisions that can affect to the profits from the RESCO model and the impact on the distribution grid.

In other words, a very effective forecasting module is particularly important for a RESCO. Improvements could be achieved by allowing applications and processes able to select the scope of the forecasting to be used by each application, depending on its requirements (e.g. generation plant, local area, wide area).

Sophisticated forecasting models are therefore envisaged, based on information from the power plants managed by the RESCO itself, making use of information concerning the recorded energy generated by these power plants and weather forecasting conditions from external sources.

Thus, the integration of a RES forecasting module into the RESCO application will contribute to improve the quality of the services offered and the economic viability of the final solution. In particular, RES forecasting will contribute to:

- Improve the maintenance schedule by trying to select maintenance slots with lower expected electrical energy generation (if an operational stop is required).
- Improve the energy market transactions due to a more flexible module that allows obtaining different RES forecasting profiles results depending on the scope (or area) selected by the RESCO.
- Improve the quality and the quantity of the services that the RESCO offers to the end-users (both households and businesses) due to more detailed RES forecasting (more personalized services and more favourable economic transactions).
- Identify low performing plants/equipment in real time without required additional environmental monitoring gadgets that increase the investment and maintenance cost.
- Improved planning for storage use (if any) and/or expansion. In fact, the use of RES forecasting profiles with different scope areas at the same time will allow to share storage resources among different infrastructures placed relatively closed.

In addition, the RES forecasting module will provide to the DSO forecasting profiles for its areas of interest, that do not have to be coincident with geographical areas (e.g. per distribution power lines). Thus, the DSO will be able to perform a better management of its assets and resources using this forecasting division.

5.5 RES AGREGATORS AND ADVANCED BUSINESS MODELS

With the view to European Union's targets, power grids' characteristics have drastically changed, moving from the traditional centralized production and consumption scheme to a more decentralized network operation. This need is driven by the increased penetration of distributed renewable energy sources (DRES), thus making it necessary to propose and develop solutions considering the energy markets' rules and ensuring the advanced operation of the power system.

The connection of DRES in the power system is a challenging technical issue, as the uncertainty related to their availability makes the forecast of their power production difficult. The variability of wind and solar generation can require additional actions to balance the system, so there should be sufficient resources available to accommodate significant up ramps in case of intermittency or down ramps in cases that RES generation is available during low load levels. Solar generation is often more coincident with energy consumption, however, loss of solar generation at sunset cannot meet the evening demand [64]. Additionally, the increased energy imported in the network from DRES poses new challenges to the power grid operation, as over-voltages, reverse power flows, congestions and malfunction of the protection devices are only some of the issues that may arise.

As DRES penetration in power networks is highly desired, mainly due to their environmental friendliness, there is a need to revise the current monitoring and control practices in power networks. To this end, the transmission (TSOs) and the distribution system operators (DSOs) are highly concerned, as they have to guarantee the secure operation of the electrical grid. The technical solutions proposed should focus on the development of control functions and ancillary services provided to markets in order to enable the system operator "to provide the consumers a reliable supply of electricity at an acceptable power quality level and cost" [65].

In this context, the INCREASE project [65] focuses on proposing solutions to increase RES penetration and ensure their normal integration in the power network. Hence, a three-level control architecture was proposed (Local, Overlaying and Scheduling Algorithm) to control the local PV generation regarding the demand response units. The control algorithms were integrated in a simulation platform to test and validate their performance in specific networks in four countries (Austria, Belgium, Slovenia and the Netherlands).

More specifically, local control is responsible for resolving local voltage issues, using advanced PV inverters. Overlaying remote control considers voltage and other measurements needed to provide remote set-points for PV inverters and on-load tap changer transformers. Finally, scheduling control aims to exploit the suggested control strategies by introducing market signals, optimization schemes, etc. [66]. The simulation platform in INCREASE was developed to be used as a software tool for the analysis of smart grids from the DSOs. It performs "simultaneous simulations of the power grid, the distributed intelligent controls and the communication system, using multiple layers" [65], thus facilitating the DSOs to estimate the DRES influence in the network.

In INCREASE [65], the results of the simulations were used to assess the proposed business models using the multicriteria Value Analysis Tool (VAT). This tool "calculates the aspects of control strategies needed for conducting a comprehensive socioeconomic assessment" [65]. VAT uses the available information for financial, environmental, energy generation- and energy security aspects of the proposed solutions and is used as "a decision support tool for policy makers, potential investors in renewable technologies and for market actors" [65], indicating the advantages and disadvantages in terms of costs, involved actors, business performance and regulatory boundaries.

Apart from the technical issues, the economic challenges of the DRES integration should not be neglected. Hence, the investigation of the regulatory framework and the grid code structure is crucial in order to provide reliable ancillary market services for the electricity grid operation and develop flexible market products.

As mentioned above, the presence of DRES in the power grids can cause conventional plants to turn on and off more frequently or to adapt their output levels with the changes in RES production to satisfy the demand. This can result in the increase of both cycling and start-up/down costs. Solutions that provide flexibility to the grid, such as advanced load forecasting, fast dispatch and larger balancing authority areas, demand response services and reserves management are only some of the interventions that can contribute in cost minimization [64]. More specifically, forecasted values for RES production can be considered in unit commitment, as the grid operator can more efficiently commit or de-commit generators when DRES intermittency is predicted. Forecasts can also contribute in reducing the amount of operating reserves, thus reducing the costs for balancing the system. Fast dispatch can overcome the uncertainty in RES energy production as it reduces the need for regulating resources, thus enabling the commitment of the most economical resources. Reserve management practices can be used to lead to substantial cost savings. Such actions can include placing limits on wind energy ramps to reduce the need for reserves availability and enable RES to be used for ancillary services. Limiting up ramps on wind generation can also reduce the need for balancing reserves, as reserve levels are set to cope with large changes in wind output with low probability of occurrence, resulting in lower costs [64]. Wind and solar power plants can also be exploited to provide regulation, inertia, or other ancillary services as they can provide down reserves at very low cost.

RES can also play a significant role in energy markets. As they have near-zero marginal cost their participation in market dispatch leads to a reduction in energy prices. However, this type of market is not sustainable "because some generators may earn insufficient revenue to cover both their variable and fixed costs" [64]. This has led to significant interest in capacity markets. Another option is to provide incentives to generators to operate in a flexible manner. As the objective is to ensure sufficient ramping capability and real-time flexibility, this may require changing the dispatch set points of some generators [64]. Demand response services are also considered as a tool for flexibility. Demand response can be used to supply reserves and ancillary services and can contribute in RES integration, leading to peak demand reduction. For this reason, demand response is considered as a tool to enable higher penetrations of RES in the network. The use of demand response as a real-time flexibility tool to balance the power network ensures the secure operation of the grid in cases of energy deficit or energy surplus. Demand response can also lead to cost savings compared to changing the output of generation units, curtailing energy or maintaining additional reserves.

Another option to achieve flexibility in power networks is by using flexible generating sources. The flexibility of generation units can be calculated "by their ramp rates, output control range, response accuracy as well as minimum run times and off times, startup time, cycling cost, and minimum generation level" [64]. Particular types of generators can operate in a flexible way, by modifying their ramp rates, lowering the minimum generation levels, speeding up start-up, or lowering wear-and-tear costs to facilitate them to perform load following. Natural gas and hydropower plants are more flexible compared to coal and nuclear base-load units, which are among the least flexible. For other generation units, flexibility can be achieved through modifications, or through the addition of new flexible units that implies investment and maintenance costs. Wear-and-tear costs can be mitigated by upgrading equipment and performing preventive maintenance [64].

Markets should be able to define the flexibility needed in real time and predict the desired level of flexibility for future investments. The above described solutions could result in improved efficiency with higher penetrations of renewable energy sources. However, this requires a better understanding of the integration of higher levels of wind and solar energy in the cost mix of generation sources, as well as a better understanding of the value that the various flexibility options and metrics provided in order to decide for the optimal solutions [64].

The role of an aggregator can be a combination of different roles such as "an energy supplier offering aggregation services, a service provider specialized in aggregation services collaborating with a supplier or a joint venture between a traditional supplier and a service provider or by an independent market actor" [67]. When the aggregator is characterized as independent, he can participate in creating more competition in the market, contrary to combined aggregators, which less often support competitiveness, as they are more compatible with the existing market schemes. In the BestRES project [67], a review of the existing business models in Europe for RES aggregation are presented, as the innovative business model suggested in the project is based on them.

In many countries, the regulations concerning the relationships among independent aggregators, balancing responsibility providers and suppliers are not always well-defined. This results in problems concerning balancing and financial compensations for energy suppliers as well as data protection issues. In order to avoid such kind of problems, combined aggregators overcome regulatory difficulties, thus being more compatible with the existing electricity market design [67].

Two business models are investigated in BestRES project for combined aggregators: the combined aggregator-supplier business model and the combined aggregator- Balancing Responsibility Provider (BRP) business model. In the first business model, the aggregator and supplier offers can be combined and offered as a package to the consumer, thus avoiding financial agreements between suppliers and aggregators. This model seems to be a promising one, as there will be no or very few limitations for its development in countries with wholesale electricity market schemes that support competition in markets. In this model, "retailers are in the best position to become aggregators because they have connections to the electricity market and an existing relationship with the customers" [67] . Another option is the combination of the roles of the aggregator and the BRP. In this scenario, "the aggregator has an agreement with the consumers of the supplier and the supplier will have to be compensated for the electricity that was sourced on day-ahead or other markets" [67]. Therefore, the correct calculation of the sourcing costs of the supplier may be difficult. Furthermore, when the aggregator contracts with multiple customers from different suppliers, there might be additionally more practical issues. Finally, it is worth mentioning that the combined aggregator-DSO model is not suggested, as regulated and unregulated roles should not be combined.

As for independent aggregators, their role is of great importance in the increase of competition among market players. In countries where the relationship between aggregators and suppliers is clearly defined through regulations, the implementation and development of ancillary services, demand response schemes, battery storage bids and other types of aggregator services will be facilitated. Nevertheless, the compensation of the supplier for imbalances caused by these services impose new challenges for the suppliers.

For the independent aggregators, three business models are suggested in BestRES: the business model for an independent aggregator as a service provider without any responsibility, the business model for an independent aggregator as a service provider with responsibility, and the business model for a prosumer as aggregator [67]. In the first model, “the aggregator is a service provider for one of the other market actors but doesn’t sell at its own risk to potential buyers” [67]. In this case, the aggregator has no balancing responsibility but the other market actor is the one exposed to financial risks and losses will have to be covered by grid users through tariffs or by other BRPs in the balance settlement. The second business model is similar to the previous one but in this scenario “the aggregator sells at its own risk to potential buyers such as the TSO, the BRP and the wholesale electricity markets” [67]. The actions of the aggregator can influence the position of other market players so interactions between them need to be regulated. It is obvious that the complexity of such interactions will increase in the future because more independent aggregators will participate in the market and more aggregators will make contracts with prosumers that with different BRPs. Finally, commercial and industrial prosumers can also have the role of aggregator for their own portfolios [67].

6 CONCLUSIONS AND RECOMMENDATIONS

Power grid networks all over the world are undergoing profound changes. In the effort of reducing carbon dioxide emissions, electricity is being and will be increasingly produced from variable renewable energy sources (RES), like wind and solar power; a fact that has important consequences for the management of distribution grids: distribution systems will not only continue to face varying electricity demand during the day (statistically predicting loads has always been crucial to grid stability), but will increasingly need to cope with fluctuations in the generation side as well.

Three technological trends - Electrification, Decentralization and Digitalization - are affecting the supporting technologies and the way in which distribution grids are managed (Section 2.1), paving the way towards a system where traditional boundaries between producers, distributors and customers are blurred, increasing the complexity of system governance and posing several challenges to distribution grid management:

- Increasing distributed energy resources requires the real-time management of bidirectional power flows - "Prosumers", since intermittent energy sources, such as wind and solar, must be counter-balanced by "smarter" distribution grids and by energy storage that can provide capacity to the grid when demand is peaking, reducing the mismatch between supply and demand;
- Shifting from centralized to decentralized grid management, while maintaining grid stability and security, implies the need for real-time grid monitoring and for new application/services gathering data from interconnected smart devices that will replace or integrate traditional equipment, in order to improve the level of automation for distribution management operations.

Distribution grid management operations are typically supported by several, interconnected systems: DMS, SCADA, GIS, AMR and ERP (Section 2.2).

A Distribution Management System is at the core of a distribution system ensuring the overall operation of the entire grid or part thereof. This architecture may still work effectively in a scenario of increasing penetration of DER and microgrids in the distribution grid, but all components need to be updated or upgraded extensively in order to support the transition from passive networks to active networks with distributed DER. Real-time monitoring and control through a SCADA system, for example, requires more complex algorithms and more complete data acquisition infrastructures in order to maintain operations reliability and safety. More generally, data and application integration are challenging operations for a DSO that wants to modernize their own heterogeneous existing systems (section 2.3), and our recommendation is that such steps are taken timely and progressively, in order to effectively sustain the benefits that RES intensive bi-directional grids can deliver without compromising grid operation reliability.

However, no matter how sophisticated current management system and techniques can get, at very high rates of RES production the time mismatch between power generation and power demand will inevitably lead to a substantial challenge for the stability of the electrical supply that can only be counterbalanced by energy storage. More generally, integrating and combining energy storage with RES generation (Section 3) could positively affect the management of distribution grid, delivering benefits to grid stability and to DSO operations in two fundamental ways:

- **Energy Management,** decoupling RES generation from its instantaneous consumption (i.e. decoupling power supply and demand);
- **System Services**, supporting quality of services (e.g. power quality) and reliability of power supply.

Several energy storage technologies can be generally deployed today and each of them can be more or less conveniently used in order to improve the quality of service and the security of supply in the electric power system, depending on its own characteristics (such as capacity, energy, efficiency, lifetime and cost - Section 3.1) and location (Section 3.2) in the distribution grid.

Pumped Hydro Storage (PHS) is the most-widely used technology. PHS stations are usually designed for a discharge period of some hours and used to cover peak demand (high energy prices), while being recharged when demand is low (low energy prices). A study conducted by the Aero-Thermo-Mechanics Dept. (ATM), École Polytechnique and the Université Libre de Bruxelles (ULB) in Belgium [20] has found that “the economies of scale that render large PHS installations competitive are not present in small installations” leading to the conclusion that PHS is not suitable for small scale deployment (e.g. residential or district level). In contrast to PHS, thermal and electrochemical storage solutions are already commercially operated in a decentralized manner. PHS stations are hence crucial to ensuring the overall stability of the grid when confronted with large and planned unbalances between instantaneous generation and demand.

However, in case of heavily distributed RES generation grids voltage problems and overloads may occur, due to the high amount of renewables installed. An important feature of energy storage technologies is the ability to provide active and reactive power, enabling frequency and voltage local control. More generally, when installed at a distribution level, distributed energy storage can support ancillary services (i.e. frequency or voltage control), facilitating a further expansion of RES distributed generation. Batteries are probably one of the most flexible storage technologies since they can be deployed in different locations, grid levels and sizes.

As we stated before, smarter distribution grids means real-time grid monitoring and new application/services processing real-time data gathered from interconnected smart devices. Distribution networks are traditionally operated with pre-set control strategies to meet the forecast load (Section 4.1), but a set of wide ranging phenomena such as new attitude from consumers, new digital technologies, emission regulations, increasing RES integration and others are making existing systems and processes obsolete. Transformers, feeders, substations, and other grid components are requiring higher accuracy monitoring tools and a more dynamic approach to their operation, in order to maintain safe and close to optimum performance. The usual approach of any utility to this problem is to design and install a complex DMS collecting and processing data from all sections of the grid in order to allow operators to timely plan and execute complex operations to increase system efficiency, optimize power flows, prevent overloads and avoid unplanned outages (Section 4.2). Thus, in order to provide innovative operations, DSO need to collect more data, more frequently and from a larger set of equipment to allow a timely visibility of network issues (improved monitoring). As more devices get connected to the network, assessing the state of an increasingly complex distribution network will require a shift toward "Big Data" approaches and technologies, in order to timely process large amounts of information (e.g. early detection of grid problems gives more time to respond before these weaknesses extend to greater security or reliability issues).
Unbundled Smart Meter is a device that enables consumer-side, real-time information gathering for improving DSO operations and overall network functionality. Today, smart meters are characterized by complex functionalities such as Active and Reactive energy measurement and complex tariff implementations, to name a few (Section 4.3).

As we already stated, smarter grid management and distributed storage could help in counterbalance the challenges for stability of supply due to distributed RES generation. Renewable Energy Service COmpanies (RESCO) provides RES services (usually photovoltaic, wind power or micro-hydro) to end-users (both households and businesses) that do not own nor wish to maintain the necessary equipment. A natural extension of the RESCO business models (Section 5.1) involves providing batteries in addition to RES equipment. If this happens, RESCO may also play an active role in grid balancing, offering advanced service to the distribution grid: due to their ability to monitor and control remarkable amounts of distributed RES, RESCOs are in the position to deliver ancillary services to the DSO and collaborate to the stability of the grid (Section 5.2). The actions to be undertaken by RESCO in case of a voltage problem/congestion or any other request by the DSO have been addressed in the WiseGRID project: keeping voltage levels in acceptable boundaries with RES or DER implications, while reducing network losses and signalling possible network congestions, is addressed in the following WiseGRID Use Cases:

HL-UC 1_PUC_3_Voltage support and congestion management
HL-UC 1_SUC_3.1_Provide local U control through P-Q flexibility of RES inverters (Centralized)
HL-UC 1_SUC_3.2_Provide local U control through P-Q flexibility of RES inverters (Decentralized)

HL-UC 1_SUC_3.3_Improve voltage symmetry between the phases

Table 11 – Voltage support and congestion management Use Cases.

While RES energy management is addressed in the following use cases:

HL-UC 1_PUC_5_Promote RES via RESCO compagnie
HL-UC 1_SUC_5.1_RESCO asset inventory, control and maintenance
HL-UC 1_SUC_5.2_Monitor domestic RES production
HL-UC 1_SUC_5.3_Monitor domestic clients consumption
HL-UC 1_SUC_5.4_Manage energy selling
HL-UC 1_SUC_5.5_Energy cost management

Table 12 – RES Energy management Use Cases

The main service that may be delivered is the flexibility inherent to the RES units and the batteries managed by the RESCO, which may help to match local production with local demand, thus minimizing the power flows managed by DSO substations, energy losses along the lines and related voltage drop problems. Additional services may include voltage support by smart configuration of the inverters attached to the different RES assets (Section 5.4). The integration of a RES forecasting module into the RESCO management system will contribute to improve the quality of its services and, providing to the DSO prediction profiles of its areas of interest, also the DSO will be able to perform a better management of its assets and resources

In conclusion, innovation has the potential to reshape and redesign the energy sector while also benefiting the customers and the environment. Distributed RES generation, smart meters, smart appliances, electric vehicles and distributed generation combined in-situ with distributed storage will all provide promising options. We expect decentralised storage to be owned and operated by market actors. Albeit we are keen on the future role of distributed storage, while it is absolutely true that Smart Grids can benefit from decentralised storage, the economics of decentralised storage and the potential drawbacks at equipment renewal are not yet completely solved. That is why for policy setting purposes the storage option has to be considered against simpler alternatives such as concentrated storage (water reservoirs) and demand response management techniques.

Decentralised storage will potentially provide a good opportunity for distributed investments. However, the technical and financial viability of investments in storage systems is still too complex and risky to be autonomously undertaken by most final users (prosumers). This situation may provide a further role for RESCO, a subject that will be optimally positioned to act as a large actors able to shield final users from excessive complexities: if RESCOs are able to alleviate the regulatory and technical management burden for smaller actors (prosumers), distributed storage may get a boost and result in the availability of new Energy Management and system services for the Smart grid.

7 REFERENCES AND ACRONYMS

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7.2 ACRONYMS

Acronyms List	
ADN	Active Distribution Networks
AC	Alternative Current
ALRS	Automated Loop Restore Schemes
AMI	Advanced Metering Infrastructure
AMR	Automatic Meter Reading
GHG	Greenhouse gas
AOR	Area of Responsibility
ATM	Aero-Thermo-Mechanics
CA	Contingency analysis
CAES	Compressed air energy storage
CAIDI	Customer Average Interruption Duration Index
CAPEX	Capital Expenditures
CIS	Customer Information Systems
COSEM	Companion Specification for Energy Metering
CVC	Centralised Voltage Control
CVR	Conservation Voltage Reduction
DC	Direct Current
DER	Distributed Energy Resources
DG	Distributed Generation
DLMS	Device Language Message Specification

Acronyms List	
DMM	Data & Model Management
DMS	Distribution Management System
DNO	Distribution Network Operator
DPF	Distribution Power Flow
DRMS	Demand Response Management System
DSM	Demand-Side Management
DSO	Distribution System Operator
DSS	Distributed Storage Systems
DTS	Dispatcher Training Simulator
DVC	Decentralized Voltage Control
ELS	Emergency Load Shedding
EMS	Energy Management System
ERP	Enterprise Resource Planning
ESB	Enterprise Service Bus
ESCo	Energy Service Company
ESS	Energy Storage System
ETL	Extract-Transform-Load
EV	Electric Vehicles
FACTS	Flexible Alternating Current Transmission System
FDIR	Fault Detection, Isolation and Service Restoration
FLISR	Fault location, Isolation and Service Restoration
FPI	Fault-Pass Indicator
GHG	Greenhouse gas
GIS	Geographic Information System
GPRS	General Packet Radio Service
HEMS/BEMS	Home of Building Energy Management Systems
HMI	Human Machine Interface
I	Current, Intensity
ICT	Information and Communication Technologies
IEA	International Energy Agency
IED	Intelligent Electronic Device
IT	Information Technology
KPI	Key Performance Indicator
LCOE	Levelized Cost of Electricity
LCOS	Levelized Cost of Storage

Acronyms List	
LE	Load Estimation
LM	Load Modelling
LP	Load Profiles
LQR	Linear Quadratic Regulator
LV	Low Voltage
MDM	Meter Data Management
MTU	Master Terminal Unit
MV	Medium Voltage
OCP	Optimal Capacitor Placement
OECD	Organisation for Economic Co-operation and Development
OLPF	On-line Power Flow
OLTC	On-load Tap Changer
OMS	Outage Management Systems
ONR	Optimal Network Reconfiguration
OPEX	Operating Expenses
OVP	Optimal Voltage Regulator Placement
P	Active power
PC	Project Coordinator
PCM	Phase Changing Materials
PCS	Power Conversion System
PFC	Power Factor Control
PHS	Pumped Hydro Storage
PLC	Programmable Logic Controller
PLC	Power Line Carrier
P2G	Power to Gas
PQ	Power Quality
PUC	Primary Use Case
PUF	Physical unclonable Function
PV	Photovoltaic
Q	Reactive power
R	Resistance
RBAC	Role-Based Access Control
RES	Renewable Energy Sources
RESCO	Renewable Energy Service Company

Acronyms List	
RPC	Relay Protection Coordination
RSA	Restoration Switching Analysis
RTU	Remote Terminal Unit
S	Apparent power
SAIDI	System Average Interruption Duration Index
SAIFI	System Average Interruption Frequency Index
SCA	Short-Circuit Analysis
SCADA	Supervisory Control and Data Acquisition
SE	State Estimation
SET	Strategic Energy Technology
SLAM	Smart Low Cost Advanced Meter
SM	Smart Meter
SMES	Superconducting Magnetic Energy Storage
SMM	Smart Metering Management
SMX	Smart Metering Extension
SOA	Service Oriented Architecture
SOM	Switch Order Management
STATCOM	Static Compensator
STLF	Short-Term Load Forecasting
SUC	Secondary Use Case
TCS	Thermo-Chemical-Storage
TP	Topology Processor
TSO	Transmission System Operation
UI	User Interface
ULB	Université Libre de Bruxelles
USM	Unbundled Smart Meter
V	Voltage
V2G	Vehicle to Grid
VAR	Voltage Ampere Control
VC	Voltage Control
VVO	Volt/VAR Optimization
WEF	World Economic Forum
X	Reactance

Table 13 – List of Acronyms