The Road Map on Go4Flex

Grid observability

for

Flexibility

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Acknowledgements

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Authors:

Ewa Mataczyńska, PGE Dystrybucja Poland, TF1 co-chair,

Juan Martí Rodríguez, I-DE, Spain, TF1 co-chair,

Sjors van der Heijden, Stedin, the Netherlands,

Jan Kula, CEZ Distribuce, a. s., Czech Republic,

Manolis Voumvoulakis, HEDNO, Greece.

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Executive summary

The transformation taking place in the world's energy systems represents one of the greatest technological challenges that industrialized societies have undertaken. The transformation of a network designed to distribute electricity from intermittent generation sources, while involving millions of additional participants using advanced technologies, will introduce a high degree of uncertainty and variability into the future electricity network. These changes potentially threaten the security of the electricity supply and must be carefully planned to avoid a risk to the reliability and quality of supply. Electricity distribution is fundamentally changing due to variable generation from wind and solar power plants and the new loads on the consumers' side. This requires a new operating paradigm in which the operational decision-making cycles of distribution system operators (DSOs) are complemented by new mechanisms to deal effectively with the rapid development of distributed energy resources (DER). Operational control of the grid is and will be challenging due to the uncertainty associated with intermittent RES, but also with a large amount of dynamic data flows as control becomes more distributed and adaptive. Therefore, new network operating systems are needed that follow the basic principles of control theory - observability, controllability and algorithms. Currently, full observability of the distribution network is achieved at the HV level. The MV level of the network also seems to be well equipped with elements enabling observability, but in this case, full observability comparable to the HV level network cannot be spoken of. The observability at the LV grid is rather low (depending on the country and observability definition). This is mainly because LV networks have the complexity of topology with many connection points for both generators and loads. The complexity, among others, depends on the density of consumers in the area supplied from a single secondary substation and customers' power connection needs. Nevertheless, certain observability mechanisms based, for example, on equipping secondary substations with balancing meters are allowed, for the time being, to allow operational activities to be carried out in such a way as to ensure stable network operation.

What is more, controllability whitens changing market designs and network operating systems based on dynamic algorithms is not a permanent feature of network management. The challenge is that the algorithms are not easily adaptable to the unique physical characteristics of the electricity grid. Furthermore, system complexity increases with the surface of cyber-attacks. Architectures, design and development methods associated with very large and complex systems are required to meet current growth trends and policy objectives for renewable and distributed resources. The potential scale and scope of diversity require operators and systems to have greater location awareness to effectively manage rapidly changing conditions. Observability in this context is a measure of the effectiveness of network sensor data in determining system-wide behaviour. Variability occurs over shorter time cycles and a much larger area. This requires the development of an observability strategy to make network state information visible at a higher frequency and with the optimal data set to determine the overall behaviour of the electrical system. These requirements arise from the demands of protection and control systems and related market operations, the main element of which is the use of flexibility services in the network management process.

This report describes identified elements of network observability that are important in the process of managing flexibility sources for network operation. A general approach to the meaning of flexibility for DSOs in combination with network observability has been created. A generic roadmap scheme has been proposed to identify the relevant elements of observability for managing flexibility sources in a way to unlock their potential.

The text and figures presented in this report were prepared by the E.DSO TF1 ANM members, based on their expert knowledge. The main information concluded in this report is also presented in brochures published for a wider range of market participants.

1. Introduction

Development of the energy market is inevitably moving towards significant decentralization on the generation side, expansion of RES (renewable energy sources) and the need for more efficient local technical grid balancing. At the same time, the increasing availability of new technologies and market incentives will accelerate customer activation. The above elements are not insignificant for the conditions of DSOs' activity related to network maintenance and development. The increasing number of DER including energy storage, growing demand-side flexibility, prosumers, microgrids and electric vehicles, resulting in bidirectional and, what is particularly worth emphasizing, difficult to forecast, energy flows in the network, which affects the current operational management of the distribution network and its development planning. This implies the need to adapt the currently functioning technical and organizational solutions which, on the one hand, support the activation of consumers and, on the other hand, enable coping with new challenges in a manner ensuring stable operation of the network. The future role of DSOs will be to manage the grid in such a way that active entities connected to the grid actively use the power system enabling the minimization of grid limitations, e.g., related to the capacity of grid components or the quality of energy itself (e.g. voltage level), while at the same time receiving remuneration for actions taken for the benefit of the grid operator.

Such a broad spectrum of network user behaviour, combined with the concept of sector integration (and sector coupling), requires DSOs to adequately manage the network infrastructure. Thus, network observability with access to and processing of current information (on the status of network elements, topology, flows and behaviour of entities connected to the network) becomes a very important area. Multi-level analysis of available information/data will create additional opportunities for DSOs to purchase, all kinds of services provided by entities connected to the grid, to increase the efficiency of current grid operation management and high-precision planning of grid development.

If the design of the system does not provide a sufficient level of available flexibility, or if there are unforeseen, rapid changes in the conditions under which the system operates, the existing flexibility resources in the system become too small to guarantee its stable operation and ensure continuity of supply. Of course, the process of rebuilding the existing network resources can be started, by increasing them according to the planned demand/generation. However, designing and building new substations, and distribution lines may take several years, and it leads to huge financial outlays. Moreover, often as it happens under time pressure resulting from dynamic changes in the market environment, actions should be taken immediately to protect the system against extensive blackouts. Thus, the planning process is a key first step to ensure that the future electricity system has sufficient flexibility to accommodate the growth of variable generation from renewable energy sources (RES). In the absence of sufficient transparency for planning or investment, the resulting power system may not have the flexibility to operate effectively. In this case, other sources of flexibility should be used, available among the end users connected to the system.

The high level of system integration will not be possible without profound digitalization. The consequence of digitalization is the need for proper management of operational data used in the processes by system operators, which is the main element of grid observability.

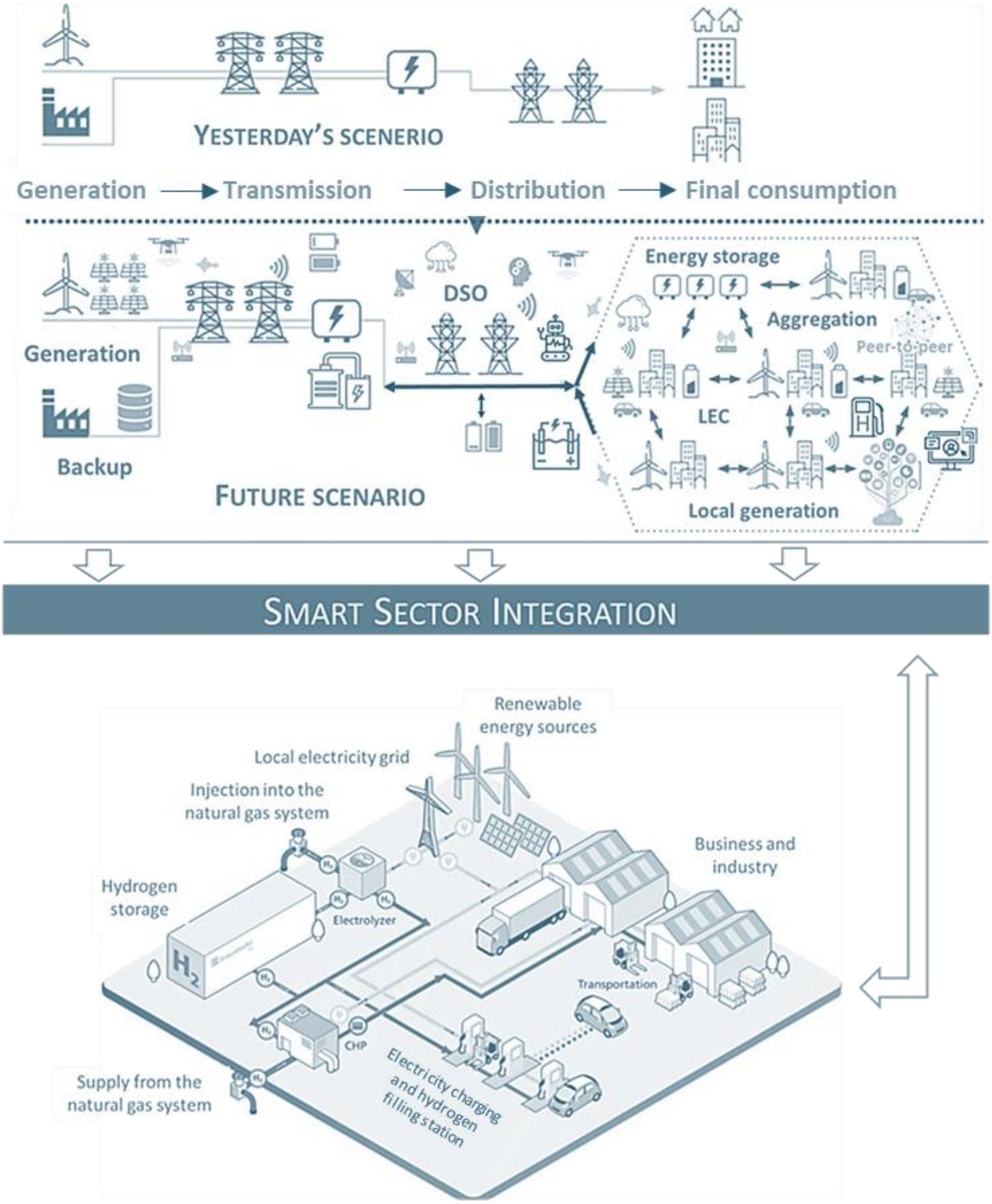


Figure 1. Future scenario of energy market model with hydrogen society integration as a part of smart sector integration[1].

[1] *Innovation landscape for a renewable-powered future*, IRENA, February 2019; *Wykorzystanie usług elastyczności przez Operatora Systemu Dystrybucyjnego*, XXV Konferencja Naukowo-Techniczna Rynek Energii Elektrycznej Kazimierz Dolny 7-9 październik 2019, E.Mataczyńska, M.Sikora, W.Lewandowski; *Representation of the integrated, networked nature of a 'hydrogen society'*, Fraunhofer IFF.

1.1. Background and scope

Documents which describe the general background of the flexibility issue, i.e. why it is an important topic and what it entails, point to the rapid development of distributed generation such as installations producing electricity from renewable sources, like photovoltaic panels or wind turbines. These two types of installations are mentioned because of their specific made of power production, which is dependent on both the time of day and the weather conditions. A such generation often referred to as unstable, can cause problems in ensuring the security of supply, i.e. continuity of energy supply while maintaining its parameters at the required level. That is why the concept of flexibility in the electricity system and related products and services is important. These mechanisms are seen as supporting the network, deferring investments over time or strengthening the network. Consequently, it can be concluded that flexibility might be considered as an antidote to nearly grid problems that result from the emergence of variable, "hard-to-predict" generation from RES installations as well as a new type of unpredictable demand.

Unfortunately, flexibility mechanisms are not the solution to all such problems. Of course, they are an element that, if used effectively, could support the electricity system, but they cannot replace the necessary upgrades and expansions as well as traditional development of the grid, which are usually said to be very costly. However, it is worth emphasizing that issues related to flexibility are the element which, in the initial phase of implementation, will be associated with considerable financial outlays, resulting both from equipping the network with additional devices monitoring its operation and IT systems processing the information to make decisions on whether or not to use market based flexibility services. Expenditures will also concern the provision of communication systems with remotely controlled network elements at a high level of confidence. Furthermore, the rapidly growing amount of various data will require not only adequate hardware resources to store them but also mechanisms ensuring the high security of these data. This includes all necessary to be incurred to implement mechanisms using flexibility coming from the system, i.e., technical, as well as market flexibility coming from the behaviours of market participants. It should be remembered that distribution system operators are regulated companies, and their revenues allowing for investments depend on the adopted model of regulation[2] and the level of rates approved by the energy regulator in their tariffs.

The report presents an approach to different types of flexibility from the perspective of actions carried out by the distribution system operators in the process of maintaining stable network operation. It also underlines the importance of network observability in the processes related to technical (operational) flexibility, but also the mechanisms that should be considered when shaping the processes applicable to market-based flexibility.

The first chapter describes different definitions of the flexibility term, indicating its possible divisions and the relevance of these divisions for the distribution system operator as well as its daily work. To talk about flexibility, it is necessary to know the possible sources of flexibility. Therefore, examples of flexibility sources have been described in a general way. The flexibility services term is also described as a market-based mechanism to obtain additional flexibility from the system. The concept of active network management is adapted from a report that was drafted in 2018 by the E.DSO TF1 ANM. The report also presents the concept of network observability. An important element of this chapter related to the presentation of the set of elements that define the set of components for the integration of flexibility sources for the operational needs of DSOs. A

[2] According to DIRECTIVE (EU) 2019/944 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 5 June 2019, Art. 32 (2) *Distribution system operators shall be adequately remunerated for the procurement of such services to allow them to recover at least their reasonable corresponding costs, including the necessary information and communication technology expenses and infrastructure costs.*

clear and understandable interpretation of the main concepts is an essential element of the entire report.

The second chapter indicates the flexibility needs of the network, thus describing the main areas of the DSOs' activities in the use of flexibility sources.

A general approach to flexibility, its activation and network observability is described in the third chapter of the report. The description is made separately for each voltage level: HV, MV, LV and as an additional element the potential future appearance of the low voltage network is included.

Then next chapters attempt to combine the above elements into a single picture describing the scheme of approach to observability from the perspective of utilising the flexibility sources as the framework of the Road Map for Go4Flex (Go for flexibility or Grid Observability for flexibility). To take advantage of the available flexibility sources, it is necessary to create the conditions under which this will be possible. Grid observability creates the basis for making it possible. The tools and the ability to management of network operations with the available observability level are the main points of the report. However, the report does not define a minimum level of observability necessary to deploy flexibility sources.

1.2. Definitions: flexibility, flexibility services, ANM, grid observability

The main issues related to the substance of the report will be based on a certain predefined range of terminology. Because the existing literature on flexibility is extremely broad, but at the same time describes flexibility issues from different perspectives, the following chapter presents definitions of selected terms from the point of view of the whole report. To understand the concepts that will form the basis of further study, necessary descriptions and clarifications have been made especially regarding the concepts of flexibility, flexibility sources, flexibility services, Active Network Management (ANM) and grid observability.

1.2.1. Flexibility

There are a lot of flexibility definitions in the subject literature that define the term:

- *Flexibility of operation – the ability of a power system to respond to changes in demand and supply – is characteristic of all power systems. Flexibility is especially prized in twenty-first-century power systems, with higher levels of grid-connected variable renewable energy: primarily, wind and solar*[3].
- *Flexibility – the ability of a power system to respond to changes in demand and variable generation*[4].
- *Flexibility expresses the extent to which a power system can modify electricity production or consumption in response to variability, expected or otherwise. In other words, it expresses the capability of a power system to maintain a reliable supply in the face of rapid and large imbalances, whatever the cause*[5].
- *Flexibility is defined as the modification of generation injection and/or consumption patterns, on an individual or aggregated level, often in reaction to an external signal, to provide a service within the energy system or maintain stable grid operation. The parameters used to characterise flexibility can include: the amount of power modulation,*

[3] Clean Energy Ministerial, *Flexibility in 21st Century Power Systems*, NREL/TP-6A20-61721 May 2015, https://www.nrel.gov/docs/fy14osti/61721.pdf ,

[4] Bonneville Power Administration, Technology Innovation Project, *Strategic and Flexible Transmission Planning*, TIP 256: EPRI P40.019, v.3.1, December 2014
https://www.bpa.gov/Doing%20Business/TechnologyInnovation/TIPProjectBriefs/2015-TIP-256.pdf

[5] International Energy Agency (IEA), *Harnessing variable renewable A Guide to the Balancing Challenge s.*, Tech. rep.; 2011, s. 37

generation forecasts, duration, rate of change, response time, and location. The delivered service should be reliable and contribute to the security of the system)[6].

Flexibility is especially important in systems with a higher share of renewable sources of energy (mainly wind and solar) changing over time. Flexibility enables connected entities to exchange energy with the grid as needed and possible, by using the natural ability of grid elements to carry loads that vary over time. A fundamental distinction needs to be made between flexibility applied /offered by market participants and flexibility applied by network operators. In the context of market participants, flexibility always refers to activities performed under the influence of external, mainly commercial, incentives. In the case of System Operators (SO), it results from the obligation to ensure effective planning and efficient operation of the network. This type of flexibility is related to the security of supply and quality of service. Such flexibility can help system operators maintain the expected level of network performance if the network is under system constraints.

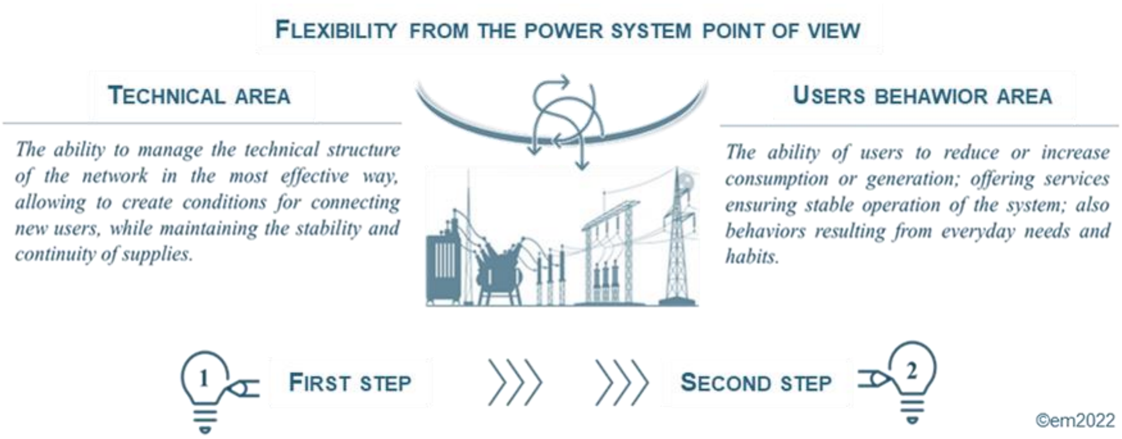


Figure 2. Flexibility from the power system point of view

Flexibility regarding the power system is not a new phenomenon, however, for the need of the report, the term concerns **the system's ability to react on a current basis to any changes in both demand and supply, which theoretically could have an impact on maintaining the stable operation of the distribution system.** The system is understood as a distribution operation area or as a part of it, that is, a certain part of its local area.

Taking the above into account, three basic types of flexibility could be distinguished, namely:

a) **Grid (technical/operational) flexibility** (network operation, congestion management and day-to-day operation) is the reaction of the system to disturbances of mainly local character (voltage, current - overload), activation by voltage and current signals (from overloaded lines at HV/ MV, use of systems commonly referred to as dynamic overload line (DOL) in the HV network) supported by communication at the operator level (automatic, or in the dispatcher mode), triggering changes in the generation schedule, generation or consumption of reactive power, changes in transformer tap changer position, network switching. This type of flexibility is a basic element in the system operation, implemented operationally in the current operation of DSOs.
Grid flexibility is closely related to the physical structure of the system and refers to the combination of technologies that determine[7]:

[6] CEDEC, EDSO, eurelectric, GEODEC, *FLEXIBILITY IN THE ENERGY TRANSITION. A Toolbox for Electricity DSOs*, https://www.edsoforsmartgrids.eu/wp-content/uploads/Flexibility-in-the-energy-transition-A-tool-for-electricity-DSOs-2018-HD.pdf, February 2018
[7] IRENA, Power system flexibility, November 2018

- the ability of supply to following rapid changes in net load,
- the ability of demand to follow rapid changes in supply,
- the ability of energy storage to balance mismatches between supply and demand at all-time scales,
- adequate grid infrastructure to allow the least-cost supply to reach demand at all times, anywhere in the power system.

b) **Market flexibility (flexibility services)** in the form of commercially available flexibility services offered by eligible market flexibility sources. This type of flexibility is activated at the moment when the level of operational flexibility is not able to cover the needs of the system in maintaining stable operation. This type of flexibility is complementary to the technical/ operational activities carried out by the DSO. The level of its use will depend, inter alia, on the regulations and incentives allowing the use of market mechanisms by the DSOs, the economic justification, and the availability of flexibility services on the local market.

c) **Investment and planning flexibility** (network development plan) is a long-term measure which eliminates the financially rigid approach to investment planning and major overhauls of energy infrastructure (generation as well as network); there is no physical activation here, investment and development plans assume that loads on existing equipment can be flexibly adapted to operating conditions, and thus the process of replacing them with new ones can be postponed or the scale of modernisation can be smaller. This type of flexibility should consider both, technical and market flexibility.

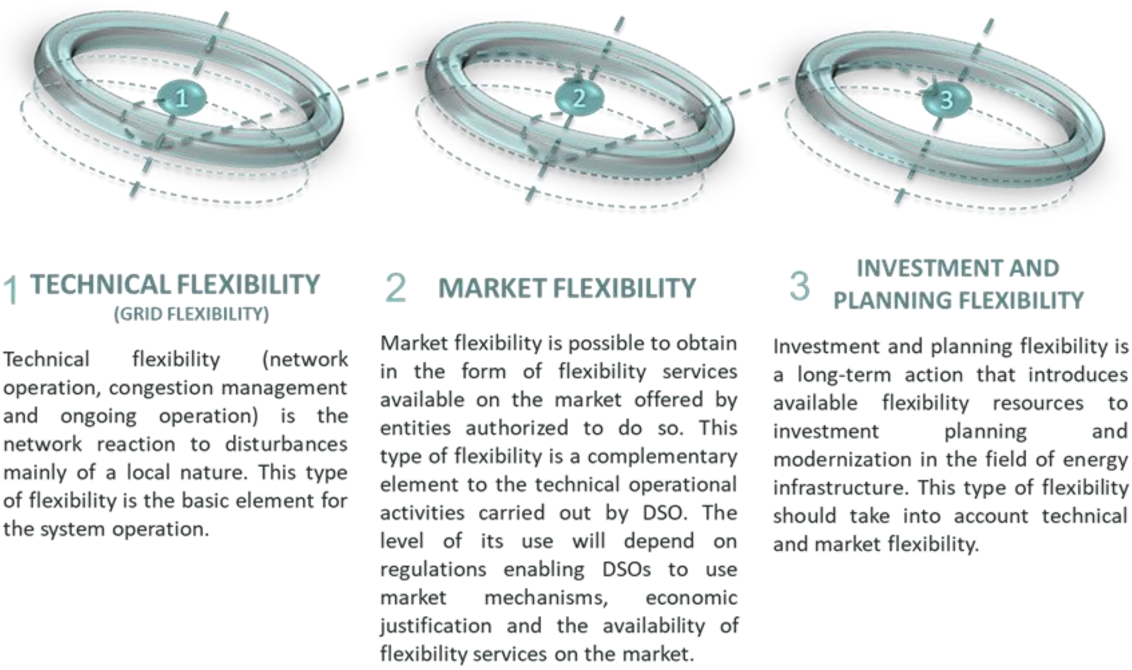


Figure 3. Basic types of flexibility.

There is sufficient flexibility in the electricity system to accommodate additional variability, but this flexibility may not be fully available without changes in the operation of the system or other factors such as institutional ones. A wide range of electricity system components affects system flexibility, from assets at the distribution level to generation characteristics, operational practices, regulatory tools, or customer activity levels. Although there are many emerging measures of flexibility and methods of assessing it, there are no standard metrics and indicators for flexibility and them ones already are still evolving due to rapid technology changes.

The use of flexibility services by the operator is an activity that will be undertaken when the technical capacity of the network is insufficient to cope with emerging problems. Moreover, the flexibility services procurement must be economically justified and preceded by well-drafted network development plans, which will take into account, in addition to expansion and modernisation, the use of available flexibility sources if this is economically more efficient.

1.2.2. Flexibility sources

Decentralized flexibility sources are comprised of different load sources with a wider variety of technical capabilities and economic characteristics to provide flexibility services. Different flexibility sources require different types of regulations, support, delivery methods and communication techniques for the most effective way to facilitate the network. Different types of sources may desire to participate in different markets according to their source characteristics. For example, EVs would suit providing short-term flexibility services, as the opportunity costs would increase substantially once EVs are aggregated and start providing bulk energy to markets.

Characteristics of flexibility sources entail the ability of the sources to respond to service requests in volume, time, availability, and cost. Also, they entail the response of the sources exhibited after the service provisioning is ended such as recovery time and rebound effect.

The chapter presents selected flexibility sources that may provide flexibility services to the DSO. These include:

- grid as a source of flexibility,
- PV and wind generation,
- storage systems,
- reactive power compensation,
- aggregators, energy communities, microgrids,
- controllable load (DSR), active customers,
- heat pumps and EVs,
- electrolysis.

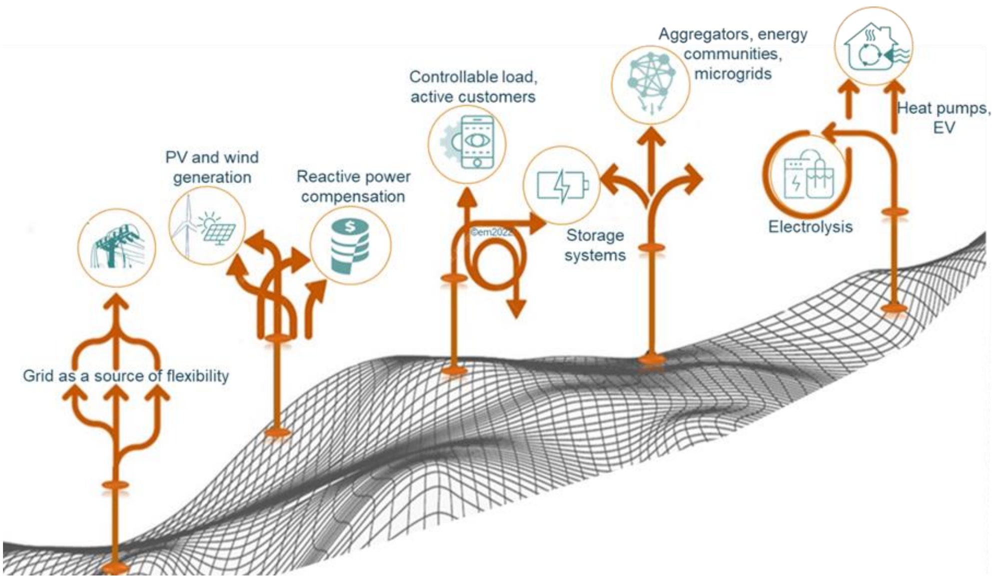
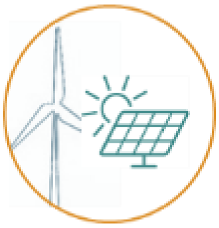


Figure 4. Selected flexibility sources that may provide flexibility to the DSO

Grid as a source of flexibility

Grid as a source of flexibility is closely related to the physical structure of the system. It also refers to the existence of advanced controls to enhance communication among system elements that enable, for example, automated control of generators, automatic activation of demand response or advanced power flow control, switching on the network topology, and manual/automatic regulation of transformer taps.

Observability: Smart meters in stations/substations/consumers - measurement of basic values. Balancing meters to determine the level of balancing of the area. Devices/sensors/systems to monitor line overloading, voltage levels, and data analysis systems. Advanced and stable communication system and data acquisition, storage and analysis necessary. Remotely controlled switches enable remote network reconfiguration. Physical measurements (P, Q, U, I) in the SCADA system are available at the line paths of the station, and deeper within the network. Balancing meters at substations. Measurement observability for generation units of RfG type B and C in the SCADA system and the possibility of remote power control at the level of HV and MV.



PV and Wind generation

At HV current overloads are the most important, which can occur in summer conditions, with strong wind, but in sheltered sections. For the most part, these risks are hypothetical, and it is possible to control them by means of DOL systems on lines and possible activation of generation limits.
At MV and LV with a large number of RES, voltage disturbances related to voltage peaks at the point of connection and in its surroundings (deep in the network) are more significant. There are a number of countermeasures, the most radical being RES generation curtailment (automatically activated, adjusted to the requirements of safe grid operation).
Whereas solar PV and wind power are clear drivers of the increase of daily and weekly flexibility needs, the seasonal flexibility needs depend on several factors that might have different and sometimes opposing impacts on its value:

- The thermo-sensitivity of power demand (which may vary by country depending on the portfolio of heating technologies, the importance of air conditioning, etc.)
- Solar production (which varies during seasons and therefore can increase or decrease flexibility needs depending on the demand profile of each country). For a country with high demand during summer, solar production can decrease seasonal flexibility needs whereas for countries with lower summer demand it will increase these seasonal flexibility needs.
- Wind production (usually higher during winter so it tends to reduce seasonal flexibility needs for most countries, which typically have higher demand during this time of the year).

Observability: All RES injecting energy into the grid (large installations, micro installations, prosumers) should be equipped with smart meters capable of recording and retrieving the necessary metering data (parameters) remotely, preferably in near real-time or on-line mode. Such metering should exist independently of the grid level. For prosumers who would like to participate in the flexibility market, it should be possible to install remote control modules for energy input and inverter configuration (cos angle and active power control) as well as protection systems for automatic disconnection in case of island generation

Storage systems

Ancillary services are separated between balancing and non-frequency services, while grid management services (for congestion management) are the third category. Network operators play a central role in procuring these services as they are tasked with guaranteeing the system's security. It is generally acknowledged that storage can provide similar services to the system similar to other flexibility sources and should hence be treated equally in a technology-neutral approach. However, an equal approach may constitute a barrier to entry if the technical characteristics of storage, such as more limited discharge durations, are not properly considered when designing the products to be procured. The possibility of storage to provide non-frequency ancillary services is even rarer than balancing services. Participation of storage in grid congestion management is at present limited to pilot projects focusing on battery systems. Albeit limited in scale, these projects are taking place in the multiple Member States, in recognition of the modularity and controllability of the technology. Nonetheless, national regulations in the many Member States still need to provide a level playing field for the procurement of such services by DSOs, while guaranteeing that all flexibility resources are in network development plans considered equally with network expansion.

Observability: pre-metered storage with smart meters with remote reading in near real time or online. Data from storage systems on the level of charge (kWh,%) is available to the network operator when this storage is participating in the flexibility market.

Reactive power compensation

Reactive power compensation is one of the well-recognized methods for its contribution to transporting electricity to customers with required standards of efficiency, quality and reliability, minimizing energy losses and improving transport processes. The proper integrated control of the reactive power flows and the voltage profile in distribution grids has become a very serious problem of complex solution, due to the characteristics of the distribution grids. Any mistake in the location and dimensioning of reactive compensators can lead to the circulation of unwanted reactive power flows, which would affect the variables that determine the efficiency and quality of the energy. Distribution grids with distributed resources require a multi-criterial analysis due to the conflict that may exist between variables when it is sought to compensate for active power from renewable generation specifically from solar photovoltaic sources.

The global analysis of electricity distribution with efficiency and quality is a complex process that depends on multiple criteria because these systems present different types of grid topologies, different construction and configuration characteristics, multiple connections, loads of different natures as well as lines without transpositions[8].

Observability: according to accepted rules for a given voltage level.

[8] A.Aguila Tellez, G. Lopez, I. Isaac, J. W. Gonzalez. Optimal reactive power compensation in electrical distribution systems with distributed resources. Review. Heliyon 4 (2018) e00746. doi: 10.1016/j.heliyon.2018. e00746 https://doi.org/10.1016/j.heliyon.2018.e00746 2405-8440/Ó 2018 The Authors. Published by Elsevier Ltd. This is an open access article under the CC BY license (http://creativecommons.org/licenses/by/4.0/).

Aggregators, Energy communities, Microgrids

The aggregation of customers is a collaboration through a dedicated IT infrastructure provided by the aggregator. From a network point of view, the local impact is not noticeable. The effect of the activity of the aggregated group (or groups) may be visible at a higher level of the network, thanks to the cooperation with the operator it is beneficial and does not lead to negative grid phenomena.

The aggregator may conclude a contract with the DSO and the energy supplier for specific behaviours of the aggregated group of consumers. They can also be flexibility services (differently understood and differently activated). If the aggregator's actions are effective, it is possible to obtain the scale effect.

An unbalanced community based on a RES network infrastructure has no particularly perceived impact on the network; it is analogous to distributed generation units connected to the MV and LV networks. A well-balanced community, dispersed in terms of area, also does not cause significantly additional network effects. A community based on its network infrastructure causes reduced power flows at the points of connection with the DSO network.

In addition, a community with power potential, e.g., in the form of energy storage, may be important for DSOs as a source of flexibility. The Communities can take advantage of the offer to shape a flexible accident load profile, provided that remuneration for this service will provide them with revenues that offset the distribution fees to DSOs, which should be incurred at a realistic level. If the community includes a source with regulatory capabilities, it may contribute to shaping the cluster profile in accordance with the needs of operators (distribution and trading), but the financial benefits should be large enough to compensate for the desire to maximize generation.

The balanced microgrid "disappears" from the operator's network. There is a decrease in the volume of energy sold, so it is necessary to maintain the capacity for a backup power supply. An area with high potential due to the ability to manage flows within the microgrid. The potential translates inversely to the degree of balance of the microgrid area.

Observability: the areas covered by energy communities and microgrids shall be metered with smart meters with remote access. The access mode will depend on the needs of the operator, including near real-time and online modes. An additional option for observability could be the possibility to obtain information about the level of technical balancing of a given area, and, in case the area participates in the flexibility market, the available level of the reserve for the provision of possible services to the network operator. For Aggregators, all points participating in the aggregation and flexibility market should be metered with smart meters (like communities). However, in this case, due to the consideration of the local needs of the network, systems and algorithms are necessary to locate the most desirable, from the network point of view, connection points that are part of the aggregator.

Controllable load (DSR), Active customers

The category of controllable load and active customers may include several groups that have the capacity of the flexibility of relevance to DSOs. These might be:

1. Customers use energy mainly for technological processes. A group with great potential for flexibility. Often the possibility of controlling the production process, which gives significant results with high power. In many cases, they are already involved by TSOs as sources for balancing or DSR services.
2. Industrial customers who are connected to the MV grid. A group with great potential for flexibility. A good source for flattening the load curve of the network in a given area or station. These customers have already analyzed the time distribution of the load many times and adjusted the tariff accordingly.
3. Schools, offices, sports facilities. As of today, the effects of flexibility are questionable, because these facilities implement processes that are not industrial technologies, but provide specific lighting conditions, thermal comfort, ventilation, and human safety. The situation would be changed by new technologies in terms of using their sources related to cogeneration, electricity storage in cooperation with RES, cold storage, and heat storage.
4. Larger entrepreneurs, and services, are connected to the LV grid. A group with some flexibility potential, however, the diversity of consumption profiles is too great to count on widespread interest in flexibility services. The introduction of multi-zone tariffs and their more favourable formula (than at present) may be treated as a step towards customer flexibility

Observability: As in previous cases, appropriate point measurement and data collection and processing systems are required.

Heat pumps & EV

Electric vehicles and heat-pumps can play an important role in the provision of short-term flexibility. The behaviour of electric vehicles with smart charging or vehicle-to-grid capabilities, and heat-pumps combined with short-term storage (2 hours), can be optimised as hours with the highest renewable generations and lower demand, therefore smoothing the residual demand profile.

The most important feature of EV for power system flexibility requirements is its predictable loading in night valley conditions, resulting from the long-cycle charging of the batteries. The additional load related to fast charging in daytime conditions will be a random process, strongly dependent on the availability of charging stations and fees for such a service.

The expectations in terms of the effects of energy storage in vehicles and its rendering in peak demand at attractive prices are very strongly dependent on the price aspects. The possibility of a two-way energy exchange is interesting. Ease of controlling demand through price incentives.

Observability: for devices connected to the customer's installation behind the meter, the main measurement on which network observability should be based is the main meter. If such a customer will participate in the flexibility services market, it should be equipped with a smart meter with remote access and the possibility of acquiring data also in near real time or online. EV chargers available to the public should also be equipped with smart meters allowing the acquisition of the necessary data from them.

Electrolysis

The whole power-to-X chain has an important role in enhancing overall flexibility, as electrolysers can serve not only to directly supply hydrogen demand enabling the indirect electrification of a set of end-uses but also convert the excess of renewable generation into hydrogen that can be stored and later converted to synthetic fuels or electricity. In this context, methanation completes the power-to-gas-to-power loop, allowing the production of synthetic gas that can fuel gas-fired plants during peak residual load episodes.

The flexibility provided by the hydrogen demand allows electrolysers production to adapt to different situations. A country with high wind share, for example, will be able to produce hydrogen in moments of the power surplus that are correlated with its wind profile. For PV installations the daily pattern of the electrolysers' operation is mainly driven by solar production. Electrolysers will produce most in moments of low demand, typically during the day when solar production is at its maximum and residual demand is negative.

Observability: from the network point of view, this is a connection source identified mainly as an additional load, but under certain conditions, it can also be a generation source. It can also be identified with energy storage. Whatever form it takes as a flexibility source, it should be metered in the same way as other flexibility sources.

1.2.3. Flexibility services

On the market side, to activate flexibility services provided by the users of the system, there must be a demand for such services. The market verifies which services are the most required. It is the grid operator who, based on the needs of the network, will determine what services, products and at what areas in the network are needed.

While the existing and binding regulation (Electricity Directive (EU) 2019/944) refers several times to "Flexibility Services", the European legislator did not provide, so far, any proper definition of this term:

- Art. 32, 1. *Member States shall provide the necessary regulatory framework to allow and provide incentives to distribution system operators to procure flexibility services, including congestion management, …*
- Art. 32, 2. *Distribution system operators, … establish the specifications for the flexibility services procured and, where appropriate, standardised market products for such services at least at national level…*
- Art. 32, 2. *Distribution system operators shall be adequately remunerated for the procurement of such services (flexibility services) to allow them to recover at least their reasonable corresponding costs, including the necessary information and communication technology expenses and infrastructure costs.*
- Art. 32. 3. *The development of a distribution system shall be based on a transparent network development plan … plan shall provide transparency on the medium and long-term flexibility services needed and shall set out the planned investments for the next five-to-ten years.*

However, in the spirit of the above-mentioned provisions:

- the term "flexibility services" refers to the possibility of **voluntary participation** in the management of the power system, for an adequate remuneration as well as to optimise network investments decisions. In particular, it should be considered at local level i.e. the

level of small energy resources connected to DSO networks (known as distributed energy resources
- Flexibility services include at least "congestion management" (art. 32(1)). In the absence of an exact definition for "congestion management", we are referred to the definitions of "congestion" as laid down in the Electricity Regulation and the CACM guideline prepared for TSO's needs. Therefore, only the definition of "physical congestion" might be relevant for DSOs. The definition of "congestion" as stated in the Electricity Regulation refers only to foreseen physical congestions caused by market trading.

Taking the above into consideration the flexibility services term was defined as follows:

Flexibility service is a service provided by active system users to the grid operator, the purpose of which is to use the energy potential of users to manage the network or to provide an alternative to its expansion. The system user should modify its production or consumption pattern over time[9]. Within this service, different products could be defined and ordered depending on the different grid needs resulting in short-term sudden undesired problems in the network. In the long term, on the other hand, it will result from the operator's strategies in the construction of a network development plan for a selected area and the accuracy of forecasting load and generation (changes in the behaviour of customers, generators, an increase in the number of new network users).

That flexibility services for DSOs should encompass as well "non-frequency ancillary services" including voltage control. Compared to the products currently used by the TSO, the DSO will need flexibility products that are more granular, highly locational and that can be used over a wider time span. Voltage control becomes more complex at the DSO level with increasing penetration of distributed energy resources. Generally, based on "*The road map on DSF*" as well as the Directive (EU) 2019/944, flexibility services for DSO encompass non-frequency ancillary services (in particular services for voltage control), local congestion management services and grid capacity management services (long term flexibility for grid development planning).

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Conclusion:

There is no definition for the term "Flexibility services" in the European legislation.

However, based on existing regulation, DSOs understand that "Flexibility services' encompasses the following:

For DSO:

- non-frequency ancillary services (inter alia: voltage control)
- local congestion management services,
- and grid capacity management services.

For TSO:

- ancillary services (balancing services, non-frequency ancillary services)
- congestion management services.

Figure 5. DSO's view on the term of "Flexibility services'[10]

[9] Mataczyńska E., Sikora M., Lewandowski W., *Wykorzystanie usług elastyczności przez Operatora Systemu Dystrybucyjnego*, cire.pl,

[10] https://www.edsoforsmartgrids.eu/wp-content/uploads/210722_TSO-DSO-Task-Force-on-Distributed-Flexibility_proofread-FINAL-2.pdf

1.2.4. Active Network Management

Active Network Management (ANM) should be treated as an essential element in the everyday operation of the power system, which enables DSOs to maintain a high level of system security and performance, especially in the case of high penetration of distributed energy sources. These elements enable to the maintenance of a daily, also in real time, stable and reliable system operation, as well as to effectively plan future directions of network development. The planning includes both short periods (up to one year) and long-term development plans. At the same time, it must consider changes taking place in the environment, such as the increasing number of distributed generations or loads, the growing amount of data from various devices that have a direct impact on the network, and it might be an important source of information supporting future decisions regarding the development of both networks and the DSOs themselves.

The concepts of ANM are broadly covered by technical literature but since the energy sector is constantly changing, in the following years the approach to network management and its self-modification will change too, adapting to the requirements of the more digitalized market as well as of more aware and active customers and at least seizing the opportunities of new digitalization and communication technologies for the grid.

Active Network Management refers to monitoring, control and planning methods that aim to optimize the use of existing network resources and enhance its hosting capacity while keeping the electrical parameters inside the acceptable range with the optimal need for reinforcements. These methods make use of automation to control grid components (i.e., modification/ adaption of grid topology) as well as grid-related flexibilities (i.e. consumption, load, generation and storage).

1.2.5. Grid observability and controllability

According to Art 2 (48) of 217/1485 SOGL regulation, *'observability area' means a TSO's transmission system and the relevant parts of distribution systems and neighbouring TSOs' transmission systems, on which the TSO implements real-time monitoring and modelling to maintain operational security in its control area including interconnectors.* The definition does not define observability from the DSO point of view.

Observability can be defined as temporal, geospatial, and topological awareness of all grid variables and assets. Any combination of a system state and inputs also can determine the system state using only the measurement of system outputs. Grid observability could be called the key to reliability, resilience, and operational excellence in modern distribution grids.

The system state is the minimum set of values (state variables) that describe the instantaneous condition of a dynamic system. State variables may be:

- continuous (physical systems),
- discrete (logical systems and processes), or
- stochastic.

State estimation for distribution grids involves a number of complexities, which is why observability for distribution grids is fundamentally a difficult issue. Complicating factors include feeder branches and laterals, unbalanced circuits, poorly documented circuits, large numbers of attached loads and devices and, in the case of feeders with inter-ties, time-varying circuit topology. That distribution circuits operate almost always in a time-varying unbalanced mode so that estimates must be made for all three phases independently; actual connectivity can be poorly known so that models typically used in state estimation would not be sufficiently accurate to use the results, and circuit-switched configuration changes can change topology in between the time of a state estimate and the time that actions based on that estimate are taken. Consequently, it can be helpful to rely more on state measurement and less on state estimation in the distribution case whenever it is possible to arrange for the necessary instrumentation. The need to provide a grid state for control purposes leads to the need for observability and therefore for sensing and measurement architecture. Sufficient sensing and data collection can help to assemble an adequate view of system behaviour for control and grid management purposes, thus providing snapshots of the grid state. The data can also be utilized to validate planning models. Measurement refers to the ability to record and monitor grid parameters such as three-phase voltage, current, phase angle, and power factor as well as DER output and performance[11].

That is why observability also can be seen as a set of qualities related to the operational visibility of the grid and integrated DER, especially in distribution grids. In a larger sense, observability may be extended to cover electrical, thermal, stress, risk, financial, utilization, and security states. The power distribution grid of the 21st century needs to be observable, and the level of awareness should be high enough to cover the requirements of grid stability and reliability in presence of intermittent generation and load.

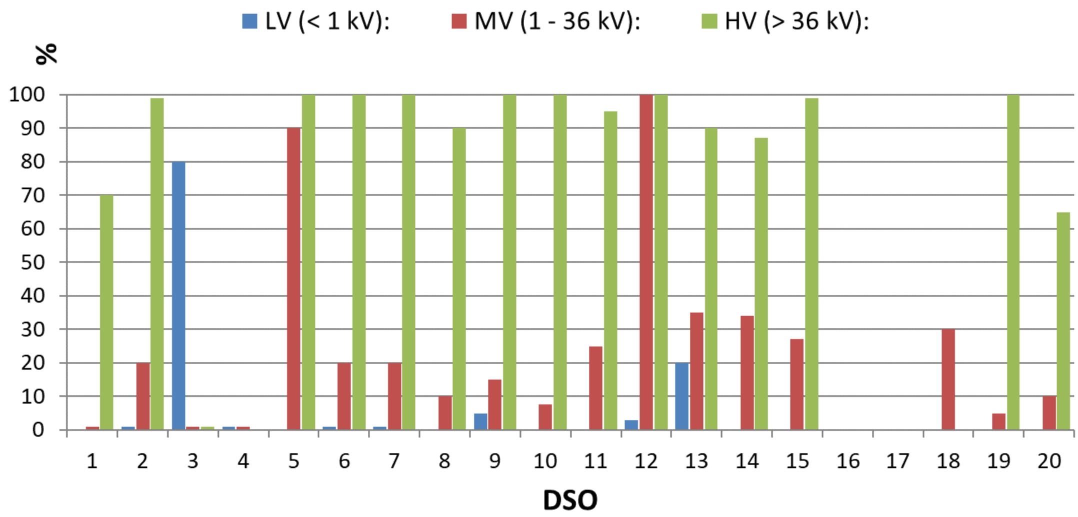

Figure 6. TF1 ANM 2018 survey results related to grid observability.

Despite the common picture, there is a wide range of system observability in the companies. The status of observability at networks traditionally reaches a high degree. At the HV level, there is almost full observability except for some rare exceptions. Typical values are between 80 and 100%. At the MV level, the degree of observability drops considerably. At the MV level, there is the biggest inequality, since the observability ranges from 0% to 100% with a lot in-between. Only 3 out of 20 DSOs give a degree of observability of 100% at the MV level, the usual values are between 5% -40%. At the LV level, the degree of observability decreases again significantly. At LV there is a range from 0% up to 30%. Only two DSOs indicate a level of about 20-30% here. All other participants (18 out of 20) here indicate small values from 0 to a maximum of 5%[12].

To achieve observability, the first step would be to develop an observability strategy based on measurement types and characteristics, then classify data by key characteristics, determine the sensor mix and build a sensor location plan. As there are no indicators defining the level of grid observability, especially at the LV, the strategy should take into account those elements determining the observability that will allow the achievement of the assumed effects (goals).

[11] DOE: "Sensor Network Issues for Advanced Power Grids" report
[12] Citation from TF1 ANM 2018 report

Moreover, it should lead to the determination of the optimal range of observability requirements. The very next step would be the implementation of a set of features and elements in the grid management system that enables an appropriate level of observability:

1. Fault Location Isolation and Service Restoration **(FLISR)**[13] – the system ensures the location of faults in the MV and LV network, automatic fault detection, isolation and restoration, and automatic circuit reconfiguration, accomplished by coordinating the operation of field devices, software, and dedicated communication networks to automatically determine the location of a fault, and rapidly reconfigure the flow of electricity so that some or all the customers can avoid experiencing outages. Network reconfiguration could be carried out in less than minutes, resulting in a reduction of the KPIs (SAIDI and indirectly SAIFI).

   Conditions for correct and optimal operation of the FLISR:

   - optimal number of radio-controlled objects in the served area (reclosers, disconnectors with short-circuit current flow, independent short-circuit current flow indicators),
   - reliable and fast communication with devices in the faulted area,
   - digital protections must be installed in the switching station feeder bays, allowing for the appropriate gradation of settings with many devices within the network,
   - correctly calculated and programmed settings and gradation of automation between the protections in the switching station feeder bays, and reclosers deeper in MV network and short-circuit current flow indicators (both for the normal system state and for emergency state). Before automatic restoration FLISR can be also coordinated by operators in the control room.
   - For an optimal FLISR operation the condition of the assets (i.e., history of failures, obsolescence), weather, and vegetation control plans are important, to make optimization between several replacement options.

2. **Controlling the voltages** in a distribution network is an important task for any network management system working at the distribution level. Voltage control is a process undertaken to maintain an optimal voltage at all points along a distribution feeder under DERs conditions. Due to the increasing penetration of distributed energy resources required for the sustainable distribution system, a new voltage control strategy is needed. The traditional voltage control strategy cannot support the increasing number of DERs in a coordinated and scalable manner to meet the operational voltage regulation requirement. Distribution network operators are increasingly facing the problem of voltage violations and are required to reinforce the networks. Usually, the voltage violations originated by DER require a system able to dynamically respond to changes in the feed-in and demand at LV. A voltage regulated distribution substation consists of a transformer where the low voltage can be dynamically adjusted by a load tap changer. In addition, supported by the power electronics converter, the energy storage system can provide fast, smooth, and flexible voltage control services.

3. **Outage Management System:** A system service used by operating entities to better manage their response to power outages, with the integration of multiple sources of data (smart meters, customer calls, etc.) integration with other utility systems to analyze possible fault locations (Geographical Information Systems (GIS) and connectivity

[13] Also called Fault Detection, Isolation and Restoration (FDIR)

databases for common node analysis) and/or integration of fault location from applications such as FLISR, and integration with computer aided dispatch systems for remedial action. The information on network quality events recorded by the smart meters installed in consumers and secondary substations, both in the transformer and in the low voltage feeders, should also be taken into account, as it is complementary to the integration with the MDMS.

4. **Power Quality Measurement, Stabilization and Simulation:** Monitoring may be continuous and handled by distributed intelligent devices in the field reporting unsolicited data only when accepted parameters are violated. Waveform data may be stored locally to allow for data requests and post event analysis. Stabilization of voltage (compensation for spikes, sags, etc.) is the automatic correction of system problems (i.e., voltage). Simulation tools include analytical and software tools that can model the electric power structure as it is designed and operated.

5. **Grid Model:** In the distribution network, the model is a data set, in a spatial context that contains grid asset details and configuration information, customer and DER connectivity details, and other relevant information to reflect an accurate depiction of the current state of the distribution system. This model is often visually represented in a GIS as well as used in power flow studies. Distribution operations use two versions: as-built and as-operated. As-built reflects the model prior to daily operations while as-operated reflects the actual real time model for daily operations.

6. **Implementation and Integration with Meter Data Management System:** MDMS includes processes and tools for securely storing, organizing, and normalizing data from advanced meters integrating data, from other meters, and making the data available for multiple applications including customer billing, analysis for grid control, outage management and others.

Figure 7. A set of features and elements in the grid management system

With grid observability increases, there is the opportunity to implement more powerful methods for detecting, locating, and characterizing all types of grid faults, foresee grid states, load and generation variations, and even asset health management and avoiding equipment failure. To achieve observability of LV grids, the data from the SMs, inverters and other measurement devices of the DSO should be correlated to the LV grid topology.

1.3. Sets of components for flexibility sources integration[14].

The requirements for the future network infrastructure that will allow efficiently integrate flexibility sources include elements related to the equipment of the distribution grid (devices, sensors, etc.), IT software and hardware as well as ICT infrastructure, used so far, but also new solutions emerging with technology development.

By digitally representing assets, the DSO will have information for planning, operations, and maintenance and the possibilities to optimize the way of working. The analyses will be more correct, and this will give better prioritization and possibilities to calculate future scenarios.

To be able to represent the asset digitally, different types of solutions must be installed, namely:

- Measuring of current, voltage and status of different assets (for 3 x phases, and it is useful to measure minimum, average and maximum values)
- Communication equipment
- Sensors for increased capacity, availability, and reliable time distribution such as pressure, UV, IR, and gas sensors.
- Standardizations of communication and automation system

Generally, the above types of solutions could be grouped into the main groups, such:

a) **electricity network infrastructure**
The modernization and expansion of this infrastructure will consider the requirements related to the introduction of smart grids. Therefore, it will not be a simple duplication of the existing patterns, but the introduction of advanced technical solutions. They will enable, among other things, remote supervision of devices, self-diagnosis, monitoring, and adaptation to work in difficult climatic conditions.

b) **measurement systems and automation devices**
These elements are used to measure the state of the network and to perform autonomous functions of automation related to ensuring the continuity and reliability of electricity supplies to consumers. Electric power protection automatics systems are the most important part. They include sensors and converters of electrical (voltage, current, power) and non-electrical (temperature, pressure) quantities, auxiliary relays and control devices.

c) **measurement systems of network users**
These elements are used to measure the quantities that characterize the energy flow at supply points and network characteristic points. They include measurements of municipal and industrial recipients, producers, prosumers, other operators, transformer stations, selected lines and circuits. The scope of the measurement includes basic electrical quantities (power, energy, voltages, currents) as well as collecting information about the quality and reliability of supplies at the measurement site.

d) **ICT infrastructure and platforms for collecting and exchanging data**
The telecommunications infrastructure will be a key element of the network equipment. It will ensure the possibility of transferring a large amount of data, both from the customers and devices to decision-making centers, and in the opposite direction. In this way, it will provide information to manage and control the network and perform functions that require interaction with the end user, e.g., demand management, load control, reporting and implementation of flexibility services. The development of

[14] ETIP SNET WG1 and ISGAN Annex6 Task Forces, *Flexibility for resilience*, 2022 (the chapter prepared by E. Mataczyńska).

telecommunications infrastructure will be one of the most important undertakings in the process of integrating the sources of flexibility in the network, and the functions performed by it will become the basis for the operation of the new network. Acquiring data and making them available to other systems and entities (energy companies, recipients) is the basic requirement of integration.

e) network management systems and business process support

Network management and business process support systems are now used as separate, loosely coupled systems. The introduction of new requirements for the network infrastructure will be related to the integration of applications within a coherent IT environment, the creation of applications dedicated to new needs related to the analysis of the network condition and support for business processes. The whole will be ensured by appropriate IT security.

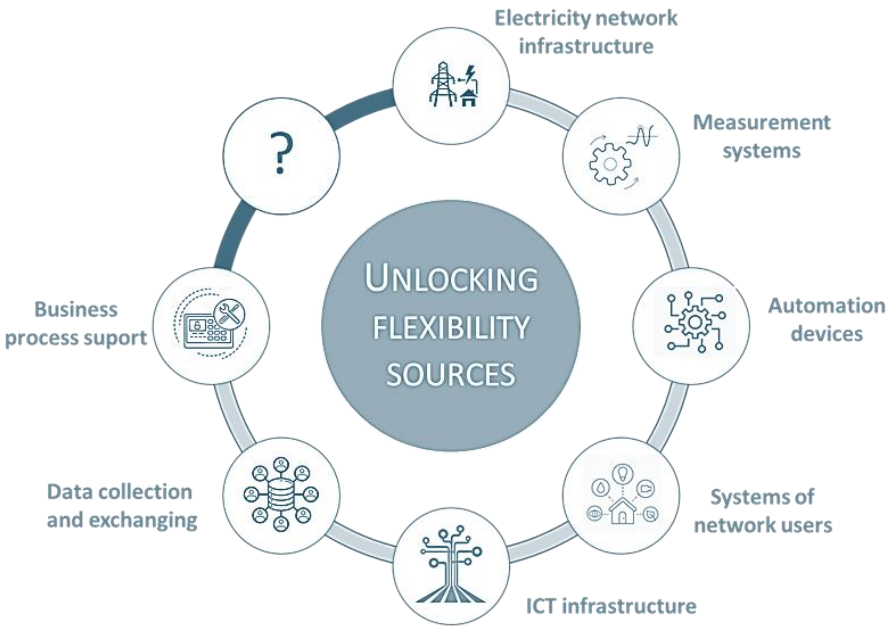

Figure 8. Sets of components for flexibility sources integration – general view

The main requirements enabling the integration of flexibility sources and their use by electricity network operators:

- Maximum network observability at all voltage levels. It will be required to obtain measurement data, data on the state of the network, generating units (including monitoring of their operation and availability), necessary for planning and optimization of the network operation (while maintaining the required technical parameters), and automated control of the network operation, including automatic reconfiguration, and restoration of the network for planned changes as well as prevention and removal of failure,
- SCADA with advanced network management systems, with the ability to detect and locate faults in networks,
- systems and algorithms enabling safe and effective automation of identification and obtaining flexibility available in the system (both on the market and based on concluded bilateral agreements),
- geographic information systems and network asset management systems,

- systems for measuring energy and conducting analysis by individual and industrial customers,
- advanced forecasting systems that allow grid operators to optimize the use of resources,
- engineering support systems,
- integrated platforms for managing the available flexibility sources, in a way that allows their use in accordance with defined, specific areas, network priorities,
- systems for identifying the area's needs of the network and with the possibility of assigning to them the available flexibility sources and flexibility services. It is important to detect and have a contingency plan when a flexibility resource provider does not provide what was agreed and therefore the network may have a problem with stability.
- two-way digital communication systems and automatic network monitoring, control, regulation and security systems,
- systems and authorizations of data coming from customers - IoT. This will allow the dissemination of the idea of smart cities, houses and communities, which can also (if certain requirements are met) be flexibility sources,
- network saturated with active customers, to coordinate the operation, will impose on the grid operator the necessity to use smart technology to quickly acquire, analyze, process and transfer more data to market participants (machine learning technologies).

A fluctuating power system that must be reliable needs automation of the operational processes. Decisions must be based on fact and there must be enough resources to handle the systems.

The operational system involves processes for surveilling and handling capacity and voltage levels, balancing the power system and planning and handling interruptions.

The operators need IT-solutions and tools to make the right decisions. Prioritized deviations and recommended actions must be visualized. The systems for data collection and data storage and visualization tools must be developed.

Other digital solutions that must be developed include i.e., tools for planning of investments and maintenance optimization. In addition, unattended decision-making should be promoted even from distributed levels without the need to make them centrally when possible.

International cooperation and standardization of platforms and interfaces makes the data exchange more effective and easier between different IT-tools. To be successful in this implementation under harmonized standards there must be consensus in IT architecture and cyber security.

2. DSO flexibility needs in the power system

The occurrence of distribution system problems depends on the confluence of many components: the capacity demand and generation in individual nodes of the grid, the network topology and the topology of the TSO network, and conditions of dynamic loading of network elements as derivatives of weather conditions.

Distribution network development analyses conducted with the deterministic method consist of the identification of overloaded network elements depending on the network topology (N-1, N-2) and the capacity demand relocation and generation (arbitrarily determined network characteristic models). Possible investment decisions are made based on the maximum observed overloads, without taking into account the expected average annual duration of overloads and the resulting energy at risk of not being transmitted to consumers or being derived from distributed sources.

The risk analyses propose the analytical process to be carried out in parallel as identification and analysis of:

- network elements whose outages cause overloading of other network elements,
- network elements that become overloaded due to outages of other network elements.

The purpose of the analyses is to determine the extent to which network overloads depend on a confluence of factors such as:

- those over which DSO has no influence (e.g., RES generation exceeding a certain value) and
- those over which DSO has an influence or can monitor and control (e.g., network topology and its actual load capacity).

If such a convergence exists, it is investigated whether the risk of its occurrence can be minimised, e.g., by coordinating network outages with meteorological conditions, contracting flexibility services to reduce generation, etc. If coordination of all outages resulting in congestion can be agreed upon for an overloaded network element and/or a flexibility provider can be found to mitigate the risks, the modernization of this line could be postponed. However, all the risks of such decisions must always be analysed, as the economic rationale must not conflict with network security

Subsequently, congested lines for which it has not been possible to identify flexibility resources to prevent congestion shall be prioritized for investment in such a way that the investment is carried out most efficiently.

In addition to the availability of flexibility resources (grid and services), also procedures for the planning of flexibility resources and IT procedures and tools for network observability (measurements) and flexibility management are necessary conditions for implementation.

The report recognizes three general needs for using flexibility by distribution system operators:

a. **Flexibility for local congestion management** could be characterized as short to medium (activation timescale from seconds to minutes) term ability to transfer power/energy between supply and demand, where local or regional limitations may cause bottlenecks/local congestions resulting in problems with energy delivery. The main reason for the need, besides keeping a stable grid during operation is to increase the amount of distributed power generation in the distribution systems, resulting in bi-directional power flows and to increase the variance of operating scenarios.

b. **Flexibility for voltage control** could be characterized as the short-term ability (activation timescale from seconds to minutes) to keep the bus voltages within predefined limits, a local (regional) requirement. The main reason for the need, besides keeping a stable grid during operation, is to increase the amount of distributed power generation in the grid, resulting in bi-directional power flows and increasing the variance of operating scenarios.

c. **Flexibility for grid development plan** could be characterized as medium to long-term equilibrium between energy supply and energy demand, a system wide requirement for demand scenarios over time. The main reason for the need is to prepare a strategy of investment planning assuming that loads on existing equipment can be flexibly adjusted to the operating conditions, and thus the process of replacing them with new ones may be postponed or the scale of modernization may be smaller than under the classical approach. The activation timescale is from hours to several years.

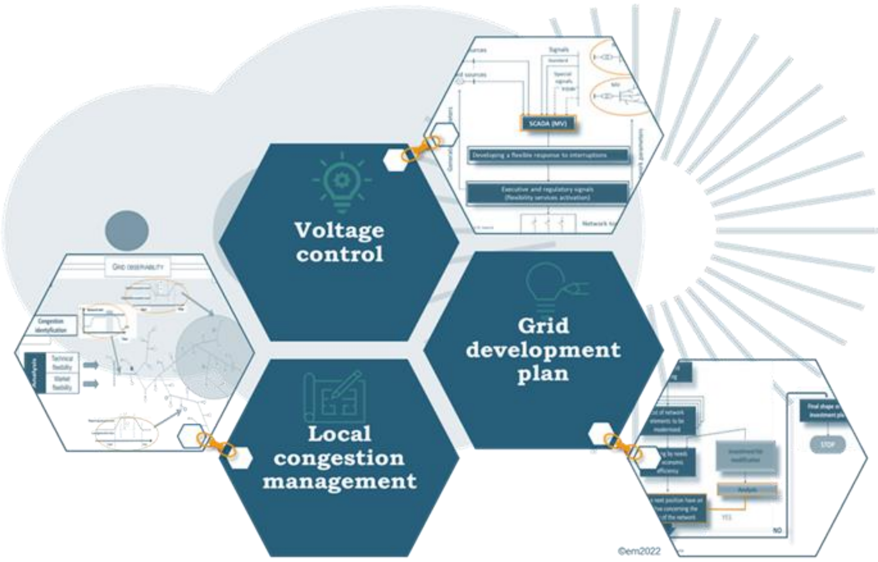

Figure 9. DSO flexibility needs in the power system

2.1. Congestion management

Congestion generally refers to a situation where demand or generation at a certain point in the distribution network exceeds the transfer capabilities. Therefore mitigating congestion can be associated with two types of strategies: to locally increase the transfer capability by reactive power and voltage control, and by coordinating the curtailment of demand.

From a regulatory point of view, congestion is defined in the Market Regulation, Article 2(4), where it means *a situation where not all trading orders between network areas submitted by market participants can be executed because their execution would significantly affect the physical power flows on network elements that cannot handle those flows*.

Physical congestion is associated with power flows in individual nodes of the electricity network. These flows are determined mainly by the technical characteristics of the network elements, the topology of the network and the characteristics of the injection of generated energy in the different nodes and of its reception. Direct control of the flows to prevent overloads can, to some extent, be implemented by means of phase shifters, however, despite the increasing use of such devices, their role in today's power systems is still not significant.

Overload, on the other hand, is a condition in which one or more constraints (e.g. thermal constraints, voltage constraints, stability constraints) limit the physical flow of power in the network. Network overloading occurs because the capacity of a given network is limited by the inherent characteristics/parameters of the physical assets (i.e. lines, cables, transformers). Overloads in the distribution network can result, for example, from voltages exceeding acceptable standards or network elements that become overloaded. Thus, overload management is mitigated by voltage control or load/generation control. In the context of congestion management, from the point of view of the distribution system operator, physical congestion is defined as any network situation where forecasted or realised power flows violate the thermal limits of the elements of the grid and voltage stability or the angle stability limits of the power system[15].

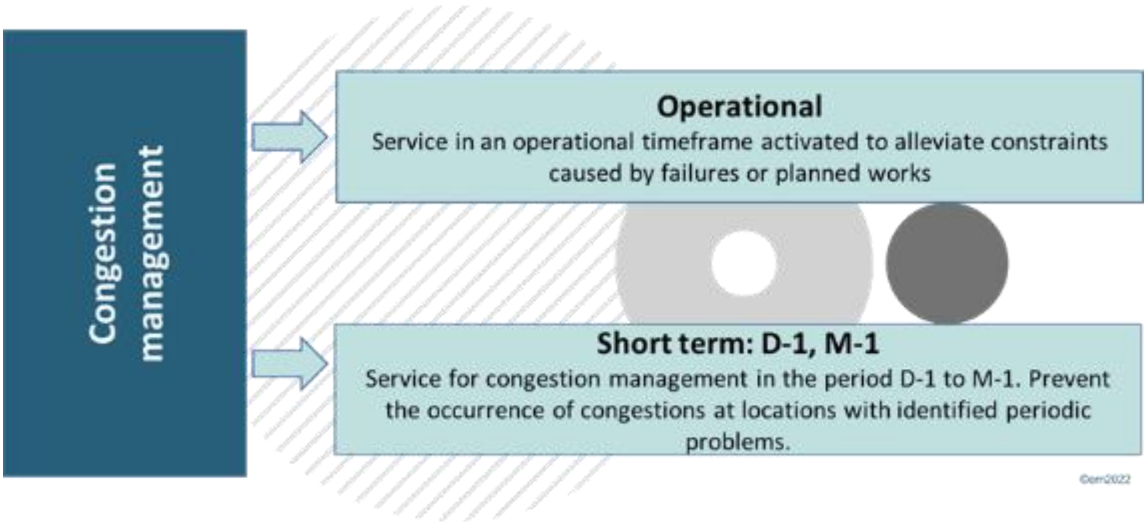

Figure 10. The need of services for congestion management

The consequences of unresolved network overloads can be severe. From incidental automatic tripping of disconnections of various network elements, through the occurrence of additional disturbances of voltage or frequency nature, to the occurrence of cascading outages leading to a blackout. The overlapping of network failures, power plant outages and extreme weather conditions leads to the exceeding of critical values of the basic technical parameters of system operation (voltage) and the automatic disconnection from the grid of generation sources and loss of voltage in the entire area affected by the disturbance. This phenomenon can be divided into two phases. In the first one, the danger increases slowly, but thanks to appropriate technologies it can be identified and predicted. In this phase, there are relatively small fluctuations of frequency and voltage, and active and reactive power flows change, bringing the system operation to the limit of stability. In this phase, it is still possible to take remedial actions (among others using available flexibility sources) to limit the risk of system failure. Furthermore, these actions may include (for the transmission grid operator) the use of power reserves (e.g. hydroelectricity start-up, increased imports), as well as network switching to eliminate overloads and voltage drops. The second phase starts when critical system operation parameters are exceeded. Its course is rapid, often cascading, limiting the possibility of taking effective operator actions. In this phase the systems of network and facility automatics act first of all, aiming at preventing the equipment from damage. As a result of overloading, power lines switch off one after another, increasing voltage drops, and frequency changes occur, which in turn cause automatic disconnection of power plant generators from the power system. This phenomenon leads to an aggravation of the

[15] Article 2 (18) of COMMISSION REGULATION (EU) 2015/1222 of 24 July 2015 establishing a guideline on capacity allocation and congestion management, Official Journal of the European Union, L 197/24, 25.7.2015

power deficit, so that the power system loses its cohesion, the power supply is maintained only in the so-called islands, i.e. regions separated from the rest of the system, where locally there is a balance between the generated power and the load.

Overloading degrades network performance and power quality. Furthermore, if left unresolved, it would lead to the shutdown of various network elements by automatic safety systems installed to prevent total system collapse. Overload management, therefore, refers to avoiding overloading of system components to protect the system from emergencies or outages, by reducing peak loads. This process addresses overload situations that were not foreseen during the long-term network development planning process or situations where network reinforcements are unable to cope with increases in load or generation. Flexibility services, designed as a clear market-oriented mechanism by having different, market-adapted products (short-term - energy products or long-term - power products that can be combined with energy products), will aim at solving or preventing congestion in the network

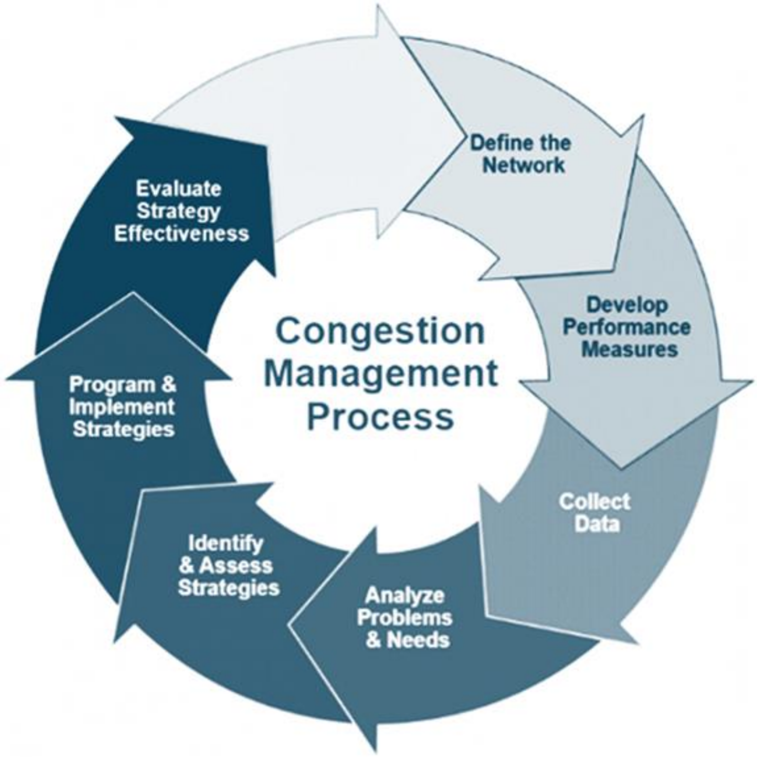

Figure 11. Sample steps under congestion management process

Congestion management may involve several methods of dealing with difficult situations in the network. From the point of view of the distribution network operator, this may be the activation of its flexibility resources available on the network. This is the default action that will be used before deciding to activate the flexibility available in the market. This is a countermeasure to maintain stable operation of the network during periods of congestion but should be considered in the context of postponing investments in own network assets providing an appropriate level of flexibility and not as a final solution. The rapid development of distributed sources and new forms of network load may necessitate network expansions, as market purchases may not be efficient from both a financial and a managerial perspective, and may create risks of market abuse. Ultimately, however, the solution that will lead to the removal of constraints may be network expansion. Of course, the alternative to network expansion can be seen from the perspective of adequate localisation of loads and generators. Here, however, a fundamental problem arises, because in principle the operator cannot control the process of locating loads and generators in its network. For large producers, who are obliged to apply for grid connection conditions, it is possible to issue them under conditions that guarantee the safe operation of the system. However, if only a notification is required for the connection of a generating installation (PV), the operator is obliged always connect such an installation regardless of the capacity of the network in the connection area[16].

2.2. Voltage control

Several PV power systems are connected to the local grids, and the simultaneous operation of these PV systems provokes voltage instabilities in the distribution lines. These voltage fluctuations can occur over the permissible limits.

Generally speaking, voltage control takes place within the framework of what is known as operational flexibility (grid/technical flexibility). This means that adverse voltage variations at selected substations are monitored and, where necessary and possible, automatically regulated using existing equipment and functionalities. At the LV network level, the operator's ability to cope with voltage variations will be through the use of existing network capacity for flexibility. Market purchase of such services does not seem possible or efficient. Of course, voltage control has to be seen in a broader context, which already refers to the emergence of areas affected by network congestion. In this context, the purchase of existing flexibility services from resources connected to the grid (prosumers, EVs, storage) is not excluded in the next steps of voltage stabilization.

Where the operational flexibility for voltage control comes from?

At every substation, the transformers are installed to link two levels of the grid (secondary substations, HV/MV). The transformers are equipped with a tap-changer, which regulates the output voltage by exchanging the transformation ratio. These tap-changers, being electro-mechanical appliances, have a sluggish response time of seven to ten seconds. This time is required to toggle only one section of the transformer, which leads to discrete voltage step-up or step-down. Therefore, the rapid imbalance between load and generated power in specific cases cannot be corrected effectively. Moreover, it is difficult to predict the deviations in power consumption. Different types of technologies have been used to produce reactive power for compensation such as static synchronous compensator (STATCOM), synchronous condenser, static var compensator (SVC), and capacitors. Electronic devices are effective for reactive power compensation but significantly complicated, expensive, and not reliable enough.

It means that the improvement of the voltage profiles in distribution grids, seeking to increase stability and reliability, could be achieved through the insertion of distributed generation, variation of transformer TAPs, voltage regulators, capacitor banks or static reactive power compensators. Static reactive power compensators can maintain a pre-programmed stable voltage level. If the voltage in the connected node is high, the compensator works in an inductive zone and consumes reactive power of the load, this can happen in hours when the compensator works in a capacitive zone and releases reactive power functioning as a generator, and in this way, it keeps the distribution system stable. The same effect can be achieved with the use of voltage regulators or with the variation in the TAP derivations of transformers, which can regulate the transformation process in different voltage transformation relations, either to reduce or to increase delivered voltage levels, guaranteeing the stability of the system of the dawn when the load demand lowers and if, on the contrary, the voltage in the node is low (peak demand times).

[16] CEDEC, E.DSO, ENSTO-E, eurelectric, GEODE, TSO – DSO Report. *An integrated approach to active system management with the focus on TSO-DSO coordination in congestion management and balancing*, April 2019, https://eepublicdownloads.blob.core.windows.net/public-cdn-container/clean-documents/Publications/Position%20papers%20and%20reports/TSO-DSO_ASM_2019_190416.pdf

Among the static power reactive power compensator devices based on power electronics, the SVCs stand out, which contain capacitance steps in parallel with reactance, both programmed by an automatic control system that decides whether the SVC should behave as a reactive generator and raise the system voltage, or behave as a load and absorb reactive from the grid by stabilizing the voltage levels to set parameters. These devices inject a considerable harmonic component that must be taken into account in the global analysis of the problem of reactive power compensation, since it is a variable that conflicts with the purpose of optimization of reactive power flows. It must be ensured that the limits of total harmonic distortion of current and voltage do not exceed the values established by the norms of energy quality.

VOLTAGE CONTROL DEVICES[17]

The classical approaches used in the distribution grids started from the assumption that the voltage decreases from the supply point to the end of the feeder. In that case, voltage control could be made in a centralized way, by acting on the OLTC at the HV/MV substation, or by changing the tap in case a manual tap changer is installed in the secondary substation. In the case of a large load increase, the solution was left to operational planning solutions, with the substitution of cables or transformers. This kind of approach led to alleviating voltage problems due to the large increase in loads.

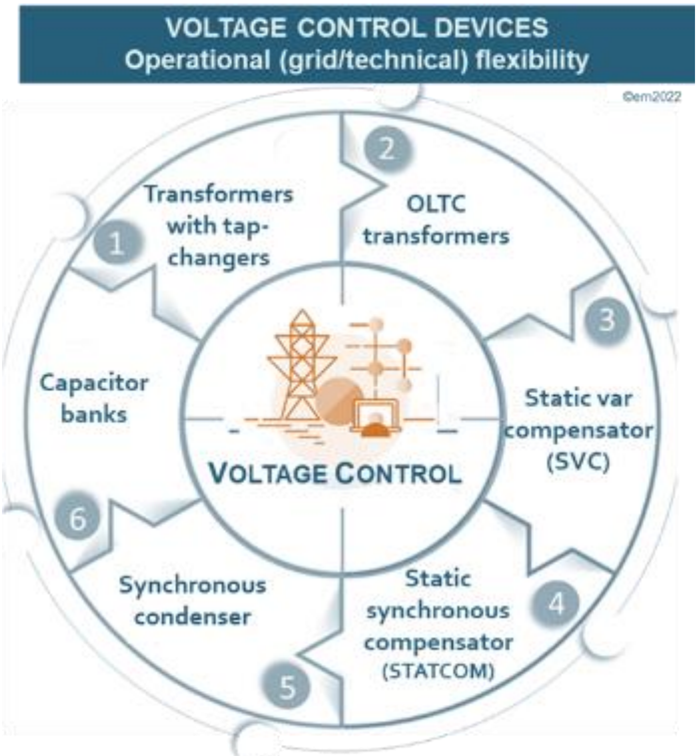

Figure 12. Voltage control devices (operational flexibility)

A modern approach for voltage control in LV grids consists of the use of power electronic devices and OLTC transformers (On Load Tap Changer), mimicking the solutions generally used in MV and HV grids. Some secondary substation transformers could be replaced with new devices equipped with an OLTC. This device is controlled automatically according to pre-defined

[17] Alessandro Ciocia, Valentin A. Boicea, Gianfranco Chicco, Paolo Di Leo, Andrea Mazza, et al.. Voltage Control in Low-Voltage Grids Using Distributed Photovoltaic Converters and Centralized Devices. IEEE Transactions on Industry Applications, Institute of Electrical and Electronics Engineers, 2019, 55 (1), pp.225-237. ff10.1109/TIA.2018.2869104ff. ffhal-02350955f

parameters (or collected in real time from the smart grid), allowing to adapt of the voltage in LV to the particular circumstances of the network without affecting the service in real time The effectiveness of these devices in case of high PV penetration is under study.

OLTC for Voltage Control in LV grids

The OLTC has several CPs across the high-voltage winding, corresponding to the taps. Each of these taps refers to a certain turn ratio. For a given input voltage, selecting various tap positions can vary the output voltage. A controller usually determines the optimal tap position. One of the most important disadvantages of this type of equipment is the occurrence of electric arcs across the primary winding when the tap commutation takes place under load. These arc discharges can cause further degradation of the materials associated with the winding or its insulation, meaning a shorter life of the changer mechanism. As such, the tap must theoretically be changed as seldom as possible.

However, in the operation of the distribution system, sometimes there are dozens of tap variations within a day, especially in those grids with high penetration of RES. The operators determine the optimal number of tap changes as a function of voltage and wear of the changer mechanism.

The controller that regulates the tap position usually determines the difference between the actual measured voltage at the tap changer and a setup voltage value. When this difference exceeds a certain threshold, a tap changing is carried out. If the voltage measurements are performed in grid nodes different from the installation point of the OLTC, communication systems are necessary. Conversely, without communication systems, the only available voltage measure is located in the secondary substation.

Other problems can occur in grids with high renewable generation penetration. The distributed generation tends to reverse the power flow in the transformer from the end consumer toward the distribution grid. Thus, the controller must be capable of keeping the voltage within limits, despite this reversal. That is why, in these cases, a variable set-point is necessary. This set-point can be either lower or higher, depending on the situation. If the reverse power flow is high, this set-point must be low, and when the power demand of the final customers is high, then the set-point should be high.

Power Electronic Devices for Voltage Control in LV Grids

The main power electronic devices used to carry out voltage control functions are the step voltage regulator SVC and the static synchronous compensator (SSC). The SVC is used for its simplicity, relatively low cost, reduced maintenance concerning the other power solutions with electronics, and the possibility of insertion without upgrading the transformer in the substation as in the case of OLTC. The SVC is composed of a thyristor-controlled reactor (TCR), a thyristor-switched capacitor (TSC), and an LC filter. The SVC installed in distribution grids performs the functions of mitigating the voltage variations, reducing the absorption of reactive power from the distribution network (thus reducing the network losses), balancing the load, and stabilizing the voltage. Automatic voltage control is carried out by the SVC through the calculation of the amount of inductive/capacitive power needed. The difference between the measured voltage and the reference voltage is used to generate the signals to command the thyristors in the SVC. These signals are then converted either into analogue signals for imposing the delay angle of the thyristors (in strict dependence on the reactive power demand in the TCR) or in digital signals based on which the thyristors in the TSC are switched ON and OFF.

The other power electronic devices capable of control voltage are PV inverters. The simplest case consists of an ON/OFF control: the generator shuts down when the voltage is close to the upper limit (i.e., within a given threshold). Distributed energy resources equipped with Q(V) and P(V) control functions based on the results of European projects allow increasing flexibility and hosting capacity in LV grids. These functions work autonomously without the need for communication with the network operator. Both functions are used for voltage stabilization in LV grids and thus for significant increasing DER hosting capacity. In case the voltage is higher than a threshold, the DER inverter switches to the under-excited (inductive) mode thanks to the Q(V) function. In case the voltage rises, even more, the inverter starts to curtail active power generation thanks to the P(V) function. In case the voltage is lower than a threshold, the inverter switches to the over-excited (capacitive) mode thanks to the Q(V) function. The inverter voltage measurement input for both functions is based on several seconds moving average. Standard inverters are usually able to be operated with symmetrical active and reactive powers in all three phases today. The inverters equipped with the mentioned control functions work autonomously, i.e. the functions curves are set inside each inverter setup menu (but uniform over the distribution area). Q and P are controlled locally only according to voltage conditions at the point of the inverter connection without any command from the dispatch centre or elsewhere. Their benefit is higher generation power connectable to the grid without any intensive need to curtail their energy production.

DERs connected to MV grids are equipped with a voltage regulation system and receive voltage or power factor set points from DSO DMS. The required voltage results from the grid operation optimization process and it can be changed several times a day. Comparing the required and measured voltage at the point of the DER connection, DER controls its reactive power to stabilize the voltage. The volt-var control for MV generation units above 100kVA is obligatory based on grid codes in many European countries.

An evolution of this method consists of active power curtailment: the active power output is reduced according to the CP voltage, changing the operation point on the DC current-voltage characteristic curve of the PV generator. The performance of this method increases when there is coordination between all the inverters in the feeder. Another proposed control combines active and reactive power management for voltage control. First, the reactive power available from the inverter is varied inside its capability limit; then, if it is not enough, the active power output is reduced. On the contrary, if the active power curtailment is not considered, because the goal is the maximization of renewable energy production, the use of only reactive power management for voltage control is analyzed.

Combined Solutions for Voltage Control

Various solutions for voltage stabilization consisting of different combinations between these types of equipment have been proposed. The coordinated control of distributed energy storage systems could include OLTC and SVR. The goal is to diminish the stress of the OLTC and the power losses. This method limits, at the same time, the storage depth of discharge to improve the life of the batteries.

The number of tap changes could be reduced based on optimal reactive power coordination achieved through irradiance and load forecast. The so-called runaway condition of the controller, which occurs when the line regulator is operated at its control limit, is taken into account as well.

The voltage in a grid with high PV penetration is controlled using various control strategies of the storage systems. A hybrid voltage/var control method for the same types of grids could be a solution. This method consists of two types of control: coordinated normal control loop and uncoordinated transient cloud movement loop. The first one is based on the scheduling of the hourly dispatches for the capacitor banks, OLTC, and SVCs. This is carried out with the help of load forecasting. The second type of control is adopted when the clouds reduce the irradiance and thus the PV power exhibits significant variations. The goal is to minimize voltage deviations as well as power losses.

Communication-assisted voltage regulation

Due to the intermittency of seasonal RESs, the conventional control schemes for OLTC and DGs fail to provide proper voltage regulation. This shortcoming can be compensated using communication-assisted voltage regulation schemes under two approaches: distributed and centralized. Both approaches involve investment in communication links and remote terminal units. The distributed (intelligent) approach is considered to be an expert-based control or model-free approach, which coordinates a variety of voltage control devices intending to provide effectively and no optimal voltage regulation with fewer communication requirements. On the other hand, the centralized approach relies on a central point that monitors the system status and optimizes the operation of voltage control equipment. Typically, a centralized optimization problem is solved to dispatch the reactive power of different voltage control equipment based on (i) load forecasting and (ii) generation monitoring.

2.3. Investment deferral (grid development plan)

Planning for flexibility is a complex multi-step process that needs to account for a variety of factors that together form a complex mathematical problem that can only be solved using appropriate tools. The process typically starts with an assessment of current needs and extends into the future. Depending on the present status, integration measures might be necessary for the future or may already be a matter of urgency, which greatly changes the list of available options and associated costs. Assessment of current flexibility is key as it creates the foundations for a least-cost, long-term pathway for a flexible power system that is ready to incorporate significant shares of RES.

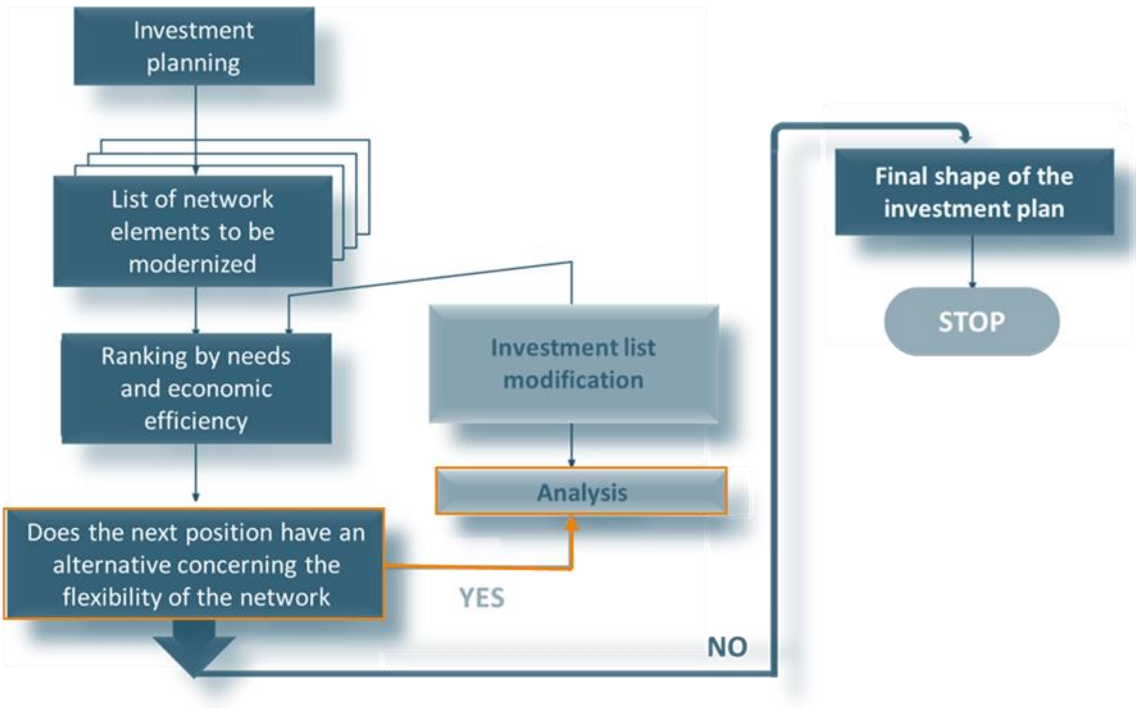

Figure 13. Flexibility in the grid development plan – general approach

In many cases, network development planning does not take into account the flexibility of network elements, with redundancy and reserve levels higher than needed. The nature of DSOs' business (regulated, dependent on NRA decisions) will change over time and then the problems of a flexible approach to investment planning will have to change. An important element of these changes will be how Article 32 of the Directive 2019/944 is implemented in the Member States, both in terms of the form and plans scope as well as incentives for DSOs to use market-based flexibility in their operational activities.

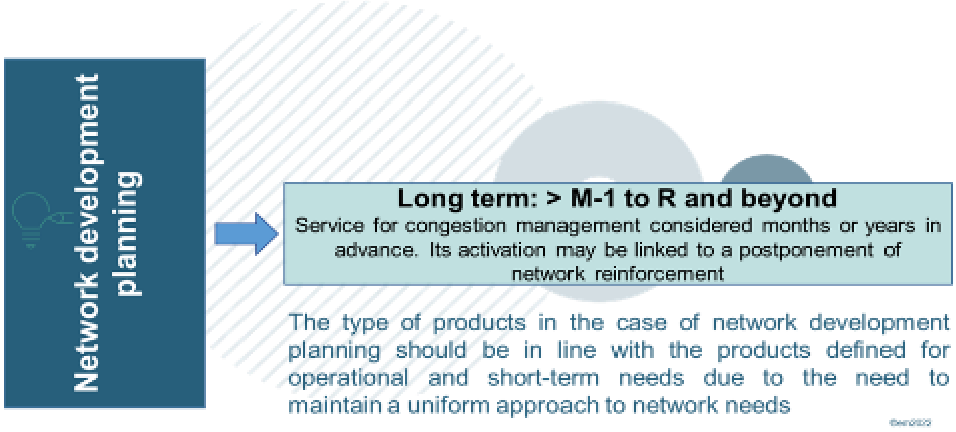

Figure 14. Flexibility services for network development planning

Investment planning assumes that loads on existing equipment can be flexibly adjusted to the operating conditions, and thus the process of replacing them with new ones may be postponed or the scale of modernisation may be smaller than under the classical approach.

Planning shall take into account flexibility in the long term, both in terms of its technical capabilities and the future flexibility services coming from the market parties.

Recognition, especially in the form of a service, carries the risk of adequately securing its availability, at least for the duration of the substituted network planned for development - the activation of the service postpones the investment in time, replacing it in the interim period.

Alternative for expansion:

- Network location information, voltage level;
- All eligible sources (generation, storage, load response);
- Need-based response time (e.g. 30 minutes);
- Utilisation decision based on the present value of deferred capital expenditure;
- All network locations were economically justified;
- Network locations where growth in connected new installations is anticipated;
- Flexibility used at the appropriate network location can help to manage congestion i.e. defer the need for reinforcement or allow the quality of service to be maintained while reconstruction (reinforcement) is carried out;

Planned maintenance management:

- Planning of network development through flexibility available on the customer side at all voltage levels of the distribution network;
- Planning work using flexibility from resources according to location registered on the flexibility platform;
- Flexible resources can also enable more efficient and flexible maintenance planning, potentially allowing maintenance activities to be completed without the need for planned interruptions (it could, for example, avoid the use of generator sets);

Coping with unplanned interruptions:

- Flexibility before failure can help to provide additional resilience to the network. Operating the network close to its technical capacity increases the likelihood of failure. To mitigate this risk, flexibility can be used to provide additional resilience during these periods.
- Post-failure flexibility would reduce the load or allow the network to be reconfigured to reduce the impact of the failure. Some network failures do not cause immediate supply interruptions, but if left unrecognised, can lead to prolonged interruptions. Flexibility could be used to reduce the risk of supply interruption until corrective measures are in place.

Figure 15. Different uses of flexibility

The contracting of services may be of a long-term nature (related to the process of investment in network infrastructure) or ad hoc, if risks to network operation have been identified that were not foreseen in the network development plan.

The demand for distribution system flexibility for the following day may be planned to use:

- Distribution grid flexibility only, consisting in particular of the coordination of the network topology with factors beyond the control of the DSO, but which may:
  a. Use of forecasts with a preset level of confidence (e.g., RES generation, customers' demand for capacity, dynamic network load). Forecasts are in principle subject to error, therefore supply reliability planning should take into account extremely unfavourable coincidences.
  b. Agree with e.g., the TSO as regards the transmission grid topology and network users as regards their participation e.g., in the energy market. It remains to be considered whether unforeseen events related to "third parties" should be taken into account at the DSO level (e.g., unplanned outages in the transmission network).
- Market flexibility in addition to grid flexibility. Market flexibility may be considered as "reserve capacity". In the network operation plans for a given period, the required capacity is specified but the use of services is not planned. The planned capacity may be activated in case of overdrawn network operation conditions, e.g., due to forecast errors or random events (distribution network emergencies).
- Market flexibility is complementary to network flexibility. Refers to situations where at the stage of planning of network operation for the following day, or in a shorter time, including real time, grid flexibility is insufficient to prevent congestion or where the DSO

is not able to activate grid flexibility resources (e.g., insufficient time for elimination of planned network outages). The network operation plans for the following day (or operatively) shall specify the required capacity and the use of flexibility services. The plans shall also take into account the required level of flexibility reserve associated with a possible forecast error of the network operation conditions.

2.4. Others

The DSO is responsible for determining the amount of energy to be contracted and conducting the open purchase process. Power plants, as well as all generation/receiving sources connected to HV, can participate directly or through aggregators, through simple interfaces and processes to obtain as many bids as possible from the market. DSOs will not need highly sophisticated sources of flexibility, but slow reacting resources (for planning purposes). It will be needed to create an advanced bidding platform with network topology information.

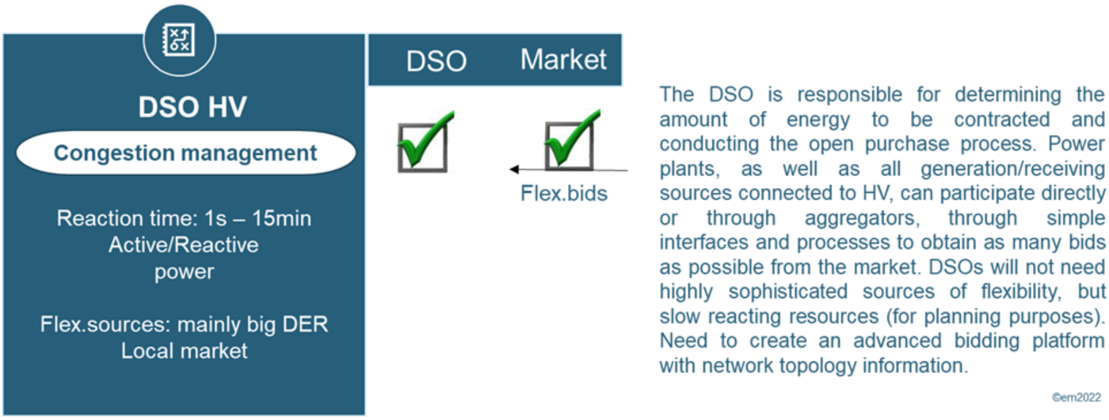

Figure 16. Flexibility for congestion management at HV

DSOs have specific line constraints (mainly in radial lines) which may limit the number of sources to be connected due to capacity or voltage problems. Advanced assets are an alternative to flexibility services. DSOs operating active network management systems can contract services from sources connected to the line to take and supply active and reactive power to stabilise the network voltage and, if required, thermal constraints. A direct contract between DSO and the flexibility source is possible.

Figure 17. Flexibility for congestion management at MV

DSOs have specific restrictions on transformers (mainly in radial lines), which usually limit the amount of connected loads/generation (heat pumps or EVs) and/or (PVs), due to thermal or voltage constraints. DSOs can implement through active system management (ASM) dynamic transformer control (DTC), based on data from dynamic load control systems. To determine the share of such resources in the flexibility platform and their qualification process.

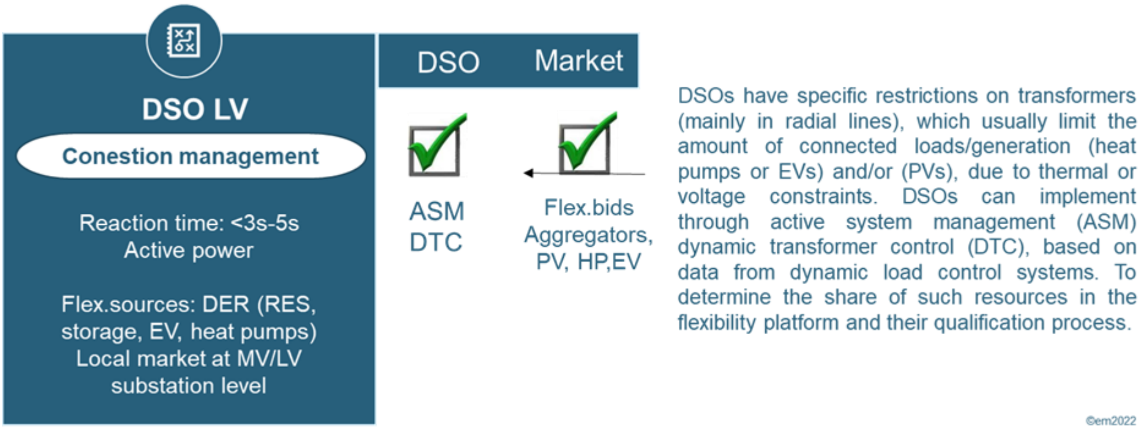

Figure 18. Flexibility for congestion management at LV

3. The main concept of DSO grid observability

The power grid is facing higher volatility when switching from fossil fuels production to new distributed production and also higher demands for new types of consumption i.e., EV, electrified roads, datacenters etc.

The power flow gives capacity issues in different areas of the grid and to solve this the DSO must make operational processes more effective and automated. The key to solving this situation is the use of IT solutions that can handle and analyze data from the power system. Access to complete and correct data is the most important perquisite to be able to analyze the state the power system is in and how it will be in the future.

Observability in the grid means the ability to observe how conditions are in different places in the grid. This is done mainly by measuring current and voltage but also other types of sensors i.e., status, temperature etc. Increased observability will give better knowledge about the grid and its behaviour and the ability to analyze it to make de right decisions.

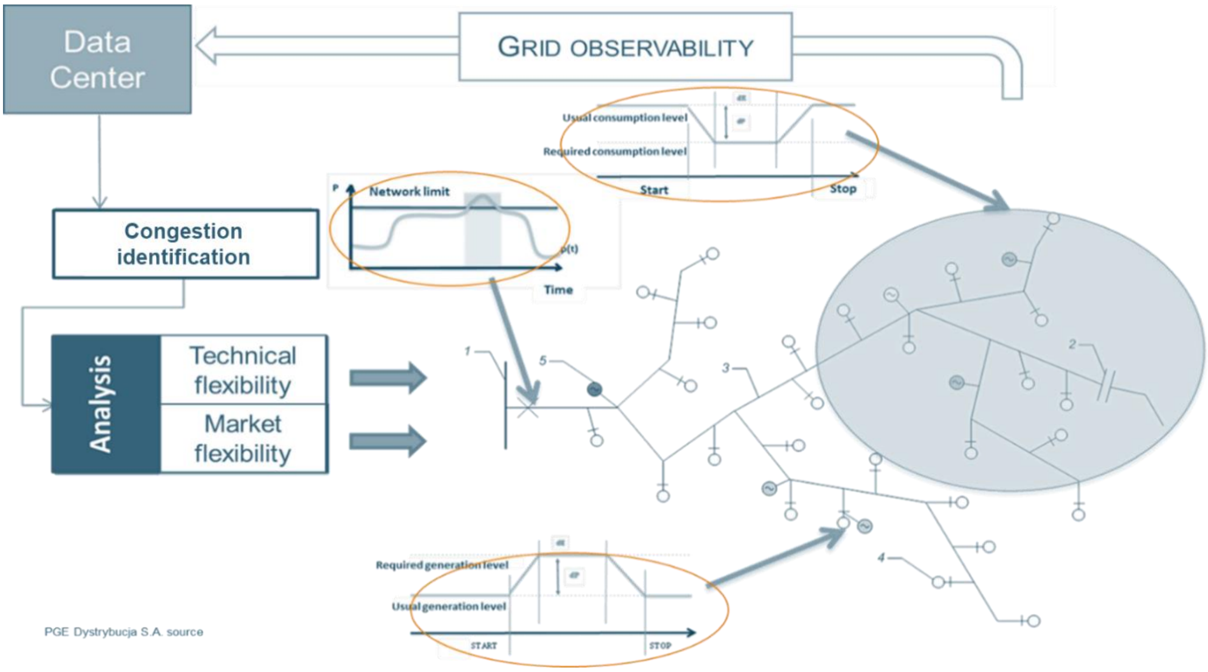

Figure 19. The main concept of DSO grid observability

Thanks to grid observability, the data acquired at the computing centre are analysed. The results of the analysis allow appropriate decisions to be made regarding the methods necessary to maintain stable network operation. Such an analysis could be carried out as follows:

- determining whether the existing tools and the level of technical capabilities (as operational actions on integrated network elements) used by the DSOs will be sufficient to ensure stable operation of the grid after the identified problem. If the level proves to be insufficient, the second step could be procuring flexibility services from flexibility sources available on the market. The ordered flexibility service must have defined parameters, at least: geographical-network location, required power or energy level, type of response, start time, duration, utilisation time,

- and simultaneous analysis of the most effective way to solve the problem existing on the network (not sequential). Thanks to advanced algorithms, it could be possible to identify the next steps to be taken to ensure technical and economic efficiency of the actions carried out in relation to both: grid flexibility and market flexibility.

3.1. HV

Under the operating conditions of the power system, the use of flexibility services at the HV network requires the expansion of the traditional SCADA system with modules ensuring communication with the dynamic overload line control systems and other disturbance detection systems. DOL solutions are one of the key components to ensure that the flexibility of the energy system can be exploited. The basic element is an autonomous set of sensors and measuring systems installed in a closed casing of severely limited dimensions, designed for installation directly on the line's working wires and requiring no additional maintenance during the entire period of operation. The devices are easy to install and, in particular, do not require precise calculations of the location on the service line. The devices are prepared for live installation and use digital prediction and a large range of elements appropriate for artificial intelligence. To measure the sag, mechanical vibrations of the low-frequency line caused by wind, heat exchange or cable temperature, among others, are used. Communication solutions provide access to real data on-line, even for sections of line where there is no radio coverage. In this situation, information from the line section is passed between successive sets of sensors until communication with the cloud is achieved, allowing the system to be installed on lines in any terrain and achieving increased reliability.

At the HV level, it is important to have remote metering of energy exchange points with transmission networks as well as with neighbouring DSOs. This is a necessary element for the proper identification of balancing areas (defined in the balancing market).

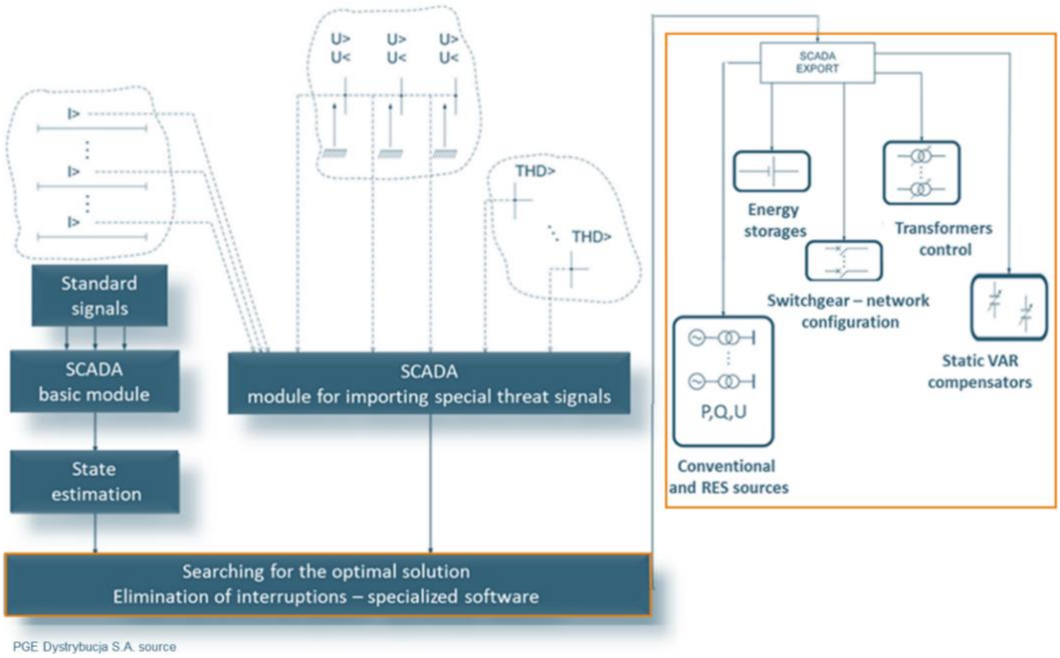

Figure 20. The main concept of DSO grid observability at HV

The next components are computer software that is quite difficult and demanding to apply - state estimation and development of optimal solutions (for elimination or mitigation of disturbances). Only based on the operation of these programs the signals exported by the SCADA system to the devices (flexibility resources) participating in the process of flexibility services offering could be worked out.

The figure above shows in a schematic way the interrelation of the above-mentioned elements of the system giving it flexibility characteristics. The response to disturbances includes overloading states, states with too high (low) voltage levels in network nodes and states with too high disturbance levels. Sources (both conventional and RES, providing flexibility services), energy storage (in the future), identified switchgear that influence network characteristics, transformer control systems (automatic and manual), capacitor banks, and static SVC compensators play an important role in their elimination or at least mitigation In the future operation of the flexible system. Facilities such as storage, compensators, etc. should be foreseen as service infrastructure that does not necessarily belong to the network operator.

An element which is equally important at the HV network level is a mechanism enabling smooth cooperation with the TSO concerning mitigating the resulting system instabilities. Given the progressing changes in the power system, characterized by bi-directional electricity flow, the use of flexibility available on the market should be based on such mechanisms that will firstly allow for unambiguous identification of the needs of both operators (TSO and DSO), their prioritization and the order of the access to flexibility sources, particularly when they are connected to the DSO network. In addition, special attention will be given to sources connected to the DSO network which provide services to the TSO, particularly in the field of balancing services, i.e. maintaining the frequency in the power system at a level which guarantees its safe operation. For this purpose, the cooperation of operators based on the use of the same data (information) for the determination of network needs is necessary.

3.2. MV

At the MV network, the support of control of disturbances by means of flexibility services should be similar, taking into account the limitations resulting mainly from the radial topology of operation of these networks and the one-sided power supply as the primary system. In MV networks the possibilities of regulatory actions are smaller, as generation sources do not provide sufficient power to achieve regulatory effects over a larger area. The role of fault location, isolation and services restoration response (FLISR) is important. It should be noted that FLISR can help perform as well network maintenance tasks and even perform dynamic reconfigurations.

To achieve favourable regulation effects and to appoint individual entities to perform flexibility services (according to the concluded contracts) both at the level of 110 kV and MV networks, it is necessary to introduce appropriate software (e.g. SCADA with the state estimation module).

To ensure a flexible response of the grid to phenomena (other than overload) related to RES connection, it could be good to introduce systems for the regulation of secondary substation transformers under load, and optimisation of inverter settings - mainly with a view to effective integration of PV installations into the system, beneficial for the grid in a global perspective; eventually standards for the introduction of these units should be developed. Extremely important network elements such as transformers (HV/MV and secondary substations) should be subject to remote monitoring of possible overload conditions, which in turn should take into account the thermal acceptability of such conditions. Metering systems of secondary substations AMI substations should be equipped with IT tools to enable analytical and statistical evaluation of the collected measurements, including the possibility of shaping customer profiles to increase network flexibility.

Information on the actual load status of secondary substations could be used to develop a new type of SCO system (self-acting frequency offloading), in which bus lines for emergency injections (under conditions of sudden global power deficit) would be selected dynamically, depending on the load status of monitored substations.

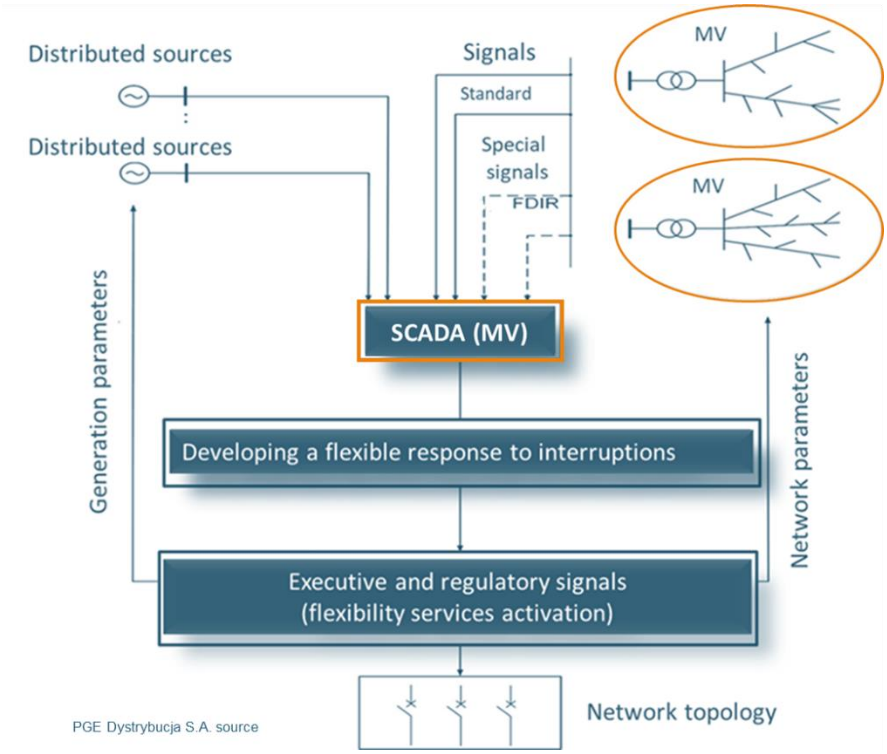

Figure 21. The main concept of DSO grid observability at MV

Having remote metering of secondary substations is and will enable the remote collection of information and real-time processing as well as analysis of this information. The results of the analyses (after taking into account all available information on the state of the network operation) should firstly focus on the identification of the current network instability, but also the forecasted one. To obtain forecasts with a high level of probability, it is necessary to implement specialised algorithms based, for example, on machine learning methods. To properly identified current and future risks, procedures should be developed to use the flexibility available in the system (network and market flexibility). The basic condition for the activation of flexibility mechanisms other than network flexibility should always be analysed from the point of view of its efficiency in terms of both the achievement of the stated objective (elimination of the disturbance) and the economic justification (the economic justification arises from Directive 2019/944).

3.3. LV

Distribution LV grids present special problems in terms of topological state. Such state information is crucial because it is the context in which grid data, events and control commands must be interpreted. The problems arise because, unlike transmission grids, the "as-built" topology for distribution grids is often not completely or accurately known. In addition, distribution grid topology can be dynamic, such as in cases where feeders are partially meshed or are tied to other feeders for reliability reasons. In such cases, circuit switches, sectionalizers, or reclosers may be operated to change the topology and such changes can be frequent.

Consequently, data flows in a given circuit section can reverse, as can voltage rises and drops. With the advent of Distributed Generation (DG) penetration on distribution feeders, power flow reversals and loops can occur, impacting protection and Volt/VAr regulation.

Low and medium voltage networks, although built in different configurations, operate as open systems. Therefore, the methods of their analysis, even though they concern different configurations (e.g. loop network, bus with branches operating with two-sided power supply) are analysed in the same way as simple radial systems.

As in the case of MV networks, the criterion for the assessment of the impact of distributed sources on the power system is the change in a load of system components under the influence of the power generated in them. Assuming that the devices and network equipment connected with the source itself and its switchgear were correctly selected by the designers and manufacturers, the essence of the problem consists in the assessment of whether the flow of the generated power (or its part) will not overload the existing network components outside the place of installation of the source. If that turns out to be the case, DSOs will either refuse to issue connection conditions for the sources or will plan a costly network reconstruction.

Installing a large number of PV micro-installations in low voltage networks can lead to an unfavourable voltage increase above the permissible value.

This can be remedied in several ways:

- adjusting the tap ratio of the 15/0.4 kV transformer,
- using the possibilities of reactive and active power regulation of PV sources,
- switching off the necessary number of sources,
- use of a dedicated special transformer in series to increase line reactance under voltage ramping conditions with simultaneous reactive power consumption by micro-installations (such systems are generally called LVR - Line Voltage Regulator)
- network modernisation (replacement of cables and transformer).

All these methods are cost that has to be borne by the operator and here the operator's activity is enforced by the RES Act and the obligation to "connect on notification", even if the connection causes problems - mainly for other grid users.

Of the several ways of reducing the voltage values during hours of maximum insolation with practically no investment, the proper selection of the characteristics of the inverters Q(U) and P(U).

However, this requires the involvement of operators, so that the certificates presented by manufacturers and installers are real and not fictitious, and that operators can force (or negotiate based on appropriate agreements) the activation of these characteristics and the selection of parameters according to recommendations. This solution will avoid, in many cases, additional expenses for network reconstruction An even more effective way may be to have the appropriate approach to the selection of the characteristics as a network service provided by the installation owner (prosumer).

AMI systems being implemented could be used to operate the LV networks as it allows the monitoring of measurements in the secondary substations.

Balancing meters used in the AMI systems and installed at secondary substations (i.e. transformers and feeders)could be used for network operation provided that at least some of them can be read in near real time. For a complete state, it would also be necessary to take into account loads and generation directly connected to the MV network.

Due to the amount of data required for processing, the AMI system will not be a real-time system, which is a prerequisite for traffic management. Therefore, the use of measurements in the LV network could be limited to selected (few) points in the depth of the LV network, e.g. places at the ends of LV lines with the lowest voltage level expected, places with high saturation of microgeneration. In particular, the use of three-phase smart meters is very interesting, compared to single-phase ones because they report all three phases. In low voltage, most of the problems are due to single-phase faults, therefore a three-phase meter is capable of detecting them and, even if they communicate by PLC, sending the incident through the other phases in a few seconds.

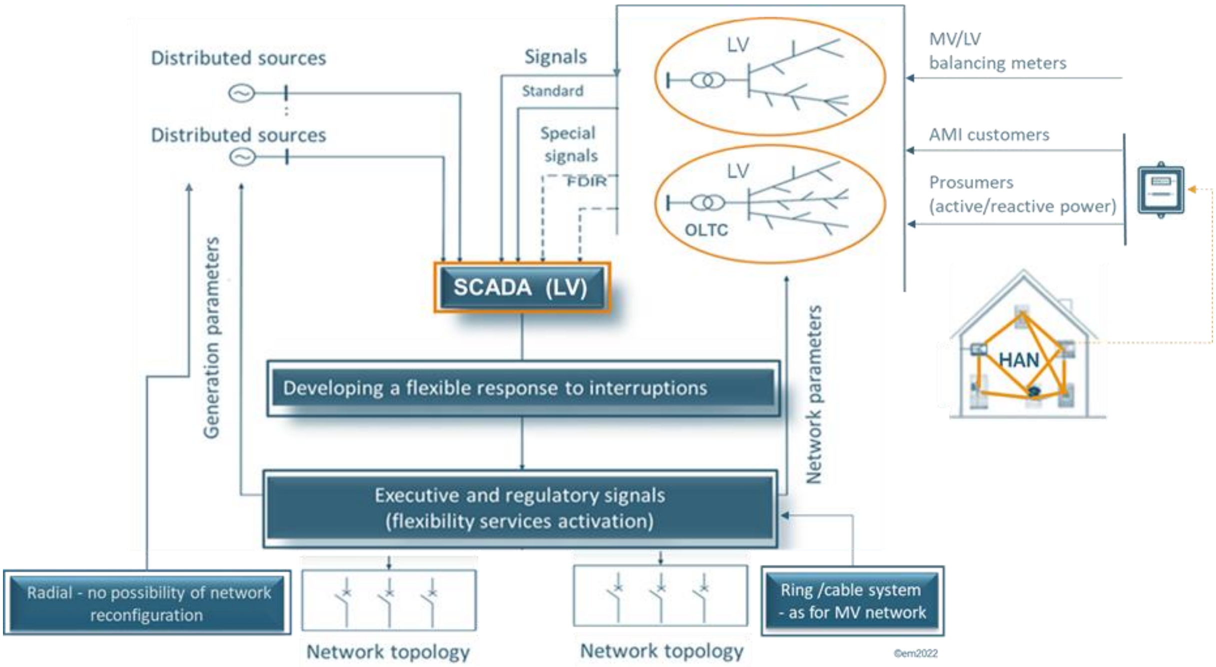

Figure 22. The main concept of DSO grid observability at LV

The advanced smart metering infrastructure enables the distribution system operators to measure and analyze electrical quantities such as voltages, currents and power at each customer connection point. Various smart grid applications can make use of the AMI data either offline or close to real-time mode to assess the grid voltage conditions and estimate losses in the lines/cables. The outputs of these applications can enable DSOs to take corrective action and make a proper plan for grid upgrades.

Manufacturers usually equip PV inverters with on-board monitoring systems which suit the needs of the (residential) plant operator. For PV systems connected to the LV level (i.e., for residential PV), data logged and cached by the inverter (e.g., power flows, AC voltages, etc.) are commonly sent to an online platform, which provides monitoring access for the plant operator. For non-residential PV plants (i.e., for commercial installations), third-party monitoring equipment is widespread, which also integrates communication paths for monitoring and remote control by the DSO or by a trading agent or aggregator. For LV-connected generators, an information flow of inverter data to the DSO, for whatever operational purpose, cannot be considered state-of-the-art. The PV inverter as a non-DSO source of potentially DSO-relevant data on LV should be made accessible. It would also allow safer operation, by being able to detect when it is being generated on an island (comment made earlier for another voltage level). One key advantage of this approach is the fact that the inverter is an existing source of data and therefore is expected to be exploitable for the DSO at a relatively low additional cost (compared to the cost for a monitoring system set up for the DSO purpose only). Until now, the main focus of the smart meter has been to provide information about consumption and/or production for consumers/prosumers and other market actors. The utilisation of the smart meter as a sensor on the low voltage grid has had less attention, although it is anticipated that it can, in combination with other smart grid devices, provide competitive advantages for DSOs to realise a more cost-efficient operation.

3.4. The future LV grids

For an electricity distribution system to evolve and adapt rapidly to variations in demand, the available resources must be optimized via intelligent technologies of smart grids. In this sense, an intelligent grid is a grid that smartly integrates new technologies to improve the monitoring and control of the operation of the system, in addition to being able to incorporate the users' actions connected to it. These networks are characterized by implementing, within the system, innovative equipment and services, new communication, control, monitoring, and self-diagnosis technologies. However, due to the fact of upcoming sector integration, the term smart grids takes on a new dimension.

Future electricity grids at LV will be characterised by a large number of distributed sources, actively managing both the consumption and production of energy. New energy production technologies on the consumer side, e.g. perovskites, energy-glazing, and energy roof tiles, together with the development of passive house technologies and energy storage, will lead to the creation of buildings or even self-sufficient areas. From the point of view of DSOs and depending on the management scenario, such an area may become invisible to DSOs or necessitate additional network management methods within that area.

Taking into account the adopted directions of development of the energy sector, which will be based on two basic pillars, i.e. electrification and integration, it should be assumed that significant changes will take place at the LV network level compared to the current operation and management models. It is therefore possible to list some general elements that will influence the model of functioning of future LV grids:

- Increased demand for electricity i.e. additional load on the grid by flows, increased fluctuations in voltage levels,
- The widespread phenomenon of bidirectional electricity flows resulting from the development of distributed generation (according to the art 2 (32) of 2019/944 Directive, ***'distributed generation' means generating installations connected to the distribution system***;
- Increased consumer activity, but also new forms of consumers taking advantage of the available opportunities to manage their consumption and production (systems managing the optimization and efficiency of the equipment, technologies and algorithms used),
- Energy storage will play an important role, as well as all elements of consumer activity leading to increased auto-consumption or obtaining additional benefits resulting from the activity,
- The integration of different sectors of the economy will result in a complex system with a large number of elements and diverse interactions between these elements. This will have a significant impact on the operation of the electricity grid, especially in the area of proper prediction of the behavior of the electricity system as one of the elements in such a complex structure,
- Sector integration will necessitate the implementation of advanced techniques for the collection, storage and analysis of data from many different sources and in many different formats. Sources of data necessary for proper LV network management will no

longer be understood as data specific to DSO, i.e. from smart meters or additional equipment installed on lines or substations owned by DSO. Importance will be given to data located on the side of all elements of the new integrated market model.

- Network management methods of the future will be based on technologies allowing for precise identification of network development needs and possible problems in managing its stable operation, which will be based on Digital Twins. DT is a digital representation of all the elements of the system together with the environment that influences its work, which will make it possible to carry out various simulations of behaviour, also when "virtually" replacing its elements with new ones with different parameters,
- Cyber-security elements will become essential. In the digitalized world, all the procedures used so far will change, as the dimension of the danger of disturbing the balance of the network operation becomes much greater, requiring constant observation, monitoring and controlling of all the elements of the integrated system, even those seemingly unimportant (e.g. a thermometer in an aquarium connected to the Wi-Fi network of the customer could be the door for cyberattack).

3.5. On-line capability to identify system status

Power system control is not an easy task due to its complexity. Massive data collection (their redundancy), connections with neighbouring systems, and increase of requirements concerning the safety and reliability of the system operation cause it becomes necessary to support the work of dispatch centers on different levels by computer systems and their protection from unimportant information. One of such areas where advanced software is used is the real-time modelling of the system. In addition to that, we must indicate that the current acquisition must evolve into a real-time acquisition. This is not an easy task due to information overload and the fact that even today, some areas of the network are unobservable. A way to identify the system state on-line is to estimate it based on measurements and data describing the network topology. The main function of the state estimator is to determine the model describing the current state of the power system as close to reality as possible, and more precisely - to determine the values of voltages and the mutual position of their phases for individual nodes of the network. Having the data determined in this way, it can be used for further calculations, such as optimisation of generated power. The procedure of state vector estimation for a power system consists of the following tasks:

- network topology analysis - obtaining the current mathematical model of the power system;
- data verification - validation of measurements (identification and rejection of measurements with errors);
- observability test - checking if the set of measurement data is complete;
- state estimation - reconstruction of the system state (determination of nodal voltage vectors and their angles);
- detection and identification of erroneous data.

4. Flexibility sources management methods

The role of DSOs is rapidly evolving due to the new technological advances, and the energy transition. Active consumers and decentralized generation as well as the emergence of new actors such as aggregators, EV charging operators, and energy communities, will increase significantly the flexibility resources that DSOs will have to manage as well as the numbers of parties that will have the potential to participate in flexibility procurement procedures. In addition, the withdrawal of central generation will increase the need for flexibility that will have to be provided by DER. This requires that DSOs will procure and use flexibility services to resolve local and central system needs (e.g., balancing and congestion management). The Clean Energy for all Europeans package[18] and the Electricity Directive[19] encourage the introduction of needed regulatory frameworks to enable DSOs to procure flexibility services using transparent, non-discriminatory, and efficient procedures.

Different approaches exist for the procurement of flexibility. In this regard, CEER identifies four main mechanisms of the highest relevance[20]:

- **Rules-based approach**: The requirements for the flexibility provision are imposed via codes and rules.
- **Network tariffs**: Cost-reflective network tariffs may be designed to encourage customers to modify their behaviour to use the distribution network more efficiently. Flexibility provision can be supported by cost-reflective network tariff structures, providing active consumers and generators with the right price signals for their use of the network. Cost-reflective tariffs incentivise network users to adapt their use of the network according to the load and capacity of the network. These tariffs can take many forms and can include aspects such as time, direction, capacity and location. Examples are time-of-use tariffs – either tariffs that are generally more capacity-based or tariffs that are higher for users who demand unrestricted access to the grid (volume tariffs).
- **Connection agreement:** DSOs could reach (generic) agreements with customers for the provision of flexibility. A solution for DSOs to prevent congestion is to access flexibility through connection agreements. If the right conditions are applied, these arrangements can help reduce network investments and create a win-win situation between network users and the DSOs. For example, instead of planning the grid to provide generators and consumers with a firm physical connection to the grid 100% of the time, contractual agreements could introduce variable network access or flexible connection agreement for generators or consumers who opted for such an arrangement. Based on financial incentives (e.g. cheaper connection costs) these parties could agree to limited access when the network is constrained. Also, for generators, it may be allowed to connect more capacity power to the grid.
- **Market-based approach**: Market-based solutions rely on a procurement of flexibility services following a market-based procedure where flexibility is provided and allocated explicitly. In this system, the price shall be fixed by the law of supply and demand, rather than by a regulated actor. The flexibility could be procured via (bilateral) contracts or in a short-term market. Flexibility providers, voluntary and explicitly participate in the foreseen procurement procedure for a certain service needed. A broad scale of market-

[18] https://energy.ec.europa.eu/topics/energy-strategy/clean-energy-all-europeans-package_en

[19] DIRECTIVE (EU) 2019/944 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 5 June 2019 on common rules for the internal market for electricity and amending Directive 2012/27/EU

[20] CEER, *Distribution Systems Working Group Flexibility Use at Distribution Level A CEER Conclusions Paper,* March 2018

based mechanisms exists to obtain sufficient flexibility, amongst which tendering procedures, auctions and continuous trading.

Among the above methods, the spirit of the Clean Energy Package dictates that market-based solutions for flexibility procurement are to be pursued in order to empower customers and active market participation. DSOs should accordingly act in their role as neutral market facilitators. The feasibility of market solutions for procuring flexibility is linked to local specificities and potentially market failure. Local specificities are defined by the availability, in numbers and volume, of technologies and services, as well as the local needs in terms of flexibility, which need to be specified.

DSOs thus will have to examine the above methods and select among these different types of solutions for undertaking flexibility management, for an efficient operation and planning of their network. In any case, all models should not distort the markets and comply with unbundling rules. It must be noted that the use of a combination of methods can be as well applied (e.g. network tariffs incentives simultaneously with the deployment of market mechanisms).

4.1. Market applications

Market-based solutions are the preferred option for the procurement of flexibility on a competitive basis. A flexibility market for DSOs is a market where several players compete to provide flexibility services to the DSO being the single buyer. In their bids to the DSO, flexibility providers take into account the value of their flexibility in other market segments, such as the energy wholesale market. Market-based procurement can be applied in different timeframes, for example through the implementation of a competitive tender for long-term provisions or a local flexibility market to address short-term needs. Short-term procurement of flexibility should always be open to all resources, including those that have not been subject to long-term contracts.

Market-based procurement forms should promote the efficient use of resources and services. From this perspective, the flexibility procurement mechanisms should be designed so that the contracted resources are incentivized to value other services when the DSOs do not need them. For instance, independent flexibility platforms can create the conditions for market places open to multiple buyers, e.g. DSOs and TSOs.

The flexibility markets with DSO participation already exist in several initiatives in different European countries - such as PICLO[21], Cornwall Local Energy Market (LEM)[22], Enera[23], GOPACS[24], NODES[25], in The United Kingdom (Schittekatte & Meeus, 2020[26]) as well as in various European projects such as CoordiNet[27], INTERRFACE[28], OneNet [29], CROSSBOW[30].

According to CEER, points to be considered when applying market models are:

- The technology neutrality, so that any flexibility resource can take part in the markets on equal terms as the rest of the participants (i.e. the same regulatory principles are applied regardless of the technology) and,

[21] https://www.piclo.energy/, (accessed on 27 April 2021)
[22] https://www.centrica.com/innovation/cornwall-local-energy-market , (accessed on 27 April 2021).
[23] https://www.usef.energy/implementations/enera/, (accessed on 27 April 2021).
[24] https://en.geopacs.eu , (accessed on 27 April 2021).
[25] https://nodesmarket.com/ , (accessed on 27 April 2021).
[26] T. Schittekatte, L. Meeus, *Flexibility markets: Q&A with project pioneers*, Utilities Policy 63 (2020) 101017, 2020
[27] https://coordinet-project.eu/projects/project , (accessed on 27 April 2021)
[28] http://www.interrface.eu/ , (accessed on 27 April 2021)
[29] https://onenet-project.eu/onenet-flexibility-products-and-market-analysis/ , (accessed on 27 April 2021)
[30] http://crossbowproject.eu/ , (accessed on 27 April 2021)

- The flexibility providers should have, as basic, short-term contracts (e. g. with a network operator) to be able to provide their flexibility to different market participants in the power system,
- Long-term contracts may be necessary in cases where there is a lack of liquidity in the flexibility services market, as well as for the planning of the grid development,
- To make sure that markets are effective, more data transparency and clarity on the type of information that is needed are required. Building confidence in the market is also key, including confidence in the parties involved and in the revenue streams
- Market-based procurement forms should promote the efficient use of resources and services. From this perspective, the flexibility procurement mechanisms should be designed so that the contracted resources are incentivized to value other services when the DSOs do not need them. Market-based procurement can be applied in different timeframes, for example through the implementation of a competitive tender for long-term provisions or a local flexibility market to address short-term needs. Short-term procurement of flexibility should always be open to all resources, including those that have not been subject to long-term contracts.

4.2. The main tasks related to market-based procurement

Given the market-based approach to flexibility procurement, several main tasks need attention. These are:

- services,
- products standardization,
- time frames,
- coordination scheme,
- baselining - remuneration models,
- trading types.

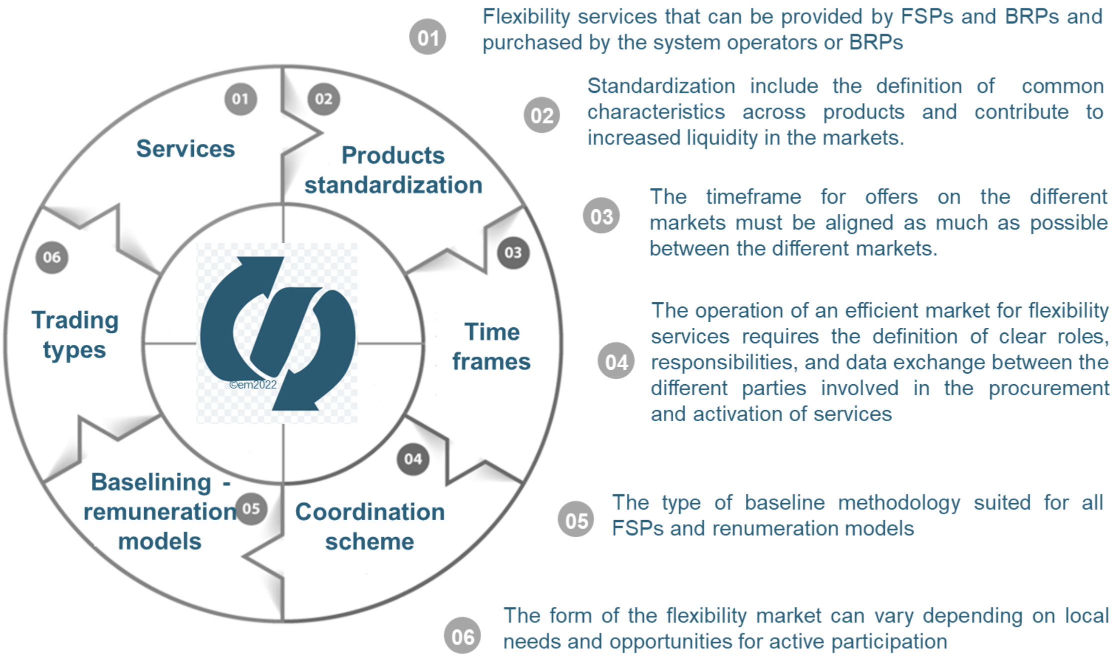

Figure 23. Market-based approach to flexibility procurement – the main tasks

4.2.1. Services to be provided by FSPs

To achieve technology neutrality so that any flexibility resource can take part in the markets on equal terms as the rest of the participants, the operators shall make procurements of services which are delivered by standard products.

Figure 24 illustrates a list of flexibility services that can be provided by FSPs and BRPs and purchased by the system operators or BRPs[31] .

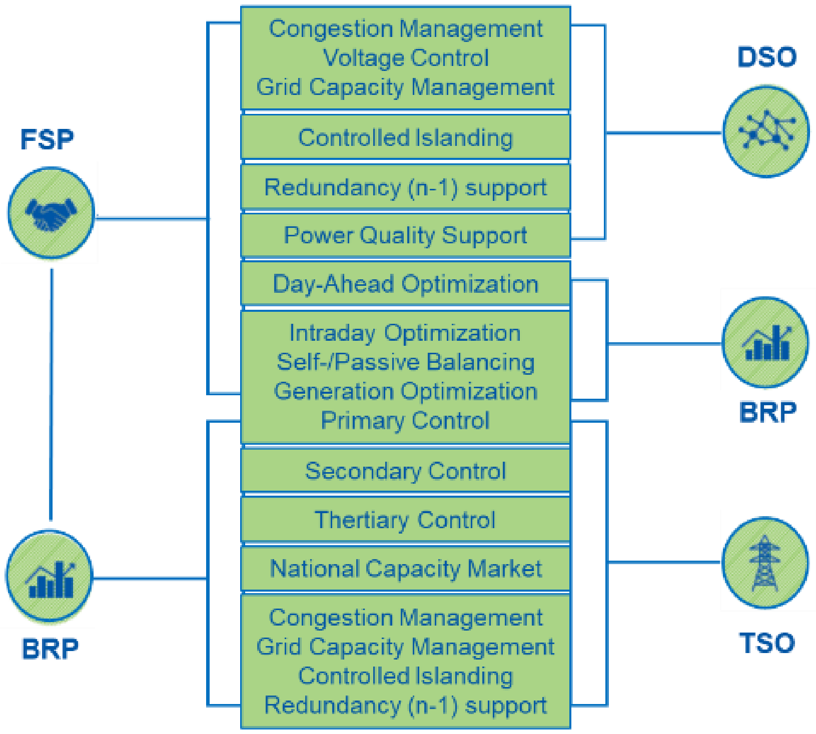

Figure 24. A list of flexibility services in relation to FSPs and BRPs

- **Balancing**: Due to the decentralization of the energy system and the abolishment of several central power plants, the participation of distributed resources in the balancing market will be necessary for the next years to achieve the energy transition without jeopardizing the system's security. A market-based procurement is already deployed in most countries for this type of service, where many different types of market players can provide frequency control services. The market is relevant only for TSOs.
- **Voltage**: Voltage control is a great challenge as generation is becoming more decentralized and fewer centralized production units remain in operation. The lack of central units capable of injecting/absorbing reactive power as well as reversed power flows in distribution networks due to high penetration of DER sources creates additional voltage issues which have to be resolved by the DSOs and TSOs. Voltage-related services are usually defined within the grid codes and are, hence, regulated and not remunerated. Bilateral agreements with the grid operator are also in place. Market-based procurement approaches are currently under analysis and development to complement the mandatory requirements.

[31] Based on https://www.usef.energy/app/uploads/2021/05/USEF-The-Framework-Explained-update-2021.pdf

- **Congestion management**: Congestion is a condition where one or more constraints (e.g., thermal limits, voltage limits, capacity limits) restrict the physical power flow through the network. When including congestions at the distribution system level, a separate market can be established only for the DSOs, or the integration with other existing markets for solving constraints at the transmission level can be considered.
- **Inertial response**: As the synchronous generation is substituted by distributed generation, the level of inertia available to the system decreases. This may lead to dynamic security issues under significant disturbances. Thus DER shall provide inertia services to the system
- **Black start capability**: This service is procured to ensure that the system (in its multiple areas) can always be restored effectively and economically and is incorporated into the TSO's restoration plans. The deployment of a market-based approach could incorporate new providers and technologies.
- **Controlled island**: As in the case of the black start service, controlled islanding mainly depends on the location and the nature of the grid under consideration, which hinders the development of markets for the procurement of this service.

Table 1. summarized the different procurement approaches for such services. For some of them, there is already an existing market mechanism (such as a balancing market).

Table 1. Different procurement approaches for each system service[32]

SERVICE	PROCUREMENT APPROACHES	EXPLANATION
Balancing	Market-based	A market-based procurement is already deployed in most countries. Many different types of providers can provide frequency control services.
Congestion management	Market-based	The efficiency of the market-based procurement will depend on the nature of the congestion and the voltage level.
Voltage	Regulated / Bilateral contracts / Market-based	Voltage-related services are usually defined within the grid codes and are, hence, regulated and not remunerated. Bilateral agreements with the grid operator are also in place. Market-based procurement approaches are currently under analysis and development to complement the mandatory requirements.
Inertial response	Future market-based approach under analysis	Technical developments are still necessary for the provision of this service by intermittent resources. ENTSO-e is currently considering including inertial response as a future system service to be procured via market-based mechanisms.
Black start capability	Bilateral contracts Future market-based approach under analysis	Specific to the TSO's grid restoration plan, depending on which, the TSO may request some support from the DSOs. The potential of new types of providers needs to be investigated to define a future market-based black start service provision.
Controlled islanding	Bilateral contracts	Reserve procurement long-term ahead. In addition, local balancing and voltage control may be necessary.

[32] Based on INTERRFACE_D3.2-Definition of new/changing requirements for Market Designs, IAEW (2019),

4.2.2. Market products

A market-based allocation of the abovementioned grid services products for grid services shall be defined. These products may be either standard products or specific products. Standardization and harmonization include the definition of common characteristics across products and contribute to increased liquidity in the markets since the more buyers use the same product specification, the more providers can deliver the standard product. Thus standardization enables market parties to effectively bid into one or more markets, by providing one or more services.

Standardization of products may include the definition of the following parameters:

- Minimum/maximum bid size (e.g. 1 MWh or 10kW),
- Minimum/maximum duration (e.g. 15 min / 60 min),
- Definition of congestion point (identification of the congested area),
- Bidding period: time granted to the market parties to offer bids,
- Selection period: time required by the system operator to select the bids which will be activated,
- Activation period: time before activation signal and ramp up period (1h, 15 min, 0 sec)
- Maximum ramping period (15 min, 5 min, …),
- Minimum full activation period (15 min, 30 min, …),
- Mode of activation (automatic, manual),
- Availability window (per day, per week, per year),
- Frequency: Maximum number of activations (per day, per week, per year),
- Recovery time: Minimum time between activations,
- Recovery conditions,
- Baseline methodology,
- Measurement requirements,
- Pooling allowed (Yes / No),
- Penalty for non-delivery (fixed or dependent on the bid size and/or duration, €10.000, €1.000, …).

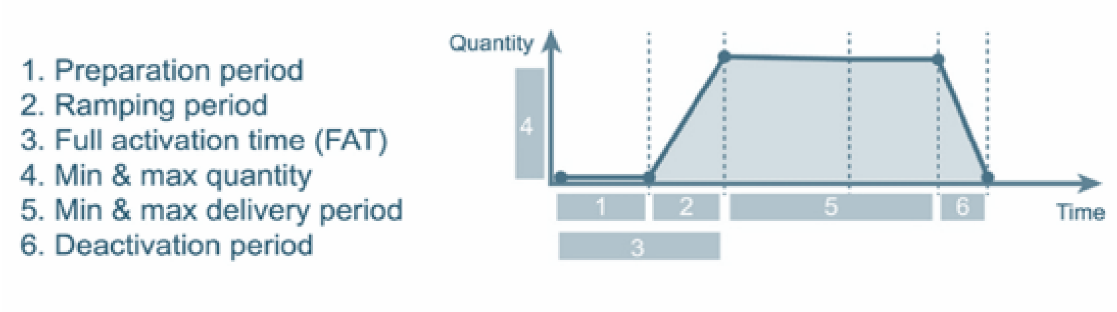

Figure 25. The visualization of some product parameters[33]

4.2.3. Market Timing

Market-based procurement can be applied in different timeframes, and since FSP can more than one market operate. The timeframe for offers on the different markets must be aligned as much as possible between the different markets. It is attractive for FSPs to participate in different markets to stack value and make their products profitable.

The following parameters shall be identified in a market mode

[33] CoordiNet Project, D1.3, 2019, p. 25

Market horizon/Optimization period/Delivery window:

- Time granularity/time step: Time granularity for the market clearing (e.g. 1 hour on the day-ahead market).
- Gate closure time: Time at which orders from market participants can no longer be changed and no new orders can be accepted.
- Clearing frequency: It defines how often the market is cleared (e.g. every day for the day-ahead market).
- Max market clearing duration (also called maximum activation optimization function): maximum time allowed to the market clearing to find a(n) (optimal) solution.

4.2.4. Market coordination

The operation of an efficient market for flexibility services requires the definition of clear roles, responsibilities, and data exchange between the different parties involved in the procurement and activation of services. Since services are procured by both TSO and DSO and are provided by assets connected to the transmission and distribution grid, it is important to establish the corresponding TSO-DSO coordination for a market solution. In the past, roles and responsibilities were clearly distinguished between TSOs and DSOs. However, the energy transition, from central to decentral energy generation, increases interactions between system operators and requires revising the allocation of roles and responsibilities to manage these interactions.

Different coordination schemes may be proposed according to the identification of the flexibility needs, the stakeholders involved in the procurement and the access of the TSO to the flexibility assets connected to the distribution system.

Some coordination schemes may define more decentralized markets than others, which implies that in the former smaller markets have to be cleared, either in parallel or sequentially. Sometimes, bids may be cleared multiple times when they are cleared in a first market and then sent on to a second market.

Depending on the location, more or less coordination between the affected DSOs and TSOs would be needed. It must be noted that during the operation of the island, at least balancing and voltage control services will be also needed.

SmartNet[34] project identified five coordination schemes (CSs) that could enhance interaction between system operators[35]. From the first to the last CS discussed in the horizontal reading direction, there is a gradual expansion of the DSO role. Figure 26 gives an overview of the different CSs.

[34] https://cordis.europa.eu/project/id/691405/results ,

[35] H. Gerard, E. I. R. Puente and D. Six, "Coordination between transmission and distribution system operators in the electricity sector: A conceptual framework.," Elsevier Utilities Policy, vol. 50, pp. 40- 48, 2018.

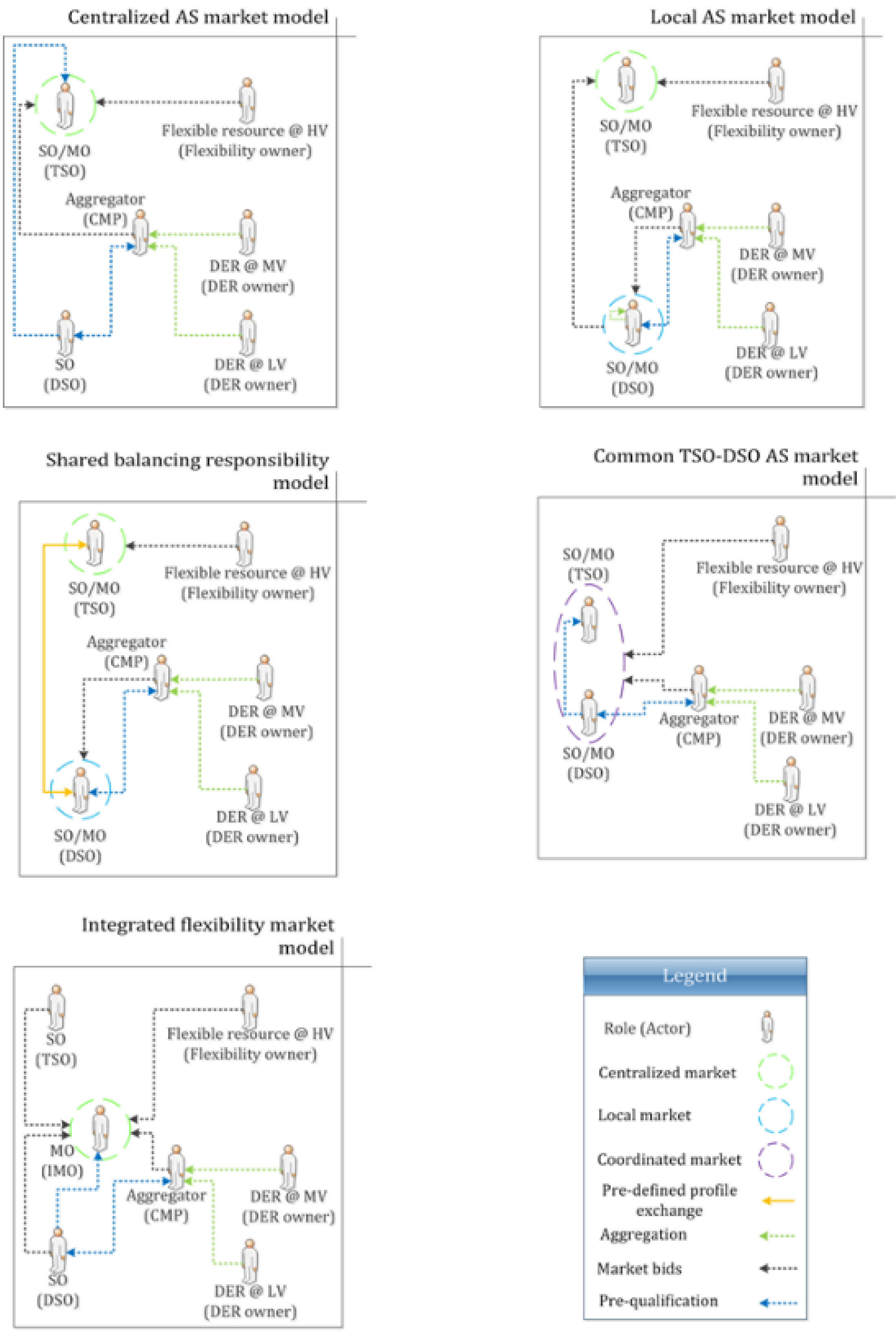

Figure 26. Comparison of various ancillary services (AS) market models[36]

[36] FlexGrid, *A novel smart grid architecture that facilitates high RES penetration through innovative markets towards efficient interaction between advanced electricity grid management and intelligent stakeholders. OPF objectives and challenges towards smart grids with high RES penetration*, H2020-GA-863876, Deliverable D5.1, 2020

Centralized AS market model. For both resources connected at the transmission and distribution level, there is one centralized, common market for AS (e.g. frequency control, congestion management, and voltage control). Regardless of whether the resources are connected at the transmission or distribution level, the centralized market is in this CS operated by the TSO. The market operator determines the technical needs to operate the system in real-time and communicates the required amount to the market. The TSO contracts flexibility from DER directly from the DSO grid without taking into account the distribution grid constraints. A prequalification process could be optionally added to ensure that the activation of DER from the distribution grid is respecting DSO grid constraints. In this coordination scheme, the DSO is not involved in the procurement and activation process of AS by the TSO. In addition, the DSO is not procuring local flexibilities to solve local grid issues in real-time or near real-time.

Local AS market model. A separate local market for system services is implemented for flexibility resources at the distribution grid, which is operated by the DSO and cleared before the centralized AS market is operated by the TSO. FSPs send aggregated flexibility bids either to the local or the AS market, depending on whether they are connected to the distribution or the transmission grid. When the local market is cleared subject to the DSO's local constraints, the selected bids are reserved for the DSO's local use. Bids that are not selected and not procured at the local market, can participate in the AS market where the resources connected to the transmission grid participate. The role of the TSO is limited to the operation of its own AS market.

Shared balancing responsibility model. This is a variation of the Local AS market model with both a Local and a Central market. The difference is that the Shared balancing responsibility model does not allow resources from the distribution grid to be offered to the transmission grid. Instead, the DSO is responsible for balancing his distribution grid according to a pre-defined schedule between the TSO and the DSO. The pre-defined schedule can be specified either at the level of the entire DSO-area, or it can be determined for each TSO-DSO interconnection point. The market clearing of both markets occurs simultaneously.

Common TSO-DSO AS market model. The Common TSO-DSO AS market model is proposing a common market for flexible resources connected to both grids. The operation of this market is done by both system operators, to optimize the outcome of the system as a whole. As such, the TSO has access to AS services from both grids, while the DSO can still use flexible resources from the distribution grid. There is no upfront priority for the TSO or the DSO. In practice, the implementation of this market model could consist of one single platform), or multiple smaller platforms (separate local DSO markets for local grid constraints) that are connected (decentralized variant).

Integrated flexibility market model. This CS allows both regulated (SOs) and deregulated (commercial market parties) parties to procure flexibility in a common market. All market players that need or want to offer flexible resources can do so by communicating their needs or bids to the market operator. This market operator should be an independent market operator to ensure market neutrality and to make sure that a level playing field is created for all players. If the market functions properly, this implies that resources are allocated to the party with the highest willingness to pay. This might result in SOs who do not necessarily receive what they asked for and therefore would buy additional capacity upfront.

A more recent approach to the classification of coordination schemes has been performed in CoordiNet project. Figure 27. illustrated the classification of coordination schemes.

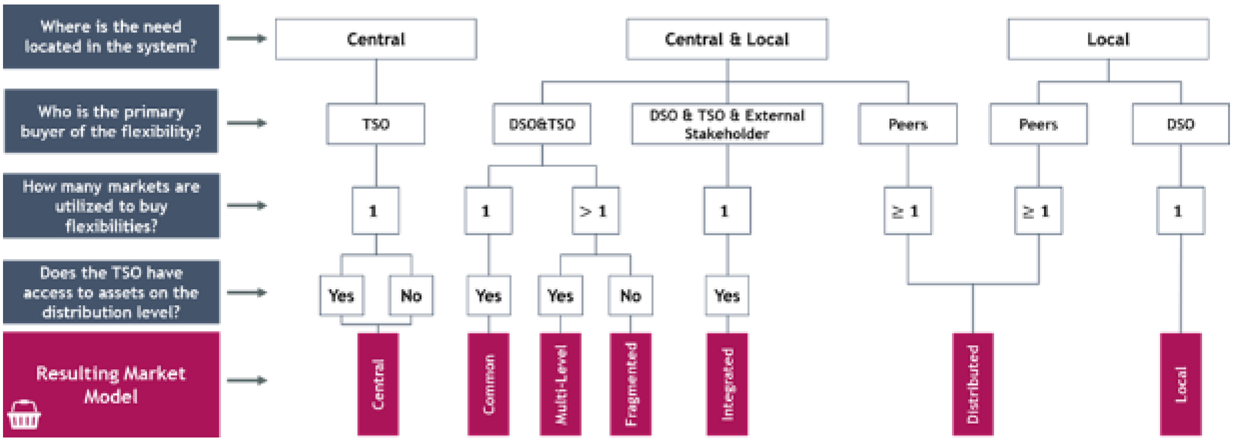

Figure 27. Different TSO-DSO Coordination Schemes[37]

The following market models are derived from the above classification:

- Central Market Model
- Common Market Model
- Multi – Level Market Model
- Fragmented Market Model
- Integrated market model
- Distributed Market Model
- Local Market Model

4.2.5. Baselining

Baseline methodologies can be classified into different groups depending on characteristics such as the type of data that is used and the method governing how the selected data is processed to calculate a baseline for a given period. For example Meter Before - Meter After (MBMA) baseline methodologies are widely used for accurately estimating the level of service delivered under real-time dispatch conditions and short activation periods. It is also a preferred baseline for services with frequent activations as it does not require the use of significant amounts of undistorted historical data. For these reasons, MBMA baseline methodologies are very common in balancing products.

MBMA baseline methodologies are most commonly used for products that have a short activation period and a short time between the activation request and the start of the activation. However not for all products (grid needs, data availability) this one would be the best. That is why it would be reasonable to take into account all relevant parameters before setting baseline methodologies.

Another example: historical baseline methodologies are commonly used for products such as mFRR, adequacy and DA/ID. Particularly for adequacy and DA/ID products, which are characterized by longer activation periods and longer times between the activation request and the start of the activation, historical baseline methodologies tend to be preferred compared to other less accurate baseline methodologies such as MBMA methodologies. In contrast, the use of historical baseline methodologies is limited for products such as FCR and aFRR, which are characterized by short activation periods and a short period between the request for activation and the start of the activation.

[37] CoordiNet Project, D1.3, 2019, https://private.coordinet-project.eu//files/documentos/5d72415ced279Coordinet_Deliverable_1.3.pdf

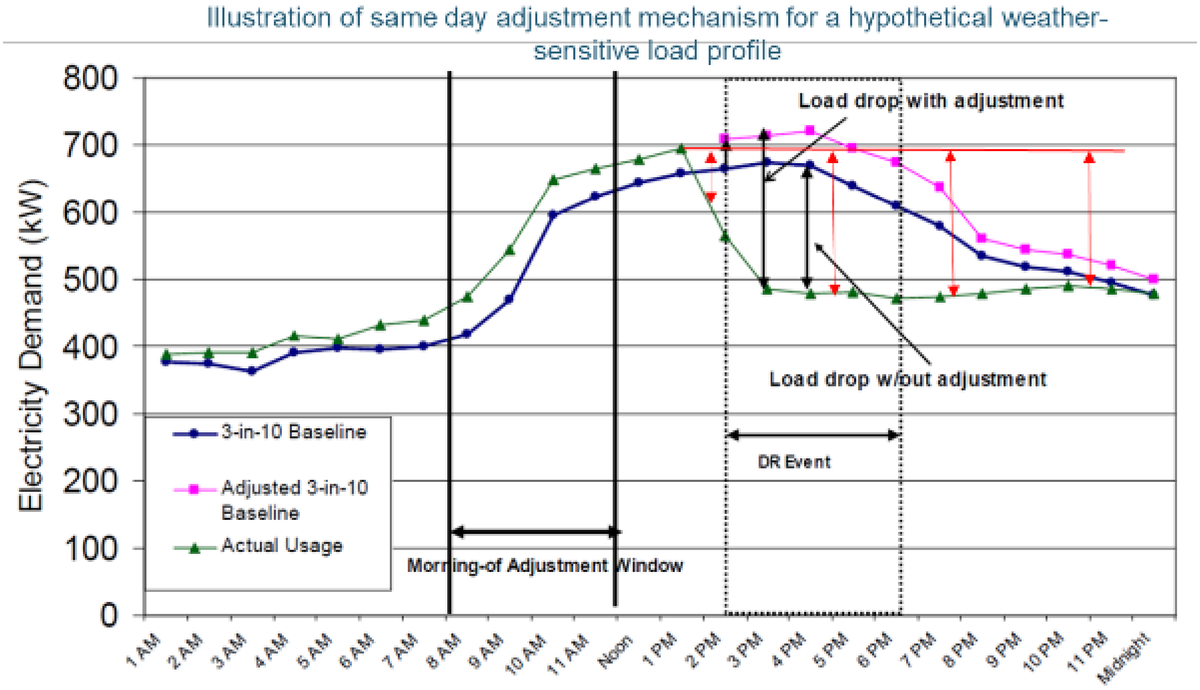

Figure 28. A hypothetical baselining methods[38]

4.2.6. Trading types (market architecture)

The design of a market architecture includes the definition of a set of parameters

- Market Timing
- Trading Types
- Auction Types
- Pricing Methods
- Constraints
- Network Representation
- Objective Function

[38] Adopted from B. Kaneshiro, Baselines for Retail Demand Response Programs http://www.caiso.com/Documents/PresentationBaselines_RetailDemandResponsePrograms.pdf

5. Communication

The key to ANM is the interaction between different systems in different locations. This interaction strongly depends on fit-for-purpose, reliable and affordable telecommunications. The used solutions used could be a combination of various technologies, for example, PLC for smart meters to the secondary substation and 3G/4G to connect with the acquisition system.

The following paragraphs present an overview of the different technologies which can be applied to implement these telecommunications.

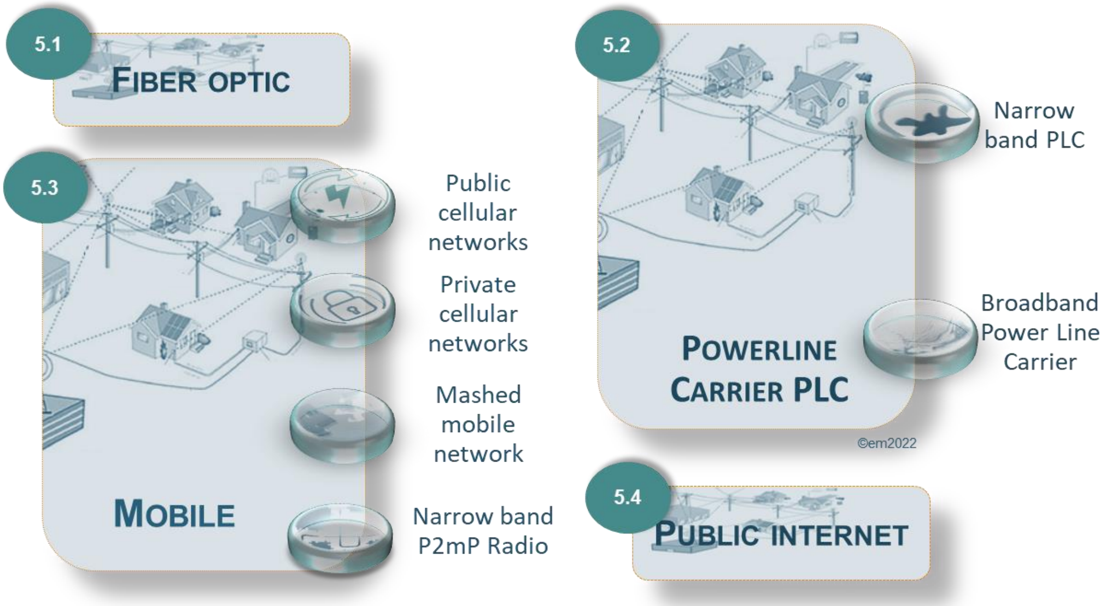

Figure 29. An overview of different communication technologies

5.1. Fiber optic

Primary substations were traditionally connected using dedicated cupper wires (pilot cables). These cupper wires were originally used for serial low-speed communications, however, nowadays they can be used to establish digital subscriber line (DSL) broadband connections. The deployment of dedicated fiber optic connections at primary substations began more than 20 years ago. During this time they have become the standard to connect primary substations to the central system landscape and have made the installation of pilot cables just residual for very special situations. Dedicated fiber optic connections present notable advantages in terms of stability, reliability and transmission capacity. The problem with the use of this type of connection to provide telecommunications for ANM is related to its high deployment costs, which make them not feasible for most ANM sites which are connected to the grid at secondary substations. An exception is those sites were fiber cable is available because of another purpose, e.g. provide a telecom circuit by differential relays, in such case the fiber optic connection can be used for ANM telecommunication.

5.2. Powerline Carrier (PLC)

Power Line Communication is a technology which allows the utility to deploy telecommunication links without relaying in either any third party or any extra infrastructure as MV and/or LV cables, owned by the utility, are used to transmit the data. This fact makes PLC a reliable and affordable technology. What is more, the use of PLC seems to be the widespread solution for smart metering systems due to its cost efficiency.

Utilities currently use two different PLC technologies:

- **Narrow band PLC**: In this case, the amount of data transmitted is limited to a few tens of kilobits per second. The range is normally around one hundred meters and mesh topologies can be applied. These features make this technology to be appropriate for LV cables.
- **Broadband Power Line Carrier (BPL)**: In this case, the amount of data transmitted reaches a few megabits per second. The range is equally higher and up to a couple of kilometres per hope. The topologies are point-to-point or point-to-multipoint. All this makes this technology to be appropriate for MV cables, although standards for LV cables are currently under development.

5.3. Mobile

5.3.1. Public cellular networks

Public cellular networks have become obliquus in most countries allowing for them to be used to provide the smart grid telecom needs at affordable costs except in certain rural areas where the lack of coverage prevents their use.

The technologies used by the carriers to deploy cellular networks range from 2G (CDMA and GSM) to 5G, including 2.5G (GPRS), 3G and 4G (LTE). The possibility to use a public cellular network to cover the telecom needs associated with the ANM premises will need to be analyzed given the available network features. Special attention will be paid to the bandwidth, latency and jitter parameters to ascertain if the cellular network is suitable according to the telecom needs. Network stability is another aspect which will need to be considered carefully, as public networks may become unavailable under certain circumstances such as emergencies or mass events. Finally, the existence of a backup power supply in the carrier network will need to confirm as the public network may stop working following a power cut when it will be more important for any ANM premise.

The mentioned problems may be mitigated with the use of double SIM equipment, with each of the SIMs connected to a different carrier network.

5.3.2. Private cellular networks

The inherent problems with the use of public networks described in the previous section can be sorted out by the deployment of private cellular networks.

In certain countries local regulation allows the utilities to use spectrum for the deployment of cellular networks to cover the utility telecom needs. The self-owned network can be used to provide the telecom needs required by the ANM premises. It should remain clear that the private cellular network should be deployed for the whole of the utility telecom needs as its deployment to exclusively cover the ANM needs would definitively have prohibitive costs. This implies that the private cellular network will be used for ANM exclusively when it has been deployed by the utility for other purposes or in conjunction to cover other purposes.

The technology which could be used to deploy these private cellular networks is LTE. Although it could be possible to deploy private 5G networks in the near future.

A private cellular network should allow sorting out the problems related to bandwidth, latency, and jitter as the utility control on the network makes it possible to implement an appropriate QoS policy to cover the telecom requirements. In addition, the stability problems are, equally minimized because of the utility control over the network.

5.3.3. Mashed mobile networks

Another wireless option is mesh networks. Typically, there will be a master station at the primary substation which connects the remote nodes to the central network. The remote nodes connect among themselves in a meshed topology and retransmit the messages to let them get to the next node. The use of this technology allows for achieving savings because it is not necessary to prepare any network planning, the nodes establish the mesh topology automatically when they are deployed. A mesh network standard which is already in use by utilities is Wi-SUN / IEEE 802.15.4g.

5.3.4. Narrow band P2mP radio

Utilities traditionally deployed narrowband radio in the VHF and UHF bands to provide the telecom links between the control center and the field electrical assets. Point to multipoint topologies was normally implemented, with bandwidths of some kilobits per second.

This technology has evolved to incorporate Ethernet connectivity which replaces the traditional serial interfaces. The bandwidth remains around the same magnitude and it is still a technology which can be suitable for rural environments where public networks are not available and other private technologies have massive costs.

These features make narrowband radio a candidate technology to provide the necessary telecom links for ANM.

5.4. Public internet

A may less obvious telecommunication technology is the public internet. Nevertheless, with a fast-increasing amount of DER needing interaction with network operators it must be considered as a candidate to provide the required connectivity. This is still more convenient taking into account that DER owners already connect their units to the internet for other purposes. To achieve the interaction between the utility OT network and the DER locations strong cyber security measures shall be implemented. The QoS parameters, bandwidth, latency and jitter as well as the actual availability shall be considered before the telecom link deployment.

6. Assign flexibility management tools to specific needs – the Road Map

The main objective of European utilities to have ANM today is to face regulatory pressure to defer network investments (as opposed to the current recognition of all investments). This is:

- To offer a service to DER that allows faster connection to the grid, not conditioned to the construction of a grid reinforcement or extension,
- To prevent overloads to keep generation rights, in real time in the event of simple contingencies (N-1).

In the long term, European utilities seek to be prepared to manage efficiently all kinds of flexible sources and be prepared to become a DSO in the future. In this regard, not all are in the same position.

6.1. Different control levels

This has to do with the different levels of maturity of the utilities to become a DSO and to be able to perform ANM activities.

The following pyramid reflects the different levels of technological evolution required to apply the different state-of-the-art available technologies, together with the technical capacities required. At the same time, it presents the general idea of **grid observability through the Road Map**.

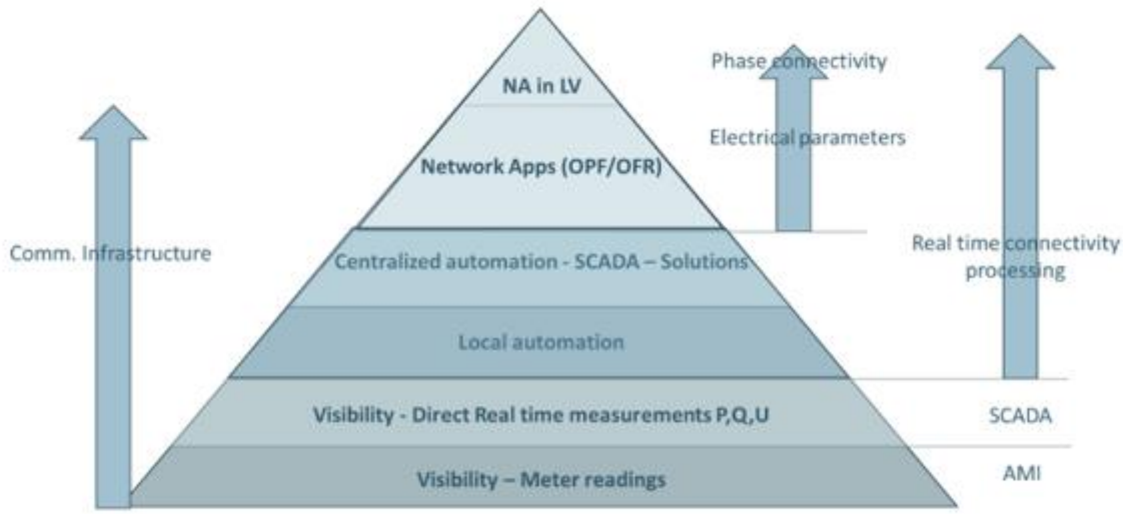

Figure 30 Grid observability of technical evolution different levels

Starting from the base, which describes the minimum technical capacity, to the very top based on electrical network apps in real time.

6.1.1. Visibility – Meter readings

Smart metering is a must-have step to enable flexibility management and a whole new range of business models, as it's essential to confirm provided services to invoice them.

The utility needs to know in advance where the technical constraints will occur in the grid, and where the flexible sources are, to broadcast for services to mitigate them.

At this level of maturity, no matter how setpoints are given (internet, phone calls,….etc) , readings in the 4 quadrants of active & reactive power are required in such a periodicity that ANM services can be checked and controlled.

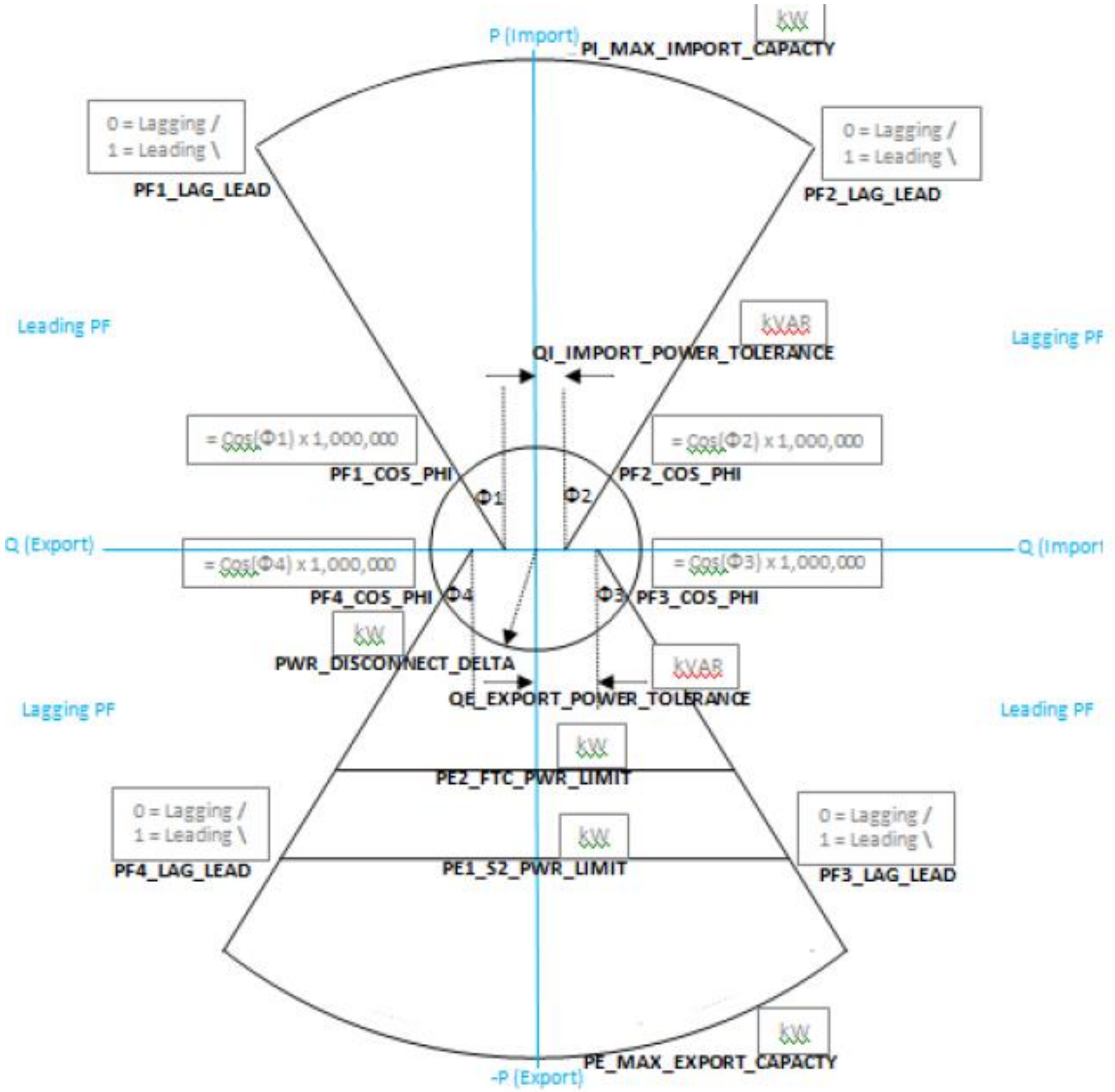

Figure 31 Response curve of the inverter

Even if ANM is performed at a small scale, AMI technology is required, or access to it, supported with some communication infrastructure.

This level of ANM implies several risks when dealing with distribution networks. It is difficult to foresee where technical violations will occur in the grid as the distribution network changes a lot, there are topological changes, programmed works, or incidents that can make the task very cumbersome.

6.1.2. Visibility - Direct Real-time measurements P, Q, U

At this level, we are assuming real-time visibility at the station level (or secondary substation). SCADA technology should be in place for the utility to know in real time where technical (current or voltage) violations occur.

Real time values will trigger the request for ANM services to mitigate the violations. Monitoring analogue and digital values from specific points and making decisions on the network to determine if the connected DER power stations are allowed to generate full capacity or to be constrained to an optimal level.

Access to real time information can come from direct connection to RTUs or in the case of the DER, thorough platforms when they exist. Interactions between RTUs and IEDs are possible to

As in the previous point, this level of ANM can only be deployed at very specific areas, as it is difficult to identify where technical violations occur in the distribution network. The number of constraints is limited or the logic becomes impossible to handle.

6.1.2.1. Primary substations

On primary substations, most DSOs have (advanced) substation automation (SA) systems that can provide the needed data. This SA can deliver detailed data with pretty high sample rates. Because of the often redundant wired (fiber) communication the connection is stable and reliable. For ANM applications around primary substations with outdated SA it can be an option to create a dedicated RTU to collect the necessary measurements.

6.1.2.2. Secondary substations

In the past secondary substations never had any form of digitalization. Around 2010 DSOs started to make the first steps on this level. Nowadays some DSOs have digitalized a significant number of their secondary substations. Regarding measurements, there is a difference in complexity for MV and LV. For LV it’s pretty easy to attach the voltage and click current coils on the cables. Retrofitting MV measurements is more complex. Especially for cable networks. Not all cables or joints are suitable for current coils. For the voltage, there are no transformers in place. The only option is an inaccurate capacitive voltage detection system (if available).

6.1.2.3. Customer substations

Customer substations are normally not equipped with digitalization. Of course, they have a smart meter for billing. This data can often be used by the DSOs but is not available in real time. Concerning the requirements for generators (RFG) several countries start to implement a real-time interface to limit the DER when needed and receive measurements. Probably in Germany is the most mature country on this point. These measurements are carried out by the customer and delivered to the DSO over the real-time interface. In most cases, the DSO has a DER box at the customer substation which is connected to the production unit via the real-time interface. A DER box consists of an RTU, modem, IO and UPS.

6.1.2.4. Basic Real-time information to interchange with DER to perform ANM

In both centralized and local solutions, to perform ANM it is required to know if the DER is connected or not. The best way is to obtain the topological statuses of the switches, or at least, to obtain a digital value for the DER connection status (if the DER is connected to the network and active or not).

To know the magnitude of the production/consumption of the DER it is desirable to have the measurements, in terms of active and reactive power (MW/Mvar) or the current value (AMPs) at least, to prevent overloads.

For the same reason, when voltage violations are potentially feasible, voltage measurements (kV) should be required.

In basic ANM solutions, trip controls are required at the customer circuit breaker (OPEN command), or the direct connection at the secondary substation. These commands should simultaneously block the reclosing automatism. In particular, when DER are bigger than 5MW this capacity is a mandatory requirement in some EU countries.

When this function is available, a blocking control is strongly recommended to avoid possible islanding. This control disables the DER reconnection until the lockout is deactivated.

In addition, much other information could be of interest individually or grouped, such as the health status of the equipment, power supply etc.

A basic list of points will look similar to this one.

SIGNALLING			ELEMENT	INFO TEXT	FUNC TION	STATUS
DI	**DO**	**ME**				
1			BREAKER	BREAKER status	I1	**CLOSE/OPEN**
2			Switch	Isolator/Switch status	I1	**CLOSE/OPEN**
3			RECONNECT	RECONNECT permission	I1	**ENABLE/DISABLE**
4			TELETRIP	TELETRIPING	I1	**CONNECT /DISCONNECT**
5			RTU	EQUIPMENT FAILURE	I1	**ALARM/NORMAL**
	1		BREAKLER	TRIP COMMAND	C0	**OPEN (TRIP)**
	2		LOCKOUT	RECLOSING DISABLE	C0	**DISABLE**
	3		TELETRIP	TELETRIP ENABLE and READY	C1	**CONNECT/DISCONNECT**
		1	P	ACTIVE POWER	M	**MW**
		2	Q	REACTIVE POWER	M	**MVAR**
		3	**V**	**VOLTAGE**	**M**	**KV**

Table 2 A basic list of telecontrol points to manage observability – I-DE example.

Beyond DER disconnection, more sophisticated ways of performing ANM should include active and reactive power set points, or even voltage set points in cases where the DER is capable of voltage regulation and is entitled to provide that service. This could be done using digital UP/DOWN commands or, more desirably, analogue set points where possible.

SE	ELEMENT	INFO TEXT	FUNC TION	STATUS
1	Pset	ACTIVE POWER SETPOINT	SE	**MW SETPOINT**
2	Qset	REACTIVE POWER SETPOINT	SE	**MVAR SETPOINT**
3	**Vset**	**VOLTAGE SETPOINT**	**SE**	**KV SETPOINT**

Table 3 An example of list of tele control points

6.1.3. Local automation

A distributed real-time control system that continually monitors power flows across pre-defined Constraint Location(s) and uses this information to calculate (in real-time) and allocate export and/or import capacity available to connected DER in line with agreed commercial Principles of Access (PoA) governed by a Connection Agreement, or directly regulatory restrictions.

This level of ANM requires some automation devices at a local station (or secondary station) for real-time algorithms to handle decision-making and the prosumer side.

They require SCADA technology at the primary or secondary station from where the ANM is performed, and remote access to visualize and control the prosumer. Local control is installed at the DER connection point, monitoring the connection parameters against user-defined constraint levels and regulatory limits.

There are plenty of products in the market already from different vendors, performing different local ways of ANM.

Typically, they will have automation mode on/off, and working algorithms:

- Voltage Management
- Power flow management (considering seasonable ratings)
- Automation Algorithms

Remote mode on/off:

- SCADA control
- ANM set point

They will default to fail to a safe mode in the event of any failure scenario.

Some of these products have a central controller (with an HMI) to be placed in the local substation, many times scalable to large areas, or to control at different hierarchical levels. They can be integrated into larger ANM schemes

These solutions work well for fixed topologies but require maintenance and reconfiguration when the network grows or is reconfigured.

It can mean local control loops based on the measurements. Like limiting DER based on voltage measurement. It can mean failsafe functionality. E.g. limit DER power if the link to central ANM is broken

6.1.4. Centralized automation - SCADA – Solutions

When the above solutions are hierarchically scaled up to the utility central premises, the solution becomes centralized.

In the first approach, all local ANM solutions will be integrated into an ad-hoc platform parallel to the operational ADMS. This simplifies the installation and the maintenance of the local automation, being central, but requires full network processing and communications infrastructure to reach all the local points and prosumers.

In a more evolved approach, the utility will implement all the ANM logic in the ADMS platform when it's on state-of-the-art technology and there is enough technical capacity to do it.

Versus the first basic approach, implementing ANM logic in the central SCADA/EMS/DMS system provides many benefits to the utility:

- Avoids additional costs, licensing, infrastructure
- Facilitates O&M and standardization
- Benefits from real-time network image (topology processing)
- Can provide many sub-products such as island detections

Although this solution is valid to cope with a big number of ANM situations, it also has its limitations, as it requires continuous maintenance that increases as the increase of programmed sequence, but also complicates the network operation.

6.1.5. Network Apps (OPF/OFR)

This is the most generic solution because it works with the real time network using any kind of flexibility. The problem is that it requires a long-term investment in digitalization and a large cultural change in the utility.

It requires an accurate state estimation of the network to feed Optimal power flow algorithms where all the flexible sources have been parametrized.

The prerequisites to run this solution down to the MV grid are:

- An accurate network model (topology)
- Electric characteristics of the network equipment and flexible sources
- Minimum network observability

Additionally, to include the LV (for many DSO in the UE):

- Phase connectivity – as the network is unbalanced

6.1.5.1. Electrical calculation

The electrical calculation consists of defining the state variables of an electrical system that describe the situation of the network at a given time. This is done by the State Estimator (SE). On a practical level, this is a voltage and angle value for each node of the network, discounting the angle of the reference node. SE can be extended to those parts of the near external, the equivalent models, to estimate the whole network which is modelled.

6.1.5.2. Load flow

The System should provide the operators with kW, kVAR, kV, Amp on the present state of the distribution network. The current electrical connectivity information is derived from the SCADA database for tele-transmitted or manually updated devices. It executes periodically and upon any change in the distribution network affecting the results as well as on the operator's demand, such that it reflects the actual state of the distribution network. So, the Load Flow will have value in itself. It provides insight into power flows, technical capacity violations and network losses, and provides simulation capability which are part of the requirements as well.

6.1.5.3. Optimal Power Flow

Based on an estimation of states and quality load flow, the various OPF (Optimal Power Flow) algorithms have to allow optimization of the electricity network based on different economic functions (costs, security, losses, etc.) using all the control variables available to them: load tap changers of transformers, controllable shunts, line capacities, batteries, topological reconfiguration, different forms of demand side management, and any other form of current and future available flexibility in the networks.

It handles 3 main aspects:

- Objective function
- Control variables
- Constraints

As an example: "Active power cost optimization"

- Objective function:
  - Minimize (pseudo-) costs of control variables
- Control variables:
  - Tap positions and shunts
  - Active power rescheduling of generators
  - Battery
- Constraints:

- Current limits of lines
- Apparent power of transformers
- Voltage magnitude of busbars

Being the frequency of execution (time spanning) relevant for the real-time sequence (continuous State Estimation calculations). This means that the execution periodicity of the OPF could be parametrizable, either on a time basis (e.g. 5 min) or based on the number of SE calculations (e.g. every 3 times)

The result of this processing is the optimal values of the control variables in each execution, considering all constraints and limits. In the first phase of implementation, it can be provided as a recommendation to the Control Centre operator, and may eventually lead to direct runs in closed-loop mode, automatic on the network, monitored by the operators.

The Optimal Power Flow is used to enhance system operations. Adjustments to controls are recommended to achieve optimization objectives.

The basic optimization objectives are as follows:

- **Active power cost optimization**: The active power production cost is minimized by varying the active power control variables while meeting all the limit constraints.
- **Active power security optimization**: Active power control variables are rescheduled for the minimum amount required to relieve all constraint violations.
- **Reactive power security optimization**: Reactive power control variables are rescheduled for the minimum amount required to relieve all constraint violations.
- **Loss minimization**: Reactive power control variables are rescheduled to minimize active power distribution losses and meet all constraints.
- **Full optimization**: Performs cost optimization followed by loss minimization.

The algorithm should work with all the network or a subset of it. The subnetwork model may consist of a single feeder or a group of feeders connected to one or more feed point(s).

The subnetwork model can include both radial and meshed configurations, as the topology dictates. Meshed networks contain loops and parallels. The term “loop” is used for the contour between elements within one injection source, while “parallel” is a connection of the elements between two independent injection sources.

The OPF execution can be launched from the button panels of the main windows, as well as from the diagram and it could be run in study or real-time mode.

To perform ANM real-time mode is required:

When performing the optimizations, it is possible to try a progressive series of control strategies in a single execution. The various controls have priorities assigned that allow you to determine the order in which controls are used. A subset of the available controls is used to solve the specified optimization problem. The subset of controls is expanded to include the next level of controls until the optimization objective is met. Controls can be enabled or disabled on a global or individual control basis.

Constraint priorities are specified for individual constraints during optimizations. Enable or disable capability for individual constraints are provided so that you can control which constraints to consider when executing an optimization study.

The OPF relaxes constraints that cannot be met using the available controls. The global limit relaxation capability relaxes the limits of constraints from long-term to medium-term limits, and if necessary, from medium term to short-term limits.

The optimal limit relaxation capability relaxes the limits as necessary to obtain feasibility.

The target is to run the OPF algorithm in a close loop combining utility owned flexibility with any other flexible source.

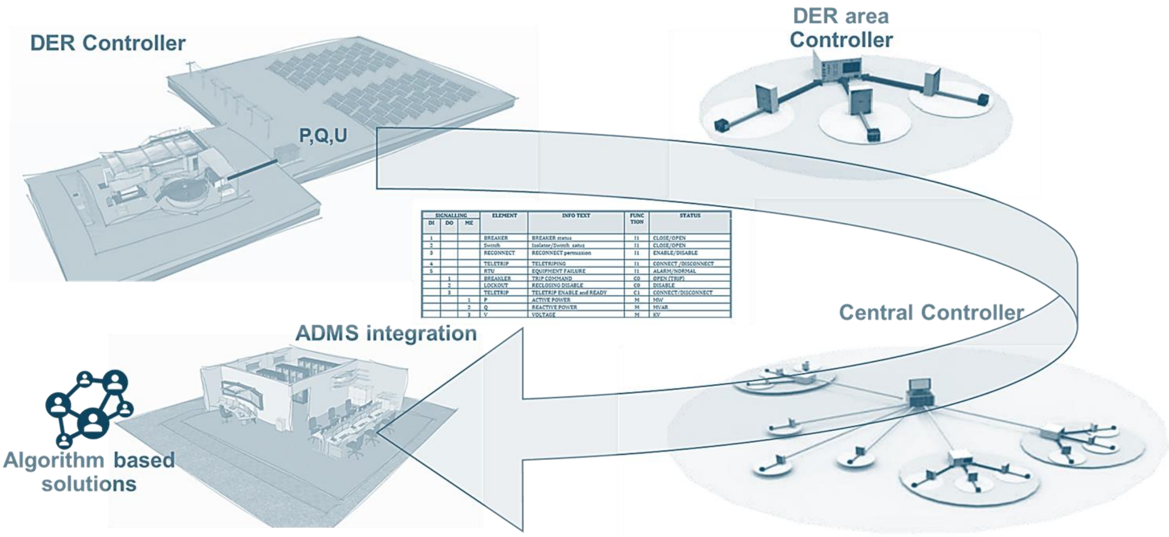

Figure 32 The road map: Scalable solutions

6.1.5.4. Optimal Feeder Reconfiguration

The OFR (optimal feeder reconfiguration) function determines the optimal network configuration to eliminate adverse operating conditions such as line or transformer overloads. This function proposes to the operators a series of switching actions that would enforce the reconfiguration of the distribution feeders reducing the system losses and equilibrating the loading of the primary stations. As result, loads on one feeder are transferred to another feeder, etc., changing line and supply transformer loadings.

Different types of objective functions should be supported by the OFR, some of them are as follows:

- Removal of constraint violations.
- Load balancing among supplying primary stations.
- Minimization of feeder losses.
- Multi Objective.

System operational constraints such as line and supply transformer loading and voltage limits are automatically accounted for using penalty factors.

To run the OFR the user is required to specify the area, the number of NOPs that the algorithm steps over to be considered and the desired objective function.

The results of the Feeder Reconfiguration function include a switching procedure, and the values of the objective functions before and after the feeder reconfiguration.

The target is to run the algorithm in a close loop for emergency conditions.

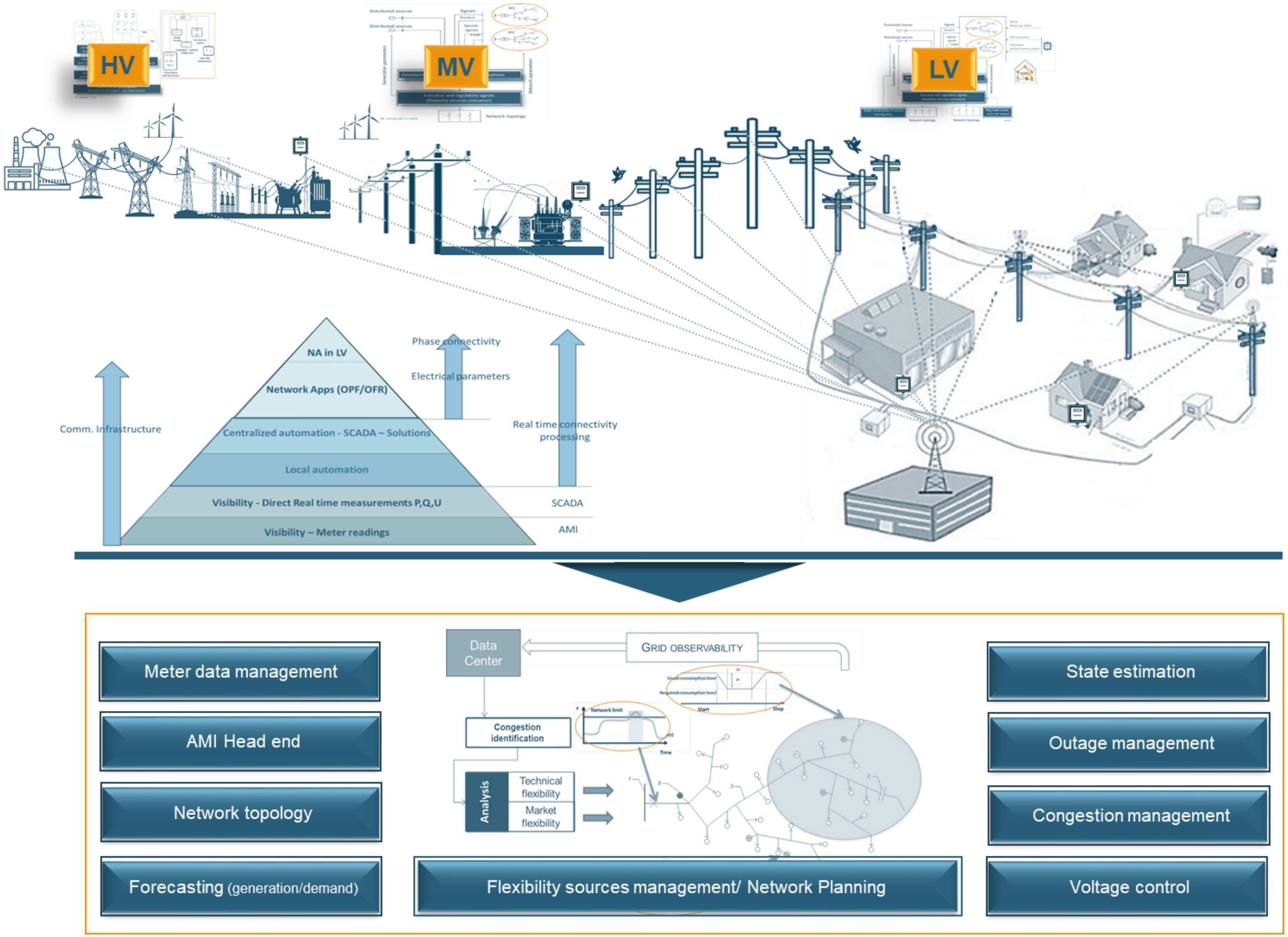

Figure 33. The general idea of grid observability for flexibility: the Road Map

6.2. Exploring flexibility

The following chart summarizes in three groups the use of flexibility by DSOs:

- the flexible resources,
- the services to be requested/provided, and
- the access to flexibility.

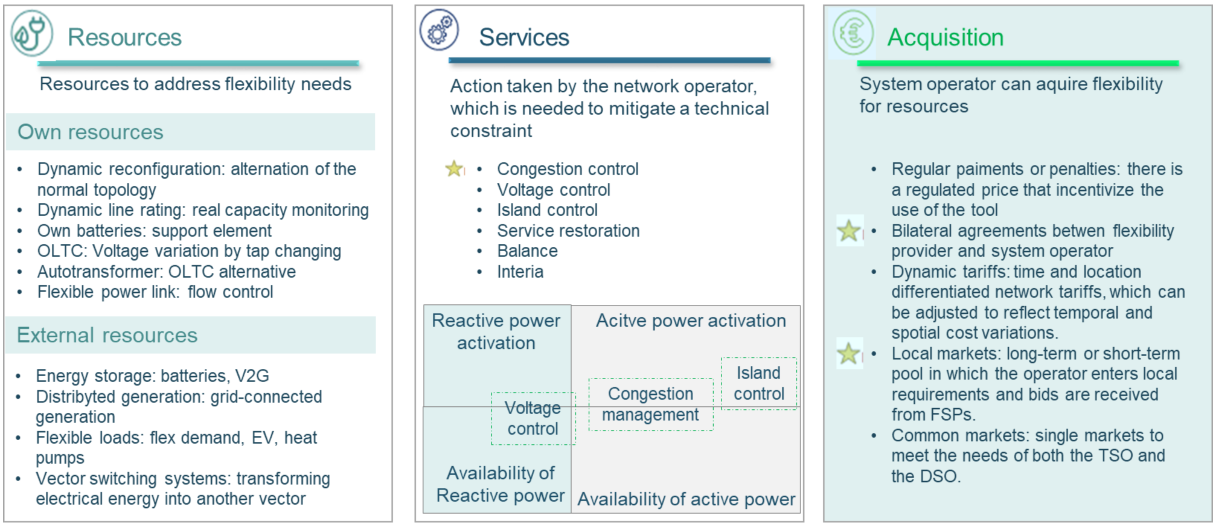

Figure 34. Three groups the use of flexibility by DSOs

7. Use cases

7.1. Standard real-time DER interface for The Netherlands

The energy transition is ongoing. Increasing amounts of DER such as solar photovoltaic (PV) systems and wind turbines are connected to the power system. The existing transmission and distribution networks are not designed to handle large amounts of DER, which are placed often at the borders of the electricity grid. Dutch system operators are more and more often confronted with a shortage of network capacity and cannot reinforce their networks at the same pace DER can be installed. In the Netherlands, system operators, therefore, investigate and implement congestion management as a method to overcome the time needed to reinforce their transmission and distribution networks. The Dutch regulator furthermore announced regulatory changes, enabling system operators to apply congestion management on a large scale [ACM2021].

One of the systems system operators needs to safely apply congestion management is an interface between connected customers and their system operator. In 2020 the collective Dutch system operators, united in Netbeheer Nederland (NBNL), started a project to describe a real-time interface (RTI) to enable system operators and connected customers to communicate in real-time in terms of grid capacity. Two versions of the RTI are anticipated. One for the short term and one for the long-term. For both versions, the focus is on RfG category B (1 MW – 50 MW) and communication through the RTI refers to behaviour on the point of common coupling. The initial use cases in scope are primarily related to 1) congestion management (e.g. curtailment), and 2) connecting generation without redundancy (so-called 'N-0').

Creating a logical interface between DSO and customers on the substation level is not self-evident. This will be explained by the use of the SGAM architecture with an IEC 61850 design for both versions 1 and 2.

7.2. Active Network Management Logics in the Central SCADA system (LANM) in Spain

VHV grids in general, and 132 kV grids in particular, are normally operated in a meshed mode in many European countries, to guarantee the supply in the event of the loss of any power source (loss of head-end substation, busbar, transformation, line failure, etc….., n-1 Guarantee).

This topology implies, however, that these networks are exposed to circulations of power flows unrelated to their function, due to parallel transmission flows (called "sub-transmission", if they are induced by higher voltage networks) which, in certain scenarios, can lead to overloads by exceeding the nominal values of the conductors.

This situation can lead to tripping due to a fault or unwanted contact. In the best-case scenario, the Control Center can anticipate executing decoupling commands to avoid sub-transmission.

However, there are situations (high overloads) in which preventive actions by the Control Center are not possible, since the overload situation may occur spontaneously and unexpectedly.

This problem has a clear example in the 132 kV network in mid-Spain, the A-B axis between the StationA 400/132 kV and StationB 220/132 kV, but there are many more cases of application.

It has been proven how, in the event of several simple contingencies (N-1), high overloads can be produced, caused by sub-transmission, which would lead to tripping of other elements and could even result in chain tripping with the market loss of a large extension, breakage of elements, etc. This risk has occurred up to 200 hours per year based on historical data when considering generation rights.

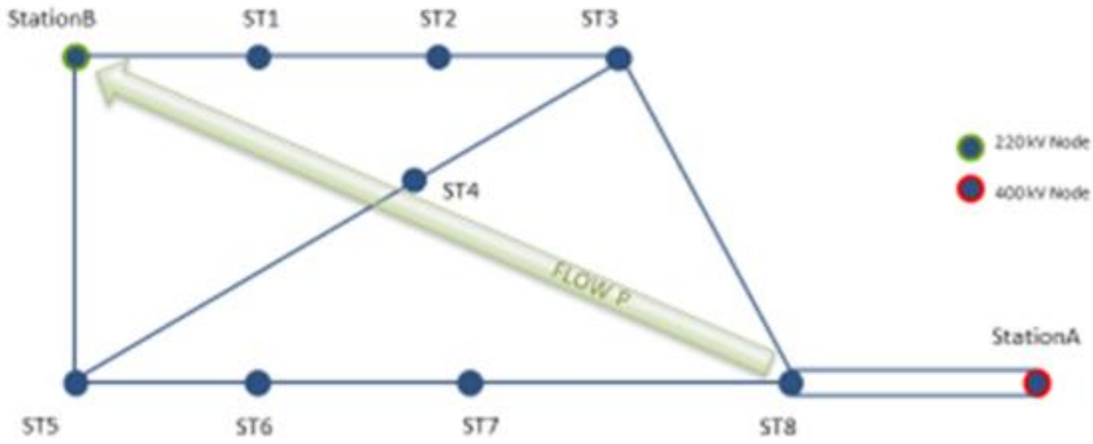

Figure 35 Description of the topology

Contingency	Overloaded equipment		Load (%)
N-1 ST5 – ST6 132kV	ST3	ST8	101,6
N-1 ST5 – StationB 132kV	ST3	ST2	118,3
	ST1	ST2	104
	ST1	StationB	119,9
N-1 ST6 – ST7 132kV	ST3	ST8	97
N-1 ST3 – ST2 132kV	ST5	StationB	110,8
N-1 ST1 – ST2 132kV	ST5	StationB	103,4
N-1 ST1 - StationB	ST5	StationB	111,8
N-1 StationA – StationC 400kV	ST5	ST6	105,7
	ST5	StationB	129
	ST6	ST7	96,4
	ST3	ST2	139,2
	ST3	ST8	140,7
	ST1	ST2	124,7
	ST1	StationB	141,7

Table 4 The results of the contingency analysis N-1

The implementation of conventional protections could solve this problem by employing thermal image protections in strategic switch-bays that disconnects the axis under a predefined load situation. However, this solution has many drawbacks:

Installation of protections at the switch-bays (they do not exist in most of them).

Trips in stand-alone mode (not considering other parameters or network status), potential simultaneous trips and risk of leaving part of the network de-energized.

Potential trips of circuit breakers with protection, are not in the ideal positions to disconnect the network optimally (load balancing, over/undervoltage).

Fixed, non-programmable calibration of tripping settings. To be done on-site only.

Limitations in future scenarios not covered by the current solution (new generation).

For this reason, I-DE has decided to implement a set of SCADA logics in the Control System (program named Logical Active Network Management, LANM) that, through the monitoring of certain variables and when certain conditions are met, is capable of opening switches to decouple the network.

Specifically, the coming algorithm will:

1. Monitor the load magnitudes of the different sections.
2. Monitor the status of the switches on the main line and in StationA.
3. Open the programmed positions when there is a 100% load concerning the Summer/Winter Rate in any monitored section.

The main program parameters are:

- Data: Rate Summer/Rate winter of each span (matrix).
- Variable to be monitored: the power of any span ≥ Seasonal rate x factor (usually 1)
- Conditions: Switch status (open/closed) to select the most suitable manoeuvre and avoid zeros. It could be replaced by other electrical quantities (V, I, P).
- Execution: Open positions programmed to decouple the axis.

In addition, to make it more generic, the program in the ADMS can be parameterized through a configuration file to customize the logic to handle many other different situations. As new DERs are connected to the I-DE networks, the program must deal with possible overloads or voltage limit violations in many other areas. Using SCADA values, it will continuously check for technical constraints and send disconnect orders to mitigate them when they occur.

The next steps of the program contemplate more precise instructions, such as reducing the load injected by the generators without having to completely isolate them and other analogue commands.

This solution at StationA will go live in Q1 2022, and two more in Q2 2022, for a total of 12 deployments over 2022. However, plenty of ANM contracts are foreseen in the short term to be faced with this algorithm.

7.3. Battery Energy Storage System (BESS in CARAVACA DE LA CRUZ - Spain)

The proliferation of PV plants, in the Murcia region, has caused voltage regulation problems in some MV lines. During the hours of greatest solar intensity, the voltage rises in the areas where there are PV plants nearby. On the Archivel line, there are several large plants connected at different points of the circuit.

On the other hand, as they are rural areas with dispersed populations and very long lines radially operated, the rate of network incidents is high.

For these two reasons, the DSO has decided to deploy a 1.25MW/3MWh energy storage system to provide flexibility services to the grid, to help solve the local problems.

The BESS is remotely managed from the ADMS.

Provided Services

The most frequently used service is voltage regulation during daylight hours. Levels of 22kV were frequently exceeded on this 20 kV line. Since the date on which the BESS was installed, a daily voltage correction action has been scheduled in the area near the PV plants.

Other more rigid voltage regulation systems work in steps, producing fixed responses that can be activated or deactivated, but storage systems, as far as they are based on power electronics, are more controllable and show two main desirable advantages:

- They admit to receiving a simple setpoint (the desired voltage level) but provide a complex response (flexible output depending on the needs).
- High-speed reaction, which allows them to respond immediately to changes in the environment.

The different generation capacities of the PV panels, depending on the elevation of the sun, the presence of clouds and other atmospheric phenomena produce important variations in the line voltage (some of the slow progression and others instantaneous) and the battery adapts its response to each change, in real time, depending on the needs.

Creation of electric islands. In these remote places where the network is less meshed, it is not always easy to have a second backup line for all the populations. In the event of a network failure with loss of service, consumers are affected more frequently as far as the population is at the end of the line. For this reason, the battery has been located looking for a balance between proximity to the PV plants and proximity to the last large population close to the end of the line.

The BESS is also considered by the FLISR program as an available injection source for restoration, allowing the island mode. This way the quality of service improved dramatically. The year after the storage system was installed, the local SAIDI was improved by 90% compared to the previous year and by 68% compared to a year earlier.

In addition, the scheduled grid interventions on the line or the substation have been possible since then without interrupting the electricity service to most consumers, who have not even passed through zero during the network-island transition.

During the periods of operation on island mode, the generation plants connected to the island have been able to continue generating and have contributed to extending its duration over 7 hours, on several occasions.

7.4. Customer engagement through innovative solutions and new market models (OneNet, Czech Republic)

General description

The demo aims at the utilization of flexibility aggregated from decentralized energy resources, battery energy storage systems (BESS) and demand side - large consumers (DSR). The focus is on sources of 0.5 MW installed power or above, connected to the distribution grid and large consumers connected to 110 kV.

The goal of the DEMO is to develop the market for non-frequency services to be used by grid operators and other grid users. CZ DEMO will establish a country-wide solution (IT platform) for the flexibility of grid services; there will be tested participation of flexibility providers of various sizes in the whole area covered by two major DSOs in the Czech Republic.

The new platform will cooperate with the existing platform for frequency services namely through a traffic light scheme allowing to share of relevant data between DSOs and TSO. Apart from TSO and DSOs, there are two aggregators involved in providing flexibility.

Information exchange

Debate on the structure of the platform and data exchange model has been ongoing at present (that goes especially for the information model and relevant channel deployed). There are several DSOs, TSO and two aggregators as main actors in the DEMO. For the first part of the implementation, there is a traffic light concept to be used in which the following data exchange is foreseen: expected outages/outages reported from DSOs to the platform providing for each generator registered in the platform availability of the system for the flexibility activation. This information is for planned outages provided 15 days ahead. The TSO sends in the platform information concerning procured/contracted services (amount of services) for DSOs. Provider of services sends into the platform information about activated services detailing all participating resources (which is important for the DSOs in terms of quality of supply in nodal areas). The platform contains data on planned/activated flexibility for the evaluation of services provided to the TSO.

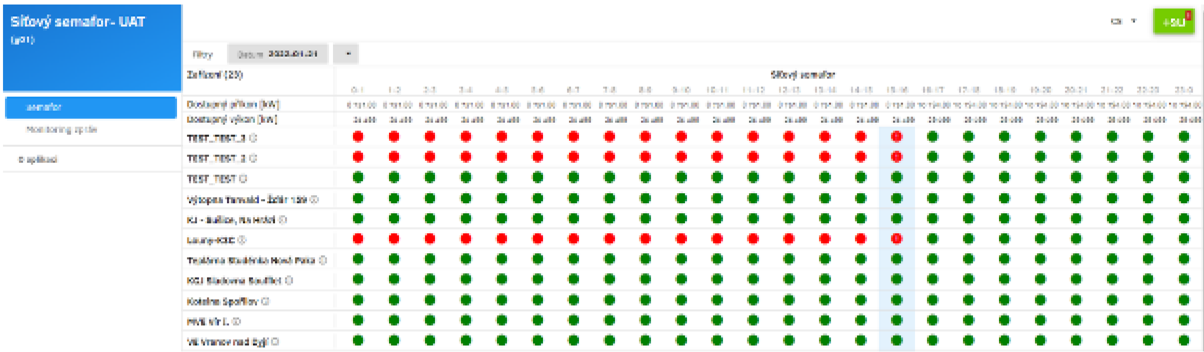

Figure 36 Traffic light scheme – an indication of the source and grid availability

The second phase of the CZ DEMO project will encompass the provision of non-frequency services from aggregators/customers to the DSOs. The system will involve a database of units/resources able to provide non-frequency services to DSOs. The information involves e.g. installed capacity as well as the location of the units/resources. To this end, the project team established a set of criteria under which resources will be identified to ensure each unit has its unique identification means. To distinguish amongst three different non-frequency services through the bidding process, there is a specific XML data format relevant to the given service. In principle, there must be included demanded capacity (in MWh for active and MVAr for reactive power) and duration of the contract. As the DSOs cannot disclose the grid topology for security reasons, the bids are passed only to resources relevant to the given nodal area. That is why the location of resources must be stored in the common register and is a vital part of the system.

Products and services

To address the needs of the distribution grid in a market-based way the CZ DEMO aims to test non-frequency services – e.g. voltage control through reactive power management, nodal area load management or management of overflow. These products are defined specifically to address the main challenges for the distribution grid in terms of the growing amount of RES and non-dispatchable resources. There are namely voltage issues and deviation of reactive power.

The marketplace will be designed by the IT provider of CZ DEMO – Unicorn. As indicated in the chart, there is an administrative section with the register of flexibility units, and information about relevant nodal areas. The market module contains information on flexibility services contracted/provided while the other module serves for evaluation and settlement. What is referred to as “congestion management” is a traffic light scheme – an indication of grid availability.

With this IT platform in place, together with services to be exchanged the project can fulfil its ambition to bring major challenges into non-frequency services procurement. As these services will be exchanged in one central dedicated place, this will bring also fundamental change to the system in terms of access to new entrants/market players.

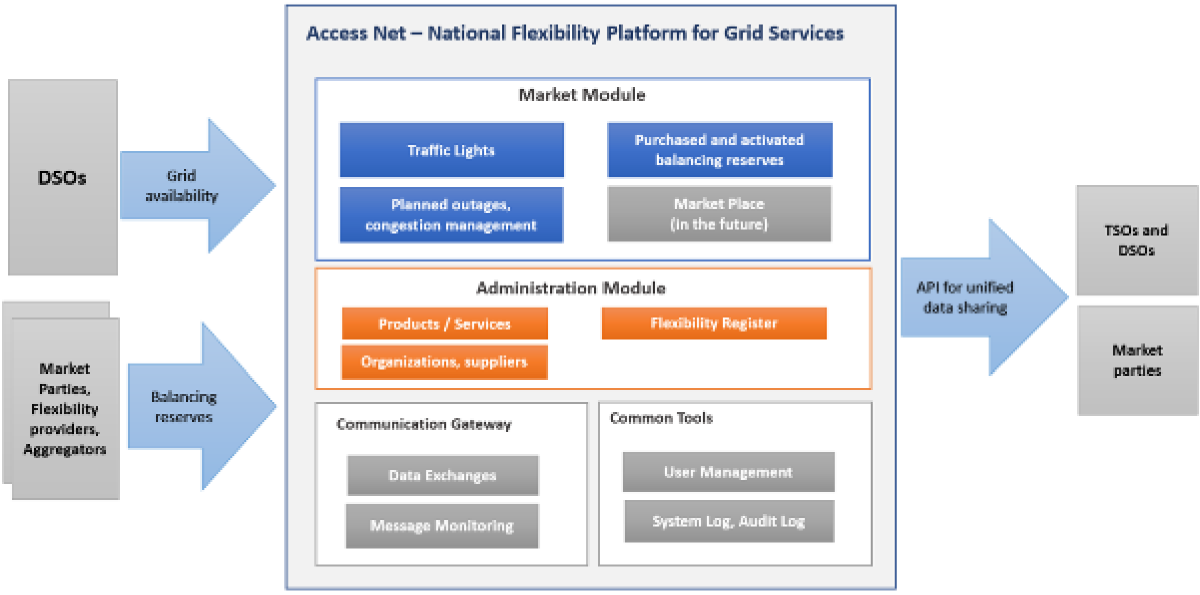

Figure 37. Access Net – national flexibility platform for grid services

As it was referred to in previous parts concerning the description of the state of play, contracts on flexibility are negotiated on a bilateral basis with units possessing relevant capacity. This excludes in fact lot of smaller units/aggregators as they are not aware of the capacities needed and DSO is not aware of their possibilities. However, participation of smaller units in terms of provision of e.g. reactive power might be an interesting business opportunity for them as reactive and active power could be produced simultaneously. This potential couldn't be used fully because of both regulatory and technical constraints.

CZ DEMO intends to reflect this growing potential for customer/smaller units in its project measurable indicators (KPIs). From this point of view, it is important to highlight the added value of the IT platform for enhancing the capacity of aggregators. Because they will be regularly updated on outages/planned outages they can use the available flexibility most efficiently.

8. Final conclusions

The future energy system will include a large network of devices that are not just passive consumers like most endpoints today but can generate, sense, communicate, compute and react. In this context, intelligence will be present everywhere - from electric vehicles and smart appliances to inverters and storage devices, from homes to microgrids, thought stations to substations. These resources could, collectively or separately, cause large, rapid and random fluctuations in electricity demand, supply and associated quality. Consequently, system stability may increasingly depend on the operator's possession of data on the state of the grid and customer-owned DERs, which simultaneously detects specific system conditions, thereby triggering appropriate algorithm-based actions in real time. Simple and scalable distributed control systems powered by decentralized information are required to meet the need for active integration of these resources/flexibility sources into markets and grid operations.

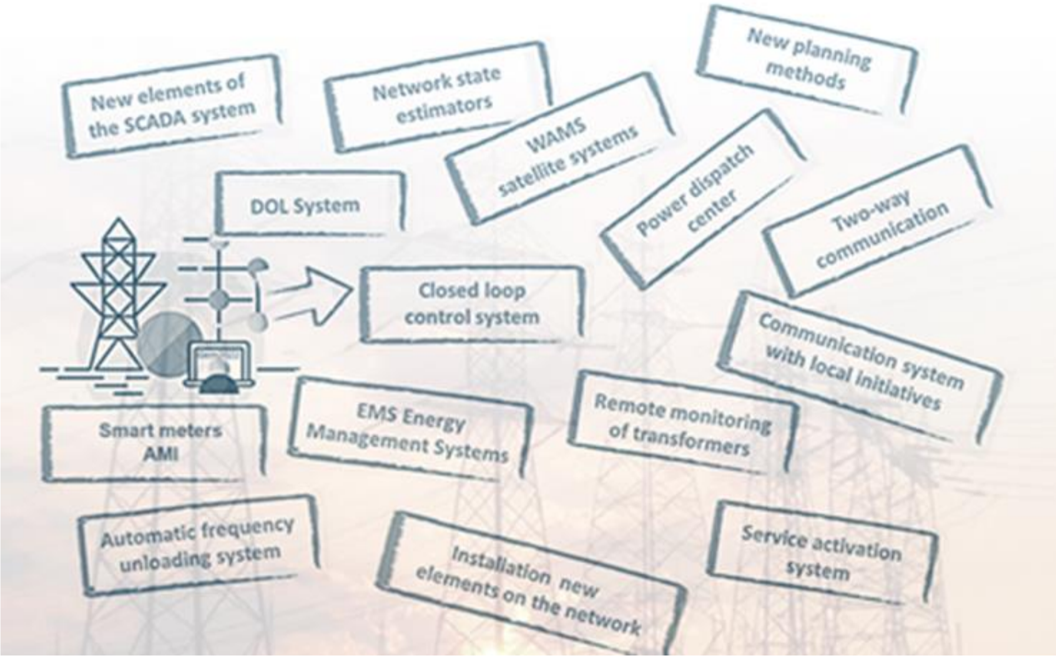

Figure 38. Achieving full network observability.

Achieving full network observability, especially at LV will not be a quick process. It requires a lot of time but also a huge amount of money to implement state-of-the-art technologies based on data for effective operation. Hence, attention must also be focused on mechanisms for collecting and storing this data, but above all, on its proper use. Proper interpretation of information from such a huge amount of data will not be possible without advanced algorithms, often combined with the automation of standard processes.

It seems that at the current level of development of flexibility sources, their technical potential and involvement in the management process, grid operation is at a level that enables their use, especially when it comes to HV and MV grid levels. The rapid development of prosumers, and DERs connected to the LV distribution network makes it necessary to accelerate efforts to increase network observability.

However, the challenge DSOs have is to select the minimum number of sensors, smart meters, etc... that allow grid operators to know the state of the entire network with certainty, without the need to carry out massive acquisitions, and spend a lot of many/time/effort just to achieve full digitalisation, not necessarily needed to achieve full network observability. All mentioned below elements have to be balanced and rationally applied.

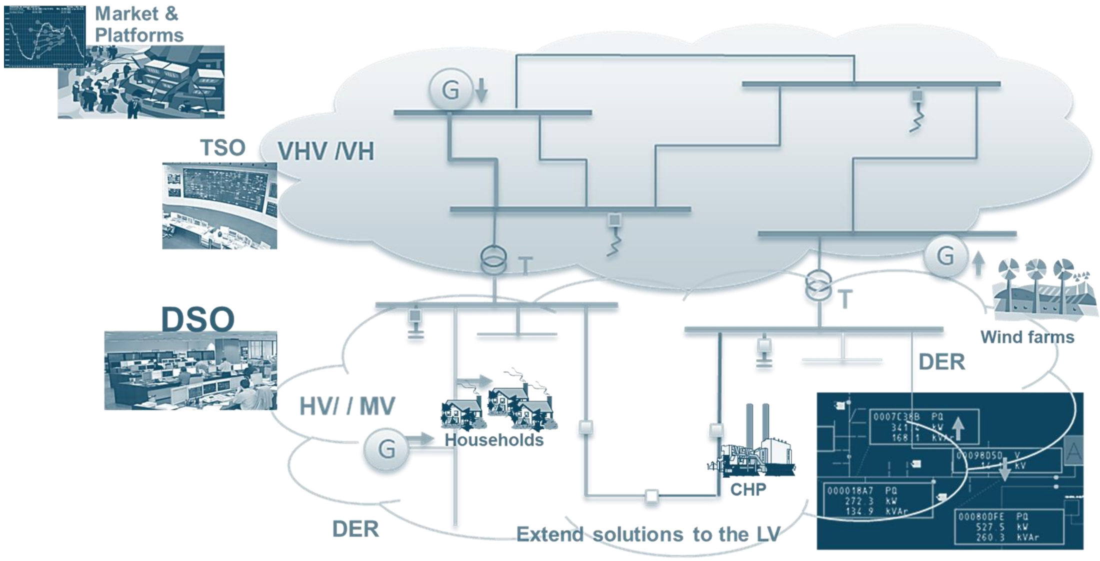

Figure 39 The road map: Up to the most sophisticated solution

With today's state-of-the-art, requirements for utilities to be prepared to handle flexibility are:

- Ensure high observability and controllability of the distribution network and develop communication systems, inter alia to manage distributed flexibility resources.
- Carry out analytical work to develop a methodology to quantitatively assess the impact of distribution system flexibility on increasing the ability to connect new users, improving reliability and reducing the cost of energy supply. The methodology should be further agreed upon with System Operators, regarding the technical and financial aspects of its use and in the processes of planning the development and management of the distribution system operation.
- Implement IT and analysis/forecasting tools as well as procedures to allow flexibility to be taken into account in the processes of development planning and management of distribution system operation.
- Integrate and coordinate activities carried out so far in the areas of network digitalization, developing of smart grid solutions, e.g., implementation of AMI metering, ADMS and passportization of network assets (among others, mapping of topology and technical parameters of the network).
- As the condition of network observability and the basis for the completion of tasks in the area of controllability – a common DMS which is part of the ADMS and already integrated with the common SCADA (the missing pieces are the Optimal power flow and feeder reconfiguration algorithms) is needed.
- ICT solutions enable the exchange of information between the implemented IT solutions.

In the long term, to handle scenarios with a high number of flexible sources (owned or external) generically, the utility will require centralized solutions based on closed-loop electrical applications that take into account all grid constraints, both power and voltage limits. Not only does it need to be observable, but the network needs to be well digitized, including accurate electrical parameters for every network equipment. This is costly for utilities today and a barrier to moving from existing pilot solutions to industrial ones, but the efforts are deserved and certainly a future requirement for a DSO.

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List of Acronyms

AC	Alternating Current
aFRR	Automatic Frequency Restoration Reserve
AMP	Amperes
AMI	Advanced Metering Infrastructure
ANM	Active Network Management
ASM	Active System Management
AS	Ancillary Service
BESS	Battery Energy Storage Systems
BPR	Broadband Power Line
BRPs	Balancing Responsibility Parties
CEER	Council of European Energy Regulators
CSs	Coordination Schemes
DA/ID	Day Ached/Intraday
DER	Distributed Energy Resources
DGs	Distributed Generations
DMS	Data Management System
DOL	Dynamic Overload Line
DSF	Demand Side Flexibility
DSL	Digital Subscriber Line
DSOs	Distribution System Operators
DT	Digital Twin
DTC	Dynamic Transformer Control
EMS	Energy Management System
ENTSO-e	European Network Transmission System Operators for electricity
EU	European Union
EV	Electric Vehicle
FAT	Full Activation Time
FCR	Frequency Control Reserve
FLISR	Fault Location Isolation and Services Restoration
FSPs	Flexibility System Providers
Go4Flex	Grid observability for Flexibility
GIS	Geographical Information System
GPRS	General Packet Radio Service
GSM	Global System for Mobile Communications
HP	Heat Pumps
HV	High Voltage
ICT	Information and Communication Technologies
IED	intelligent electronic device
IO	Input output
IoT	Internet of Things
IT	Information Technologies
LANM	Logical Active Network Management
LTE	Long Term Evolution
LV	Low Voltage
LVR	Line Voltage Regulation
KPIs	Key Performance Indicators
kW	kilowatt
kV	kilovolt

MBMA	Meter Before - Meter After
MDMS	Meter Data Management System
mFRR	Manual Frequency Restoration Reserve
MWh	Megawatt Hour
MW	Megawatt
MV	Medium Voltage
NBNL	Netbeheer Nederland
NOPs	Normally open points
NRA	National Regulation Authority
OFR	Optimal Feeder Reconfiguration
OLTC	On Load Tap Changer
OPF	Optimal Power Flow
OT	Operational Technologies
PLC	Power Line Carrier
PoA	Principles of Access
PV	Photovoltaic
RES	Renewable Energy Sources
RFG	Requirements for Generators Guideline
RTI	Real Time Interface
RTU	Remote Terminal Unit
SA	Substation Automation
SAIDI	System Average Interruption Duration Index
SAIFI	System Average Interruption Frequency Index
SCADA	Supervisory Control and Data Acquisition
SCO system	Self-Acting Frequency Offloading
SE	State Estimator
SIM	Subscriber Identity Module
SMs	Smart Meters
SO	System Operator
SOGL	System Operation Guideline
STATCOM	Static Synchronous Compensator
SVC	Static Var Compensator
TCR	Thyristor-Controlled Reactor
TF1 ANM	Task Force 1 Active Network Management
TSOs	Transmission System Operators
TSC	Thyristor-Switched Capacitor
V2G	Vehicle to Grid
VHF	Very High Frequency
VHV	Very High Voltage
QoS	Quality of Service
UHF	Ultra High Frequency
UPS	Uninterruptible Power Supply
XML	Extensible Markup Language