

PROVIDING ANCILLARY SERVICES FROM DISTRIBUTED ENERGY RESOURCES TO ELECTRICITY DISTRIBUTION GRID

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Ancillary Services

Ancillary services (AS) are services related to the security and maintenance of distribution systems such as frequency response stability, providing fast backup, providing reactive power, system restoration, black start etc. In conventional electric power systems where the power flows unilaterally (i.e. from transmission systems towards distribution systems), AS are usually provided by production plants connected to the transmission system. Various institutions emphasize the transmission system operator (TSO) as the acting agent when defining AS. In this context, European Network of Transmission System Operators for Electricity (ENTSO-E) defines AS as the application of assorted functions to ensure system security of the TSO (ENTSO-E, 2017).

EURELECTRIC defines AS as the services required for transmission and distribution system operators to provide the power quality, integrity and stability of the electrical power system at the specified level (EURELECTRIC, 2011). AS; supplied to its production, transmission and control systems, ensure that energy produced is transported to consumers safely and continuously (Luo, 2015).

The Federal Energy Regulatory Commission (FERC) of the United States defined AS as; “Given the obligations of the control areas, the services required to support the transmission of electrical energy from the seller to the buyer and to maintain reliable operations of the interconnected transmission system in these control areas. AS provided with production include load tracking, reactive power voltage regulation, system protection services, loss compensation services, system control, load dispatch services and energy imbalance services.” It is also stated that traditionally AS are provided by generators, but they require a change in the equipment that can be used to

offer variable services, to accommodate variable renewable energy resources production and to develop smart grid technologies (FERC, 2018: <https://www.ferc.gov/market-oversight/guide/glossary.asp>). In the Electricity Market Ancillary Services Regulation published by Republic of Turkey Energy Market Regulatory Authority (EMRA), it is defined as “the services to be provided by the relevant real/legal persons connected to the transmission system or distribution system, defined to ensure the reliable operation of the transmission or distribution system and the provision of electricity to the service under the necessary quality conditions”. Supply of AS varies by country. In some countries, services are provided with an ancillary service market according to the free market conditions, while in other countries, they are compulsory and in the form of services based on legal regulations.

Types of AS

From the production of electrical energy to the end consumer, energy must be handled at the quality determined by standards and regulations. In conventional systems where the power flow has only one way which is from the transmission system to the distribution systems, AS are provided from the production facilities under the control of the TSOs in order to keep the voltage and frequency parameters in certain specified limits. AS can be classified roughly as in Figure 1.

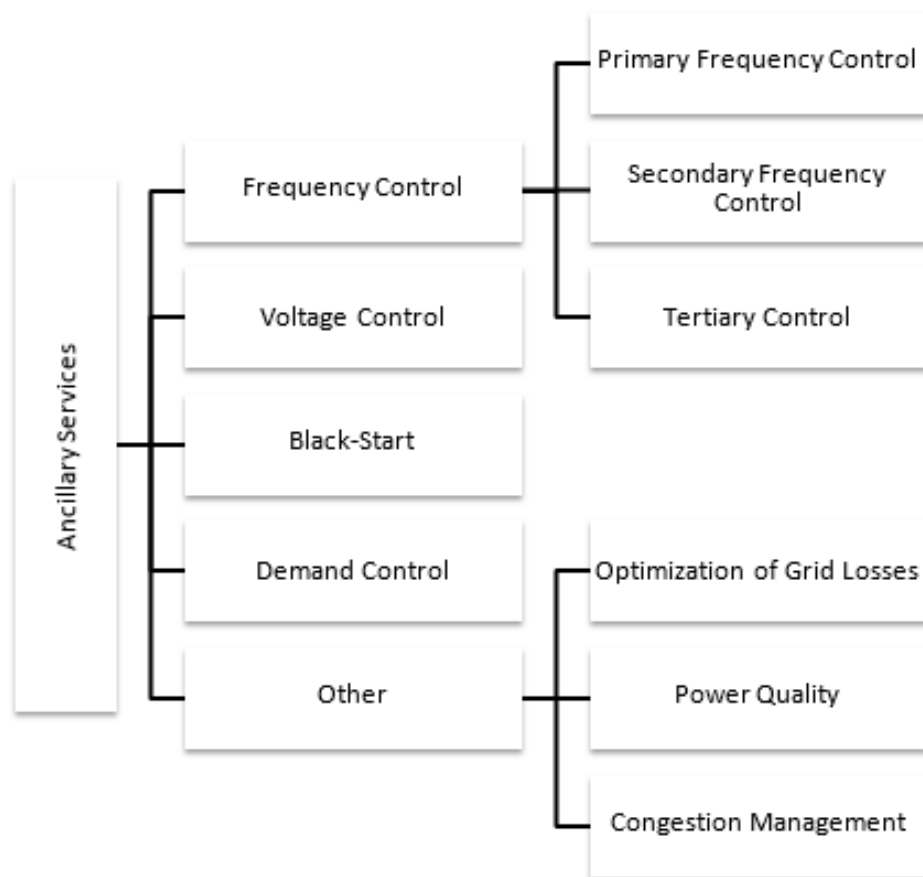


Figure 1. Classification of AS

Frequency Control:

The frequency is controlled by TSOs. TSOs are in charge of maintaining a precise balance between electricity production and consumption, which is necessary for reliable grid operation. By regulating the quantity of active power produced and/or consumed, the supply-demand balance of electric energy should be maintained in the electrical power system's 200 mHz band. A fixed percentage of the active power reserve is used for frequency regulation. In cases where the system frequency drops below the determined value, frequency control backup is used. Frequency control is divided into three categories:

- Primary frequency control,
- Secondary frequency control,
- Tertiary frequency control.

With the oscillation in the frequency of the power system, primary frequency controls are activated first. Primary control reserves in the frequency swing ± 200 mHz band are active and keep the oscillations intact. Then, secondary frequency control is activated, bringing the system frequency to nominal value. Tertiary frequency control generally provides production and consumption balance with load throw-on and load throw-off instructions. Similarly to secondary control, it supports secondary reserves with tertiary frequency control and indirectly makes primary control reserves suitable (OpHB-Team, 2009).

The response time of the system frequency resources used for the restoration of European countries and in Turkey is as follows:

- Interaction of primary frequency control sources within 30 seconds and maintaining at least 15 minutes,
- The secondary frequency control reserves should be activated within 30 seconds and increase the frequency value to the nominal level within 15 minutes,
- Tertiary frequency reserves are also expected to increase to maximum power within 15 minutes.

Voltage Control

It is a mandatory service applied to keep the voltage of the power system within the certain operating voltage limits. Voltage control in the electrical power system is largely carried out by reactive power control. In order for the reactive power demanded by the grid to be transmitted over long distances, the locations of the reactive power generation resources throughout the grid should be set and compensation investments should be made at appropriate locations. The regulation of the voltage between the determined limit values in the entire electrical power system is carried out with a three-level hierarchical system:

- Primary voltage control,

- Secondary voltage control,
- Tertiary tension control.

Primary voltage control is carried out with controllable devices such as Automatic Voltage Regulators (AVR) and Static VAR compensators. The primary side of voltage control is an automatic, local control that brings the voltage value in a given feeder to the set value. Secondary side of voltage control is a central, and again, automatic control system used by regulatory agencies to manage reactive power flows locally. Tertiary voltage control optimizes the reactive power flow in the grid manually. Based on the relationship between voltage and reactive power, equipment capable of producing and consuming reactive power is included in the tertiary control. Equipment capable of producing and consuming reactive power are included in the tertiary control. (2022, URL-2).

The reactive power needed for voltage control is provided locally at the points of requirement. Reactive power; generators from dynamic sources are provided from systems such as synchronous compensators (STATCOM). In addition, capacitor banks from static sources are provided from static voltage controllers and flexible alternating current transmission systems (FACTS) (Hung, 2011).

Black – Start

Black-start refers to re-energization processes in case the electric power system collapses in a wide area or completely after the disruptive effect. After re-energization actions are ensured by system stability, the customers are fed with the production facilities that can be commissioned without the need of an external energy source, the power system is energized and the other production facilities are commissioned. Restoration of the power system which means re-energization from system collapse is carried out with frequency stabilization and re-synchronization stages.

Demand Control

Agreements between the system operator (SO) and consumers are based on participation in frequency control by reducing the demand for electrical energy. Demand control is carried out by separating some of the burdens of consumers from the grid. In cases where the energy supply is insufficient or the demand is high, instantaneous demands are created that can be used in frequency control. It aims to participate in demand control with a large strong industrial facility.

In the United Kingdom, a maximum period of 30 minutes has been determined in demand control agreements and this period has been determined as 15 minutes in the Electricity Market AS Regulation published by EMRA. Similarly, in the UK, the demand control reserve must be at least 3 MW. In Turkey, while there is no lower limit value, it is stated that the offers of the consumers who will participate in instant demand control should be in the form of 1 MW and its multiples.

Instant demand control is realized with low frequency relays. The setting value of the

low frequency relay is based on the automatic reduction of the demand from 10% to 20% if the system frequency drops to 49.0 Hz. It is suitable for participating in the instant demand control of the cement and iron-steel industries. Consumers' demand for electrical energy can be reduced to another time period or the demanded energy can be supplied from the generator or embedded production facilities owned by the facility behind the point of measurement.

In coming years, as the renewable-based distributed resources integration in electrical power systems increases, demand control seems to be increased consumption as well.

In the statement made by European Power Exchange (EPEX), which is one of spot market managers in Europe, it was reported that the prices of electrical energy units in Germany were negative on 24 and 26 December 2017 (2022, URL-1). It is likely that excess production will occur due to seasonal and climatic characteristics, especially during long periods such as night, weekend and holidays (EURELECTRIC, 2004).

Other Ancillary Service Types: In the above titles, the types of AS that have been adopted in almost all energy markets are given. Other types of AS in different world applications are as follows:

Optimization of Grid Losses

In electrical power systems, some energy is lost due to the heating of the conductors and transformer windings. Countries like Austria and Belgium expect these losses to be compensated by the SO. Due to that, special market mechanisms have been created to dispose of the linked loss.

Power Quality

The electric power system is subject to several disruptive effects in terms of power quality. Power quality issues are caused by variations in the primary dimensions of the power system—current, voltage, and frequency—that are outside the permissible limit values. These variations lead to consumer electronics failure or breakdown. The provision of reactive power services, frequency control, voltage control, and limit values established by voltage and frequency standards would all improve power quality characteristics within the ambit of AS in electrical power systems.(Delkhooni, 2019).

Congestion Management

With the rising prevalence of renewable energy sources, AS will be provided in the long term, from the distribution level to grid connected production. In order to provide AS at the distribution level, studies have been carried out on a project basis against the lack of a definite framework on how to coordinate between transmission and distribution SOs (TSO and DSO). In order to benefit from the flexibility that can be provided by the generation facilities in the power system, it is important to establish a legislative infrastructure that will ensure the collaboration between TSO and DSO. Thus, congestion situations can be overcome with strong communication and cooperation between SOs and by making more use of system flexibility (Zipf, 2016).

Resources in Distribution Grid for AS

With the spread of Distributed Energy Resources (DER), the current roles of transmission and distribution systems, Transmission System Operator (TSO) and Distribution System Operator (DSO) are changing day by day. In conventional electrical systems;

- The transmission grid is a system with high voltage (154 kV, 380 kV, etc.), interconnected with parallel lines and bidirectional energy flows, where large production facilities and large loads are directly connected.
- Distribution grids are characterized by one-way energy flow, medium and low voltage (31.5 kV, 15.8 kV, etc.), radial, from connection point in transmission grid to loads, almost any production facility (very limited production facilities compared to all production facilities) is not directly connected and loads are only a statistically predictable system.
- Only large power plants were allowed to participate in wholesale markets, and these provided frequency and voltage control AS to the system (Rebours, 2007).

Renewable production sources with inverter systems such as solar and wind connected to the distribution grid, storage systems, electric vehicles, smart meter systems, etc. new technologies change the architecture and operation of the power system.

With the increase of renewable-based distributed production facilities connected on the distribution level, utilization of AS in the distribution grid comes to the agenda. The increase in the prevalence of distributed generation facilities in the distribution grid has significant effects on the concepts of operation, control, protection and reliability in existing power systems. Active and reactive power flows cease to be unidirectional. The energy source non continuance (cloud transitions, sudden changes in wind speed) in RES based production facilities such as wind and solar causes sudden changes in power systems. In addition, the operation of the distributed generation facilities with a constant power factor independent of the grid operating conditions causes a voltage increase at the connection point. In cases where the demand for electrical energy changes, constant active power supply to the distribution system causes increased line losses and reverse power flows from the distribution system to the transmission. Therefore, it is aimed at reshaping the ancillary service markets and providing AS from the distributed production sources of both transmission and distribution system operators; studies for determining pre-qualification, procurement, activation and settlement processes and TSO-DSO coordination are ongoing.

Below, the sources in the distribution that can be used for the AS in the distribution network are examined.

Distributed Energy Resources

Despite the advantages of conventional electrical energy systems, the trend towards distributed production resources is increasing for the following reasons:

- To meet the increasing demand for electrical energy, more fossil fuels are needed

to meet the demand in conventional energy systems.

- To meet the increasing demand, adopt the concept of consume where you produce (prosumer) due to problems such as the existing systems are not in the desired reliability and cause technical and economic losses encountered in the transmission of the produced energy to the consumed region.
- Many countries prefer renewable energy sources by reducing the use of fossil fuels that cause environmental pollution according to the Kyoto Protocol. Thus, it is desired to prevent climate change and to prevent global warming problems by reducing greenhouse gas emissions

Wind, hydraulic, solar, biomass, geothermal and cogeneration energy systems which are among renewable energy sources are preferred due to some of the mentioned problems of conventional production systems. In the coming period, it is expected that distributed generation plants based on renewable energy sources such as solar, river hydro, geothermal and wind will become more widespread. With the widespread use of distributed generation plants in Turkey it is expected to reduce the investment costs for the transport of electricity generated from east to west. In addition, it is predicted that technical losses caused by long lines will decrease. The following table shows the ratio of installed power distributed generation plants connected to the distribution grid in Turkey, according to the February 2020 report shows EMRA sector.

Table 1. Distributed generation installed power plants in Turkey

Resource Type	Installed Power (MW)	Rate (%)
Solar	5,883.41	92.36
Natural Gas	331.18	5.20
Biomass	75.67	1.19
Wind	70.83	1.11
Hydraulic	8.65	0.14
The Overall Total	6,369.74	100.00

In addition, with the developing technologies, micro grid systems are expected to be developed by using storage systems, with the spread of distributed production plants and cost reduction. Rural areas supply with micro-grid, especially long feeders in distribution regions;

- Failure to be not subjected to long-term interruptions in failures (increasing energy supply continuity)
- It will be beneficial to reduce the distribution grid investment and operating costs to be made in the region.

Reactive power support can be obtained from storage systems using solar inverters, solar power plants, and some wind power plants.

With the increase in grid integration of renewable production sources, it will have

the potential to provide AS to the grid. Many of the AS that are currently given by synchronous generators and voltage regulators might potentially be provided by inverters placed with distributed generation systems and rooftop solar systems. These services include harmonic reduction, voltage regulation, flicker control, reactive power compensation, and active power filtering. Wind turbines and variable speed generators have the ability to provide the grid more.

Energy Storage Systems

Energy storage systems are an important component in providing flexibility and supporting renewable energy integration in the energy system. It can balance central and distributed electricity production, as well as contribute to supply security. It will have a complementary effect on energy storage, demand-side management, flexible production and grid development. Energy storage can also contribute to the de-carbonization of other economic sectors and support the increased share of the integration of variable renewable energy in transport, building or industry. The role of the energy storage area with electricity, which technologies and innovative solutions seem more suitable for different purposes and possible policy approaches should be evaluated within the framework of clean energy (Kling, 2000).

Storage technologies have started to appear as more cost effective, wide-ranging and very profitable grid participants, considering today's technologies. Below are some energy storage systems.

- Chemical Energy Storage Systems
 - Lithium-ion (li-ion) batteries
 - Lithium cobalt oxide
 - Lithium manganese oxide
 - Lithium iron phosphate
 - Lithium titanate
 - Redox flow batteries
 - Vanadium redox batteries
 - Zinc bromine batteries
 - Lead batteries
 - Nickel cadmium batteries
 - Sodium sulfide batteries
 - Sodium nickel chloride batteries
 - Metal-air batteries
- Ultra / Super Capacitors
- Compressed Air Energy Storage
- Pumped Hydro Storage
- Flywheel

Storage systems can perform many functions such as frequency control, voltage control,

power balancing, commercial and improving grid power quality at the same time. This makes it difficult to answer the question of how to define storage systems in the grid. While defining energy storage systems;

- Firstly, the target application should be determined (AS, investment deferral, energy arbitrage etc.),
- Optimum power value and optimum capacity value should be determined according to the application determined. Optimum size and location can be determined with algorithms that will work according to the final purpose.
- After correct sizing, the connection level to the grid should be selected. The usage factor should be determined according to the battery technology chosen.
- The application type should be determined according to the primary, secondary and tertiary applications according to the application priority. For example, primary application is primary frequency control, secondary application is energy arbitrage, etc. priorities can be determined.

Unlike other equipment used in the electricity grid, energy storage systems have a wide variety of technologies and capabilities. Unlike other equipment used in the power grid, energy storage systems have a wide variety of technologies and capabilities. For this reason, storage technology is selected according to the application and location of the application. Battery features seem to vary according to the battery type to be selected. Battery features:

Energy capacity: The energy capacity of a battery is the total energy obtained by a full discharge, expressed in an ampere-hour (Ah) or watt-hour (Wh). Energy available from a battery is a function of discharge rate and temperature. Therefore, the capacity of the battery is usually indicated on the label next to these conditions. For many battery technologies, the energy capacity decreases over time and usage. Also, while high temperatures accelerate capacity reduction, the average charging status is also effective for capacity reduction for some technologies.

Energy density: Energy density (or specific energy) defines how much energy a battery stores (at a certain temperature and discharge rate) per mass or volume unit.

Power capacity: Power is the speed of energy transfer. The ability of a battery to charge or discharge power generally varies depending on the state of charge (SOC) and temperature. Charge rate (C-Rate) values are used to compare the charge and discharge power capabilities of the batteries. C-Rate is the normalization of the power output / input according to the energy capacity of the battery. For example, a 10kWh battery with 5 kW charge / discharge is known to charge / discharge at C2 or 0.5C. A 10kWh battery with 20kW charge / discharge is known to charge / discharge at C0.5 or 2C. Batteries with high C-Rate can charge or discharge their capacity quickly.

Power density: Power density (or specific power) defines how much power a battery can deliver or supply (at specific temperature and SOC level) per unit of mass or volume.

Response time: The time it takes for a battery system to respond to commands.

Ramp rate: It is the rate of increase or decrease of the output power of the battery system.

Cycle life: Cycle life defines the ability of a battery to withstand repeated charge and discharge. The cycle life definition is usually provided by lead acid battery manufacturers based on a specific temperature and discharge depth (DoD). For example, a 10 kWh battery with 3500 cycle life at 40% DoD is expected to have 1400 cycle life at 100% DoD. However, it should be noted that the conversion rates rarely occur in applications.

Shelf life: Shelf life indicates the time to reach the end of the battery's life if stored under ideal conditions. Therefore, this value represents the upper limit of the lifetime that can be achieved in the field. It should be noted that the ideal conditions for batteries to charge are significantly different between technologies.

Round-trip efficiency: It is the ratio of energies entering and exiting the battery during a complete charge-discharge cycle. It is a useful parameter to learn the expected loss during energy transfer.

Self-discharge rate: Self-discharge rate defines the discharge rate of the battery in the no-load state. It is usually expressed in x% per month. For example, a 10kWh battery with a 5% self-discharge rate is expected to lose 5% SOC or 0.5 kWh for a month while in standby. Self-discharge typically increases with increasing ambient temperature.

Temperature range: Batteries can be damaged or become unsafe when certain temperatures are reached. Therefore, a temperature range in which the battery has to be operated is usually determined by the manufacturer.

Voltage range: Some battery technologies are sensitive to overcharge or over discharge. As a result of this situation, manufacturers often determine a voltage range in which the battery should be present.

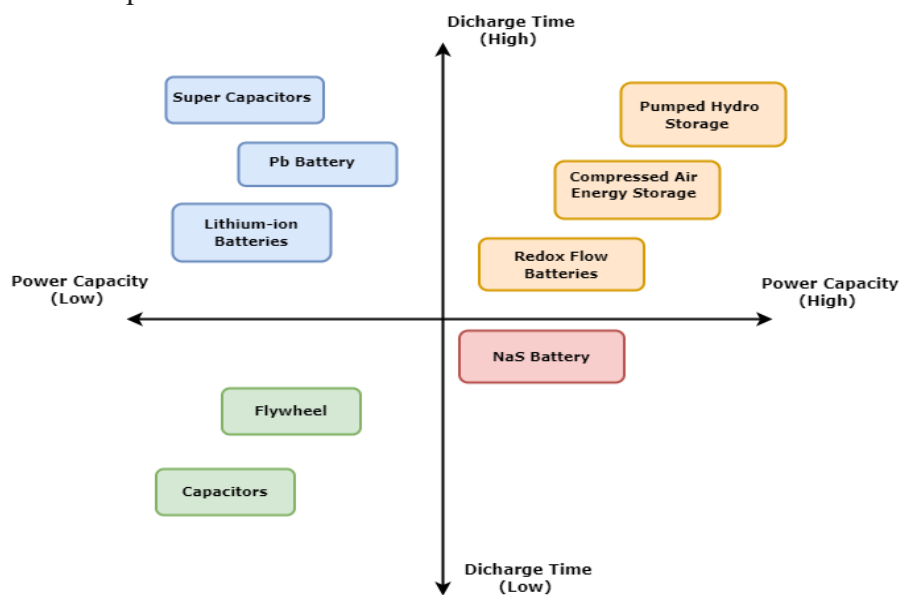


Figure 2. Energy storage systems technologies and characteristics

Participation in AS Capabilities of Storage Systems

Some storage technologies are excellent frequency and voltage regulation providers because the zero net energy source matches the zero net energy source. The fast response and sensitive control offered by storage outperform the control capabilities of many conventional production plants. Technologies that can provide repeated high-speed storage capacity without degradation in their performance are the most suitable frequency and voltage regulation providers.

In the EU countries, the need for fast and flexible storage systems will increase further in the near future, as base-loaded power plants (e.g. coal-fired power plants or nuclear power plants) are increasingly replaced by renewable production sources (e.g. wind or photovoltaic). For example, WWF Solar GmbH, located in Eberswalde, Germany, which integrates renewable energy sources into the grid, started to build a storage system to provide secondary balancing capacity using Vanadium Redox Flow storage systems (2018, The Independent, <http://www.independent.co.uk/news/business/news/germany-energy-consumer-christmas-paidsupply-demand-outstrip-renewables-wind-solar-a8129716.html>). In addition, a multi-purpose power station is being built in AK Berlin-Schönefel to provide AS to a 3,800 kWp photovoltaic system, the TSO of the German utility area in the high-voltage grid. For this purpose, 25 Vanadium Redox Flow Storage Systems with 12,500 kW power and 50,000 kWh capacity are used.

Another energy storage application was used in the black start application. The 33MW / 20MWh lithium-ion battery energy storage system (BESS), which provides grid stability in daily use and helps smooth out output from local renewable power supplies, has been used to launch 44 MW combined cycle natural gas at El Centro Production Station in Valley, in California (Divya, 2009).

Energy storage systems provide the following services in terms of AS participation in electric power systems:

- Load following,
- Regulation,
- Frequency response,
- Reserve capacity,
- Voltage support,
- Black start.

Electric Vehicles

The use of electric vehicles by the day as well as throughout the world is increasing in Turkey. In addition to adding a new load to distribution and transmission grids, the widespread use of electric vehicles can be evaluated in the context of grid reliability and load management and energy quality as they are used as storage sources (Saygin, 2019). The Electric Vehicles' (EV) batteries are designed in both directions so that EVs can support AS in the grid. In this way, it will be possible to transfer energy from vehicle to

grid (V2G) or from grid to vehicle (G2V).

In order to use electric vehicles in AS, the distribution grid manager must keep the number of EVs connected to the grid under control. In the event that the number of vehicles connected to the grid and the occupancy rate of the vehicle batteries is sufficient, the signal to be supplied will be used to start the reference part (this signal is an example of the sinusoidal signal in the grid) and to provide AS to the grid, since the voltage signal will include magnitude and phase shift.

Prevalence of Electric Vehicles

A robust charging infrastructure must be built in order to expand EV use. Since EVs represent the mobile demand for electricity, they theoretically have the ability to draw power from the grid at any time of the day, whether at home or at work, at low charge rates or by using the public charging infrastructure for fast charging. The amount, location, and timing of the electrical energy that electric vehicles (EVs) receive from the grid can vary greatly and are influenced by both driving habits and charging-related business models.

It will be necessary to coordinate the charging models with digital technologies (smart charging). With smart charging, it can be encouraged to charge vehicles with low cost, renewable electricity generation over price and control signals or when there is no congestion in the grid. The value of smart charging applications will increase if it provides support to the grid to supply power quality and flexibility. Beyond smart charging, more flexibility can also be carried out through vehicle-to-grid (V2G) technologies that enable two-way charging.

Where and when the EVs are charged is also critical for distribution electricity companies. EV's can be charged through "behind the meter" systems. Thus, the additional load is provided by rooftop PV systems and/or batteries, and charging is optimized to take place during the day at home or at work.

The value of smart charging applications will increase if it provides support to the grid to supply power quality and flexibility. Beyond smart charging, more flexibility can also be implemented through vehicle-to-grid (V2G) technologies that enable two-way charging (Sortomme, 2012).

Shura "Transformation of Turkey's Transportation Sector: Effects on Turkey Distribution Grid of Electric Vehicle" as stated in the report two different electric vehicle market scenarios were investigated. According to the "High Growth" scenario, electric vehicles will constitute 10% of the total passenger vehicles by 2030 and the number of electric vehicles is expected to be 2.5 million. The "Medium Growth" scenario, on the other hand, predicts that there will be around 1 million electric vehicles in the same year. When the average distance traveled per vehicle is 10,000 km per year and 1 kWh charge is equivalent to 6 km travel, the impact of the total country electricity demand in 2030 will be 4.2 TWh per year according to the high growth scenario and 1.7 TWh according

to the medium growth scenario (Deutsche Energie-Agentur GmbH, 2018).

The main effect of electric vehicles will be on the load management on the LV side of the distribution grid. Electricity distribution companies are expected to apply smart grid elements correctly, manage demand at micro level, and eliminate the effect of electric vehicles increasing transformer points with the help of rooftop solar panels and storage modules. In addition, electricity distribution companies; in the “prosumer” category to be formed, 1 million meters / customers, LV grid control, smart meter, big data management, communication and information infrastructure, cyber security will have to adapt their infrastructures accordingly, in other words, they will have to plan and implement the smart grid elements (Gustavsson, 2013).

Vehicle to Grid (V2G) Concept

Electric vehicles could support the grid, particularly for load balancing and spinning reserves AS. Electric cars have the capacity to discharge power back into the grid in both directions, serving as distributed energy storage. It can deliver power quickly, which can be utilized as rotating backups to maintain grid stability as intermittent production sources like electric vehicles, wind turbines, and solar power are increasingly utilized. Although they are not yet commonly used, technologies that use electric vehicles. In addition to taking off energy from the grid while charging, electric vehicles can also be considered as a mobile storage component that can power the grid. Thus, it may provide different balancing services or AS to the grid operator. In addition, it can act as a storage element that meets the demand for housing when necessary. Although the scale of benefits provided by the flexibility provided for the grid is high, technological constraints still remain. EV battery life will decrease very quickly due to the widespread use of V2G applications and the number of completed cycles associated with charge-discharge

Demand Side Management

Demand side participation is one of the increasingly important methods in developed markets. In generally, it can be defined as the reaction of customers, who can be flexible to the price. However, with the passing of the distribution grid to bidirectional power flow, the increase in the prevalence of the facilities producing energy based on renewable energy sources increases the importance of demand side management. Situations where electricity supply will be insufficient are more likely to occur than conventional grid structure. For this reason, it is expressed as demand side management that the demand for electrical energy is shifted to a different timeframe or disposed of completely against the reduction of the production amount to be provided from RES based production facilities (Delfanti, 2014). Demand side management is carried out with the following functions:

- Peak Demand Decrease
- Low Demand Time Filling

- Load Shifting
- Demand Savings
- Strategic Demand Growth
- Flexible Load Shaping

With the demand-side management, the expansion of power plants based on renewable energy sources (wind, solar, etc.) and the change in electricity consumption habits brought the necessity of making the electricity grids more and more smart. Energy storage systems, ventilation, air conditioning, lighting equipment, renewable production sources, and DSOs on how to use them all will play a major role. Demand side management should provide information such as when electricity is used and producer-consumer incentives for the spread of management. Electricity tariffs should provide information such as when electricity is used and producer-consumer incentives for the prevalence of demand side management. As a result, both producers and consumers will want to participate in demand-side management with incentives.

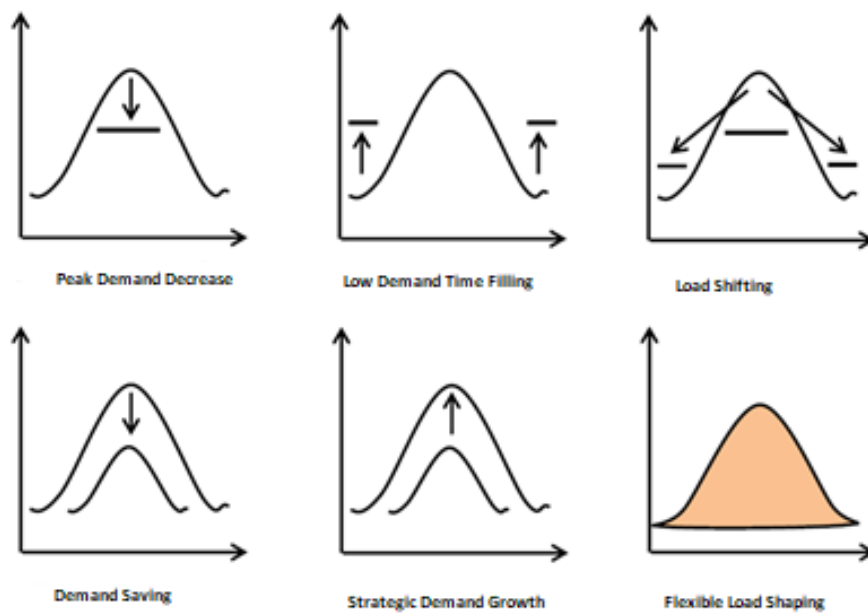


Figure 3: Demand Side Management Functions

Demand side management is carried out directly and indirectly in two different ways. The methods indicated in the figure below are detailed (Yumak, 2016).

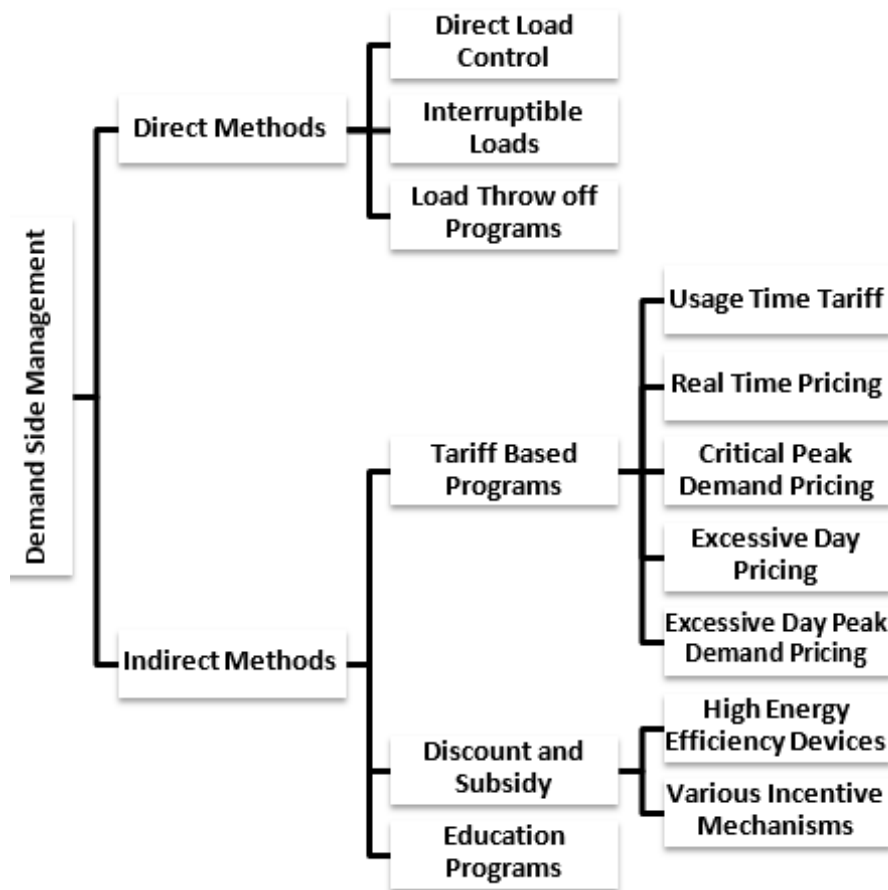


Figure 4. Demand Side Management Methods

Direct load control is the remote control of end consumer equipment during peak demand times and critical operating situations with the development of the smart grid concept. Water heater, pool pump, air conditioning systems used by residential consumers are the sources used in direct load control. Interruptible loads are reduced by the SO with demand limiters and signals in exchange for a certain pricing. In load throw off programs, consumers are offered payment or discounted tariffs to reduce peak demand for a certain period of time. It is usually carried out with large industrial consumers (ENTSO-e, 2015).

Indirect methods are evaluated under the sub-headings of tariff-based, discounts, subsidies and education programs. Tariff-based programs are briefly explained below:

- **Usage Time Tariff:** It is a fixed price tariff structure in different time periods, months or seasons.
- **Real Time Pricing:** Energy prices change on an hourly basis and reflect energy supply costs more accurately.
- **Critical Peak Demand Pricing:** Pre-determined higher energy price application for a few days or hours per year, taking into account time-of-use tariff and real-time pricing mechanisms.
- **Excessive Day Peak Demand Pricing:** A situation where higher prices are valid

for 24 hours, similar to critical peak pricing.

- **Excessive Day Critical Peak Demand Pricing:** Critical peak demand pricing conditions are valid throughout the day.

By enabling consumers to follow instant consumption values, they can shift their consumption to more favorable tariff times and / or prefer devices that operate more efficiently, thus making them pay less. In addition, under favour of the load management practices that voluntarily participate in the consumers with the incentives, the investments budgets can be reduced by using the distribution grid more efficiently. When evaluated from the perspective of the SO, demand side management is important to prevent line loadings and control technical loss parameters in congestion situations.

Evaluation of AS in Distribution Grid

AS at the transmission system level are used to balance the system and manage energy fluctuations. Services with similar features can be used for the management of local system difficulties at the distribution system level with the increase of distributed production resources connected to the distribution grid. At the TSO level, these services can be classified as frequency control, voltage control and other AS.

The table below shows that TSOs and DSOs can make AS contracts in Austria, Belgium, Denmark, Finland, Norway, Spain, Turkey (Labato Miguelez, 2008).

Table 2. Current Status Of AS Contracting At Distribution System Level

Contracting AS from DER directly connected to the DSO-grid	Austria	Belgium	Denmark	Finland	Spain	Norway	Turkey
TSO contracting AS from DER directly connected to the DSO grid	Yes	Yes	Yes	Yes	Yes	Yes	No
DSO contracting local services (for own purposes) from DER directly connected to the DSO grid	No	No	No	No	No	No	No
DSO contracting AS on TSO's behalf	No	No	No	No	No	No	No

In general, there are several restrictions on the participation of DER (distributed energy resource) in AS. In many countries today, the diversity of DER participation in AS markets is large, but the contracted volume is still marginal. It is clear, in addition to that DER has increased participation in AS markets.

Local needs for AS in distribution systems must be combined with system needs in balancing and congestion management. Sources in distribution systems such as demand management, storage systems and distributed production are expected to participate in AS for competitive AS markets for both the local and the entire power system (Singh, 1999).

Frequency Control

Primary frequency control (PFK) is the local automatic control method, it is based on adjusting the active power output of generators, especially in cases where a large power generation facility or load is cut out. Keeping the frequency at a stable point is inevitable for the power system. In generators working synchronously with each other in the power system, primary frequency control is performed automatically with speed regulators. Secondary frequency control (SFK) is the central automatic control method. It is carried out by sending automatic generation set value (set-point) to the plants through Turkey Electricity Transmission System (TEIAS-TSO) National Load Dispatch Center (NLDC) automatic generation control (AGC) software.

Increasing asynchronous resources included in the grid with new technologies will cause the synchronous conventional generators to be economically disabled. Asynchronous plants are examples of inverter-controlled renewable energy sources, energy storage technologies.

High-performance, swiftly responding inverter-controlled facilities are anticipated to have their own service category. Comparing these technologies to conventional synchronous production reveals a wide For example;

- Systems for battery storage and inverter-based production do not add much,
- Power output from solar and wind energy generation is unpredictable and only available intermittently.

However, the frequency response from a battery storage system, solar power or wind power plant is controlled by the inverter and has the potential to react faster than conventional generators. Increasing asynchronous resources included in the grid with new technologies will cause the synchronous conventional generators to be economically disabled. Asynchronous sources are connected to the system via the inverter and the system causes the Inertial Response capability potential to decrease. The current frequency control AS philosophy set is not specifically designed to eliminate this challenge (Aubut, 2013).

Other inverter-based sources including wind turbine generators (WTG) may also be able to inject active power into the system following a malfunction caused by the control system (e.g. generator failure). Many WTG producers already have access to this so-called synthetic inertia. The response of a wind power plant in Hydro Quebec with a synthetic inertia capacity is depicted in the image below (Figure 5). Without wind energy reduction before failure, this feature is possible. However, a wind turbine will give a frequency improvement period as illustrated in the figure below (Lalor, 2005).

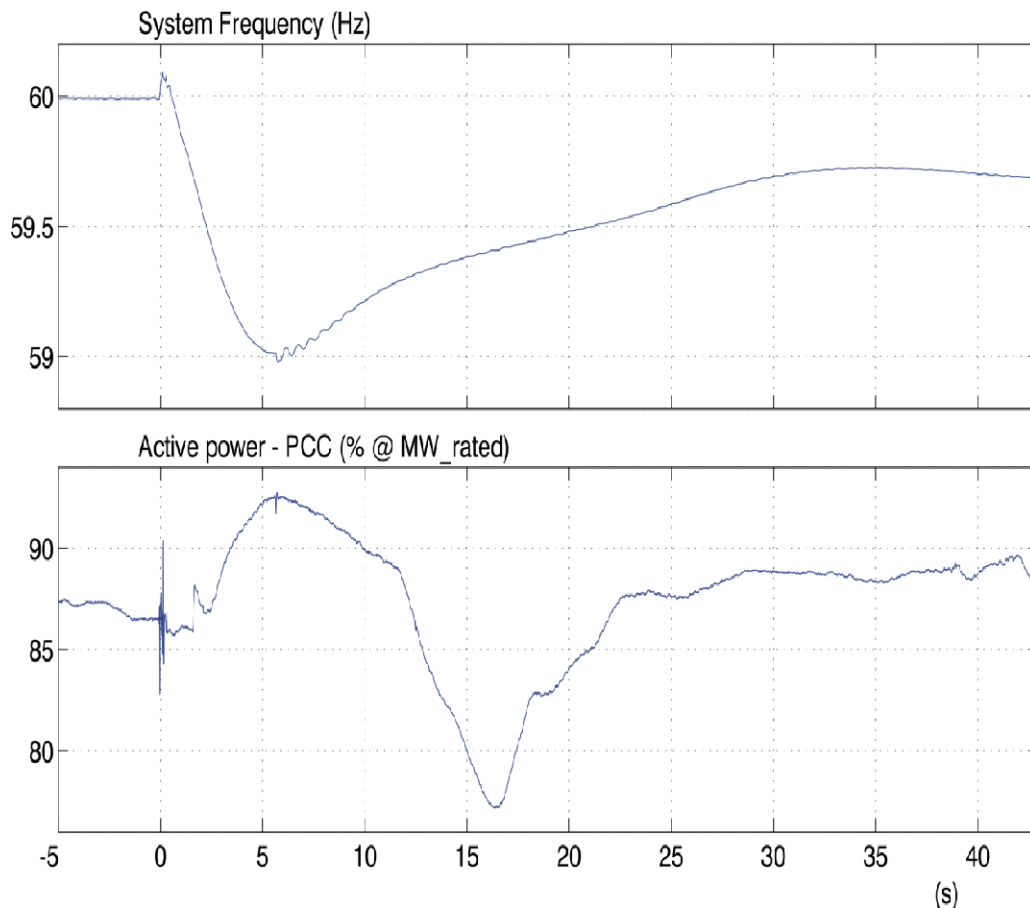


Figure 5. Wind Power Plant Synthetic Inertia Response

All synchronous machines in the circuit perform Synchronous Inertial Response after power system failures (SIR). The ability for synthetic inertia necessitates control action in response to a decrease in system frequency. Because of this, synchronous machines do not have the same inertia or natural response as synchronous machines in the event of generator failure. Synthetic inertia, on the other hand, will enhance the Rate of Change of Frequency (RoCoF) and aid in preventing system deterioration. The performance of synthetic inertia needs to be examined and explored.

Performance requirements related to primary frequency control ancillary service are defined in the Electricity Market Regulatory Authority Electricity Grid Regulation Annex 17, AS performance test procedures, Annex 17.A primary frequency control performance test procedures. The minimum performance criteria defined in the primary frequency control test procedure are summarized in the table below.

Table 3. Primary Frequency Control Performance Requirements

Requirements	Value
Reserve Capacity	Minimum ± 1 MW
Sensitivity	Minimum ± 10 mHz
Response Time	Maximum 2 seconds

Ramp Rate	Minimum Reserve / 30 seconds
Duration	Minimum 15 minutes
Tolerance	$\pm 1\%$ of Tolerance Installed Power
Success Rate	Minimum 90%

When the requirements stated in the table above are evaluated in terms of storage facilities, other requirements (reserve capacity, sensitivity etc.) are related to the inverter, except for the duration. Depending on the duration, the charge / discharge capacity of the storage facilities is determined.

In addition, according to the current regulation, storage facilities should have at least ± 1 MW and their multiples (such as ± 2 MW, ± 3 MW, not ± 1.5 MW, ± 2.5 MW). As the maintenance time is at least 15 minutes, the charge / discharge capacity should be at least 250 kWh. As a sensitivity, inverters should be able to react to changes in mains frequency at least 10 mHz and start to react within a maximum of 2 seconds. The responses should be provided within the tolerance limits with a success rate of at least 90%. For storage facilities, tolerance limits must be redefined depending on reserve capacity. For example, it can be defined as $\pm 10\%$ of reserve capacity.

Performance requirements related to secondary frequency control ancillary service are defined in the Energy Market Regulatory Authority Electricity Grid Regulation Annex 17 Ancillary Services Performance Test Procedures ANNEX 17.B Secondary Frequency Control Performance Test Procedures. The minimum performance criteria defined in the secondary frequency control test procedure are summarized in the table below.

Table 4. Secondary Frequency Control Performance Requirements

Requirements	Value
Reserve Capacity	Minimum ± 5 MW
Sensitivity	-
Response Time	Maximum 30 seconds
Ramp Rate	Minimum Reserve / 5 minutes
Duration	Minimum 1 hour
Tolerance	$\pm 1\%$ of Tolerance Installed Power
Success Rate	Minimum 90%

49 MW lithium-ion energy storage systems have been installed at coal and gas fired power plants in Roosecote, England (Energy UK, 2017). The purpose of installing the storage system is to maintain fluctuations in electricity demand, power frequency and grid stability. The system responds to fluctuations in less than a second (UK, 2017).

German utility WEMAG has decided to increase the energy storage capacity in Schwerin from 5MW to 10MW power output and from 5MWh to 14.5MWh capacity. Currently,

there is no storage facility installed in size and capacity that can participate in frequency control in Turkey. However, within the scope of the R&D project accepted by EMRA and carried out by Meram Electricity Distribution Company will establish a 1 MW chemical energy storage facility for primary frequency control ancillary service and congestion management applications in the coming days.

The power value, capacity value, storage size and location related to the design of storage facilities in MV grid should be determined. The location focuses mainly on two different architectures: central energy storage architecture and distributed energy storage architecture. High-capacity storage systems with centralized power storage architecture Turkey Electricity Transmission Company (TEIAS) is connected to the first distribution centers on feeders coming from substations. With the distributed energy storage architecture, multiple low capacity energy storage facilities are preferred over high capacity storage facilities. Low capacity energy storage facilities are connected to such as distribution centers, circuit breaker measurement cabinets within the grid and transformer centers (Koohi-Kamali, 2013).

Voltage Control

At all voltage levels in the electrical power system, the voltage value must remain within the specified operating range. Over-active power generation / consumption at low and medium voltage levels may cause voltage increase / decrease and technical loss rates increase.

If there is no production in the local area, the voltage decreases as the distance increases until the electrical energy is delivered to the consumer. When the amount of distributed production is high at the end of a line, and there is no load to use the entire production, power flows occur in the opposite direction (from distribution to transmission). As a result, the voltage can rise to very high levels or lower the voltage limits. DSOs try to minimize voltage drops (<1 pu) with compensation investments. However, it does not affect the voltage increase (> 1 pu) too much.

When the number and capacity of distributed energy resources increase, voltage change problems will increase in the distribution grid. Thus, it is necessary to control the voltage to compensate the effects of resources on the distribution grid, first of all, the reactive power properties of inverter controlled power plants should be used and then other options should be checked. With the control of reactive power, compensation investments made annually will decrease significantly. In addition, technical losses will be reduced and energy efficiency will be increased by controlling the voltage.

For the reactive power characteristics of the plants are used, the active power value at the exit point of the feeder can approach zero due to the active power generation of the plant. In such cases, legal regulations should not constitute any penal situation. Furthermore, for the distribution grid operating conditions have changed, the active powers of the plants must also be controlled by the distribution grid operator.

Table 5. Reactive Power Control Performance Requirements

Requirements	Value
Reserve Capacity	± 0.9 power factor
Sensitivity	Minimum 0,01 pu
Response Time	Maximum 1 seconds
Ramp Rate	Minimum Reserve / 30 seconds
Duration	Continuous
Tolerance	$\pm 10\%$ of the reserve
Success Rate	Minimum 90%

As a reserve capacity requirement, it is recommended that the reactive capacity, which is determined by taking into account the generation facilities, inverter installed powers and ± 0.9 power factor, is determined as the minimum mandatory requirement. For the 0.8 power factor, fixed payment business model can be developed. As a sensitivity, it can be expected to react to at least 1% changes in the grid voltage (0.01 pu). As a response time, it can be expected to start reacting within 1 second at the latest and provide the entire reserve within 30 seconds. If the reactive power control ancillary service is to be provided autonomously, these times can be reduced to a few seconds depending on the inverter capacity. As of the end of 2019, there are 1114 solar power plants connected to the Meram Electricity Distribution Company grid. In the table below, the reactive power control potential for Meram Electricity Distribution Company is shared. In inverter controlled sources, it is assumed that facility power is equal to inverter power.

Table 6. Meram Electricity Distribution Company Reactive Power Potential

Resource Type	Number of Plants (Number)	Plant Power (MW)	Power Factor	Reactive Power Potential (MVAR)	Power Factor	Reactive Power Potential (MVar)
Solar Power System	1114	920,043	$\pm 0,80$	690,032	$\pm 0,90$	445,597
Other	8	6,598	$\pm 0,80$	4,948	$\pm 0,90$	3,196

When the field type solar power plant systems in the Meram Electricity Distribution Company region is examined, 1250 kVA transformers and inverters with a total power of 1 MW are used in the typical installed power of 1 MW. While solar power plant systems are producing at full load; although transformer power is sufficient to provide reactive power control ancillary service with a power factor of $\pm 0,8$, inverter powers are insufficient. Reactive power control ancillary service can be obtained from the existing solar power plant systems if they do not produce at full load.

In addition, the number of central and series inverters in the provinces in the Meram Electricity Distribution Company region can be seen in the table below. Central inverters offer remote communication and communication options. Central inverters serve smoothly as infrastructure. A full range of data communication methods are available, including remote monitoring.

Table 7. Number of PV Inverter Types

PROVINCE	SERIES (pieces)	CENTER (pieces)	The Overall Total
Aksaray	69	31	100
Karaman	60	25	85
Kırşehir	35	23	58
Konya	375	183	558
Nevşehir	144	42	186
Niğde	104	23	127
The Overall Total	787	327	1114

Energy storage systems, which are anticipated to become commonplace in the future, will be connected to the distribution grid in addition to producing facilities. It is important to define the power value, capacity value, storage size, and location for storage facilities reactive power control auxiliary service design. According to the distributed or central connection architecture, the location determination should be connected to the distribution (Evans, 2012).

One of the difficulties of increasing the renewable energy sources is the voltage change problems instantly due to the reasons of the sun, the wind speed etc. Voltage changes cause serious difficulties to consumers and distribution grid operator. The following figure shows the production profile for a random 2-day solar power plant selected from the Meram Electricity Distribution Company region. As can be seen in the figure, production increases at noon, but production may change instantaneously at 13.00 due to the cloud coming in front of the sun or for any other reason.

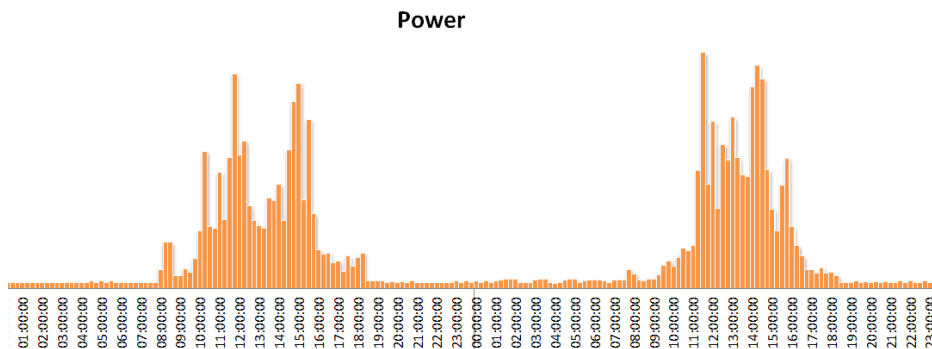


Figure 6. Production Profile For 2 Days Randomly Selected

Instant power changes and reactive power flow in the grid should be monitored effectively and communication infrastructure should be established. RTU is installed for field type solar power plants in Meram Electricity Distribution Company region. By connecting RTUs placed on the field to Meram Electricity Distribution Company's SCADA control center, an effective monitoring can be made, and even inverters can be controlled according to reactive need.

Congestion Management

Congestion management ancillary service should be used to eliminate both production-related and consumption-related congestions that occur or expected to occur in distribution grids.

In optimum distribution grid planning, distributed production sources should be close to the loads. Thus, it should be contributed to the power quality, the reduction of transmission and distribution peak loads, the need for long-distance transmission, the prevention of grid over-capacity, the deferral of grid investments and the reduction of grid losses, so that the congestion caused by production and consumption in the grid can be prevented. However, in reality, distributed production resources cannot always be close to loads and cannot be controlled. Therefore, distributed production resources do not always meet local demand.

Regarding the congestions caused by production; the increase in the prevalence of DERs in the distribution grid, the spread of rooftop type solar electricity generation in the regions where residential consumers are concentrated, congestion occurs in the transformers and lines at times when consumption in the grid is low. Especially in feeders with low load and high energy production with distributed generation facilities, problems such as overload, reverse power flow and voltage increase occur. As a result of reverse power and overload, it will cause various problems such as damage to conductors, aging of conductors and increased losses (Joos, 2000).

Also, the prevalence of EV's and the including of charge stations in the grid, charge EV batteries without any control can overload transformers and cables during peak hours, where EV's penetration is relatively high.

In order to overcome the problems mentioned in the conventional distribution grid operation, new investments are made to increase the cross-sections of conductors, or the prevalence of distributed generation resources in the relevant feeders is limited. However, in order to both investments deferral and to expand renewable-based energy production, it is necessary to monitor, dynamically control of distributed energy resources and supply AS from these sources.

Distribution grids, which traditionally have a one-way load flow, need to evolve into a grid structure suitable for bidirectional load flow and establish the infrastructure, depending on the renewable energy sources that are increasing today. At this point, it is an important requirement for distribution grid operators to provide congestion management

ancillary service with demand side participation, both for production resources and for high consumption loads such as agricultural irrigation in Meram Electricity Distribution Company region, such as industry, commercial.

With the congestion management defined as ancillary service, technical losses can be reduced by ensuring that the investments are defer in the distribution grids, the energy supply-demand is balanced and the balanced loading of the grid.

In order to provide congestion management ancillary service from production sources, primary sources of production facilities must be stored or available if needed. For this reason, storage facilities should be used in congestion management for both production and consumption.

Performance requirements regarding congestion management ancillary service should be defined separately for production and consumption facilities. Production facilities that will provide congestion management ancillary service and consumers are required to sign a congestion management ancillary service with distribution companies.

Midwest Energy provides electricity distribution to 48.000 subscribers in Kansas. In order to solve the problems experienced due to the increase in demand, Enernoc has developed an agricultural load management program. Within the scope of the program, the irrigation pumps of the subscribers are automatically closed on weekdays of the summer between 14.00 and 19.00. Subscribers who are subject to the agreement are paid by Midwest Energy. It is an agricultural subscriber using 2000 of the subscribers over 30 kW. This corresponds to a peak load of 45 MW. The electricity distribution company pays 20 dollars for each kW that the subscriber does not use. The project, which started in 2009, tripled the number of subscribers in 2011 (2022, EnerNOC, Agricultural Load Management Project, <http://www.enernoc.com/our-resources/case-studies/547-midwest-energy-grows-new-energy-supply-with-enernoc-agricultural-demand-response>).

The company PG&E charges an additional fee of 1 dollar per kW when its subscribers consume energy during peak time. This method which is applied is very expensive for farmers and the wages even increase up to 10 times of their normal tariffs. Farm owners agreed with the authorized company and installed their automatic shut-off systems on water pumps. With this method applied, the farmers are asked whether they want to take part in load management at the time of the peak and if the farmers agree, the electricity of the irrigation pumps is interrupted for 2 - 4 hours in line with their agreement.

On the other hand, the prevalence of grids where periodic loads (agricultural, etc.) are dominant, where the load factor is quite low, also offers a significant potential for congestion management in terms of load management needs.

24% of total consumption in Meram Electricity Distribution Company region is agricultural irrigation consumers. In the table 8, there is provincial information based on agricultural irrigation cooperatives in Meram DSO region. In certain periods of the

year, there is congestion in transformers and lines for agricultural irrigation purposes. In order to solve this problem, the demand side participation project is carried out with the agricultural irrigation consumer subscribers within the scope of the Ancillary Services Pilot Application project, which is an R&D project adopted by EMRA in July 2019 (EnerNOC, 2022).

Table 8. Agricultural Irrigation Cooperatives Transformer Numbers And Installed Powers

PROVINCE	Number of Agricultural Irrigation Transformers (pieces)	Agricultural Irrigation Installed Power (KVA)
Konya	722	213.502
Karaman	84	41.706
Niğde	328	28.252
Aksaray	72	13.168
Kırşehir	18	1975
Nevşehir	40	13.061

With the installation of a storage system or systems in the grid, distributed energy storage architecture should be preferred. Because when the distributed energy storage architecture is compared with the central energy storage architecture; especially, it is expected to provide maximum benefit from congestion management and reactive power control AS (to deferral investment, to minimize compensation investments, to decrease grid losses and to increase grid efficiency).

The necessary communication infrastructure must be established in order to monitor and to send warning signals the producer / consumer points to participate in the congestion management ancillary service.

Within the scope of the congestion management ancillary service, components such as smart meters and sensors are applied at the producer / consumer points. The size of the data transferred from these components to the center increases with the spread of the program. Therefore, big data needs to be used / managed effectively due to increasing data size. As a result, it can be ensured that parameters such as price and required capacity amount can be estimated in real time and accurately by making use of big data management techniques.

Micro Grid Applications

Recently, there has been a lot of discussion on the controlled and reliable integration of DER into big power grids and microgrids. Due to its flexibility, controllability, and energy management skills, the microgrid concept—which essentially entails the coordinated functioning of a group of loads, distributed generators, and energy storage systems—is highly alluring. Grid-connected and stand-alone modes are the two ways that microgrids can operate to supply loads with consistent power. A microgrid will typically function in a grid connected mode and be connected to the mains. The microgrid is separated from the distribution grid in independent mode (Jiang, 2013).

Microgrids are required to function in both distribution grid-connected and stand-

alone modes, and economically fulfill the demand on an instantaneous basis, in order to offer uninterruptible power supply to the loads. The issue of managing resources in a microgrid as efficiently as possible is a topic of intense research, and recent studies have suggested applying both centralized and distributed control schemes employing multi-agent systems, heuristic techniques, and optimization algorithms (URL-3, 2022). The highest priority for microgrids is to provide customers with a reliable power supply instead of economic benefits. Therefore, goals and energy management strategies are different in both modes. Microgrids are expected to be a part of the next electrical energy system development, not only in rural and remote areas, but also in urban areas. Planning processes should be directed to economic feasibility as a guarantee of long-term stability, as microgrids are expected to coexist with conventional power grids. Microgrids are required to function in both distribution grid-connected and stand-alone modes, and economically fulfill the demand on an instantaneous basis, in order to offer uninterruptible power supply to the loads. The issue of managing resources in a microgrid as efficiently as possible is a topic of intense research, and recent studies have suggested applying both centralized and distributed control schemes employing multi-agent systems, heuristic techniques, and optimization algorithms. (Gamarra, 2015) (URL-3, 2022).

In the case of isolation, the only structure that will control the quality of energy is the production systems that remain within the island. Thus, the production plants in the island (microgrid) must control the voltage and frequency. Therefore, dangerous energy oscillations are likely to occur in the microgrid structure. Thus, the Energy Management System (EMS) is critical for managing power and energy between loads and resources. Active and reactive power references can be checked with EMS (Zehir, 2013). Several functions are used to examine microgrid management, and they are categorized according to a temporal scale.

Long-term energy management includes the following:

- Forecasting RES output on an hourly basis, accounting for production costs and environmental effects,
- Management of controllable loads not connected to the grid according to the inspection requirements,
- Offering a suitable level of power reserve capacity in accordance with the electrical market and the predicted load demand,
- Maintenance frequencies.

Short-term energy management includes the following;

- Real-time power distribution, rms voltage regulation and primary frequency control via DERs,
- Real-time power distribution via DERs. (Gustavsson, 2013)

Improving Power Quality

Any issue with voltage, current, or frequency deviation that causes a customer's electrical equipment to malfunction can be categorized as a power quality issue. Power plants can currently only manage voltage; they have no control over the current a given load draws. As a result, they make an effort to maintain power quality standards within a given range.

While various definitions of power quality are not consistent with each other in the literature and standards, generally everyone's perception is the same. On the other hand, modern industrial processes working with new electrical equipment are affected by the lower power quality more than older equipment. Considering these situations, higher quality power is needed every day within the scope of our industry and individual life.

In power systems, harmonic voltage levels and flicker effect mentioned by specified in part of Annex 1 of the Grid Regulation in Turkey. It is not known exactly how much of the deterioration of the power quality is from the consumer and how much from the grid. Negative effects due to harmonics are generally not detected. The deterioration in power quality is also gradually increasing. Filters are used to eliminate current harmonics in power systems. Filters are classified under two main titles as passive and active harmonic filters.

Black-Start

According to the definition in the Electricity Market Ancillary Services Regulation of the Energy Market Regulatory Authority (EMRA); It is defined as energizing the transmission system through production facilities that can be commissioned without the need for an external energy source, supplying electrical energy to customers and re-commissioning other production facilities if the transmission system is partially or fully black-out (Turkey Energy Market Regulatory Authority-EMRA, 2017.)

Re-commissioning the system after the system is black-out is another task of the SO. For the majority of the producers need to get electricity from the grid to energize themselves and start production, they cannot facilitate reboot after failure. Therefore, black-start services are required from production facilities that can be commissioned without the need for an external energy source. When we consider that the supply of start-up services from energy sources with black-start capability is a purely public good, it is clear that this task is given to the SO, a regulated actor. In principle, both TSO and DSO are eligible for this service.

The use of storage systems in black-start is in trial phase, on May 10 2017, an electricity company in Southern California successfully demonstrated the use of a black-start by firing a deactivated combined cycle gas turbine with a battery energy storage system.

By using the black-start capability of the said battery energy storage system, an electricity generator and grid were energized, respectively, without the need for external transmission lines, thus the grid power functions were restored. 33MW / 20MWh

lithium-ion battery energy storage system (BESS), which provides grid stability in daily use and helps smooth out output from local renewable power supplies, was used to operate the 44 MW combined cycle natural gas turbine at the Imperial Valley El Centro Production Station in California.

Optimization of Grid Losses

International regulations are specifying that distributed productions should not cause to an increase in losses. It is also specifying in the EMRA Electricity Market Unlicensed Electricity Generation Regulation that one of the purpose of distributed energy resources is to reduce losses in the.

Power plants to be connected to the distribution grid have the purpose of reducing losses in the distribution grid. However, integrations without any calculations can increase distribution grid losses. For example, a large group of power plants to be connected to the end of a relatively low feeder load will create an inverse power of greater power than the power previously carried in the related feeder, since only the load condition is considered in the respective feeder design, resulting in increased loss in the related line. The integration of distributed energy resource into the distribution system will reduce the load of transmission transformers and reduce losses. However, the direction of losses decrease and increase in the distribution grid area which the distribution grid operator is responsible will directly depend on the locations of the distributed energy resources, the load distribution in the related region and the line / cable cross-section carrying the related power. For this reason, it is necessary to make loss analysis in production integrations and determine the connection points and line cross-sections that will prevent loss increase.

Regional Capacity Rental

Regional Capacity Rental Ancillary Service is a mechanism that enabling the required capacity to be established in the regions needed in the market structure in order to increase the supply continuity and quality and to fulfill the economic needs of the regional system, if the distribution system does not have sufficient capacity to ensure supply reliability.

Meram Electricity Distribution Company's rural distribution grid realizes unforeseen long-term power interruptions due to reasons such as pole demolition from ice load or wind force, conductor breaks, especially in winter when there is heavy snowfall. In terms of economics of scale, there are no system strengthening investments in order to feed these scattered small loads supply with long feeders safely. For this reason, in order to meet the electrical energy needs of small residential units in the feeder failures that may occur in distribution grid, demand management can be provided in a hybrid micro grid with renewable energy source so that the energy need of the load can be meet continuously. Technology, DERs and consumption diversity play an important role in the development and adoption of micro grids.

Regional capacity rental ancillary service can also be used for micro grids in order to increase supply continuity and quality and meet the possible regional system needs economically if there is not enough capacity in ensuring distribution system supply reliability (Holtinen, 2012).

The Electricity Market Ancillary Services Regulation is regulated on the basis of the fact that only the TSO provides regional capacity leasing ancillary service and it does this in order to overcome the transmission system congestions and ensure supply security against transmission system congestions. The regulation needs to be reorganized by the DSOs, in particular for regional capacity leasing items, in order to ensure the continuity of supply in the distribution system and to overcome grid congestion, so that they can receive this ancillary service for microgrids and include storage systems.

TSO-DSO Coordination

The conventional power grid is a unidirectional power flow, and the electricity produced in conventional power plants is designed to deliver electricity to consumers connected to high, medium and low voltage levels. The task of the TSO in the conventional electricity grid can be summarized as the safe operation of the power system, the balancing of the power system in the balancing area, the measurement of electricity demand in the HV grid, ancillary service supply and the maintenance of the HV grid. Some of the task of DSO is to operate and maintain the MV and LV grid, deliver electricity to consumers, manage the grid capacity to minimize grid capacity costs and measure the electricity demand in the MV / LV grid.

However, in recent years, large amounts of RES have been connected to both the transmission and distribution grids, and it has become difficult for production to be programmable at the transmission level. In addition, power flows are now bidirectional in distribution grids, and a relatively high volume of electricity is generated at the system's MV and LV levels. The logic of making a strict distinction between transmission and distribution systems has disappeared, and TSO and DSO roles must be redesigned as a result.

While TSOs generally serve hundreds of large industrial consumers and producers, DSOs generally have millions of residential customers as well as thousands of medium-sized commercial customers. In addition, today there are thousands of medium-sized producers (eg solar PV, wind, biomass, etc.) at the distribution level. In the future, hundreds of thousands of unlicensed small producers (eg rooftop PV panels, etc.) are expected to be active in the distribution grid at medium and low voltage levels (Kanchev, 2011).

It seems that DSOs will need AS as well as grid reinforcement investments in order to cope with this new situation and difficulties in grid operation. However, a stronger cooperation between TSOs and DSOs will be required to guarantee the current level of

supply security.

Due to the situations mentioned above, the need for coordination between TSO and DSO becomes more and more important. SmartNet basically offers five models for TSO and DSO coordination.

Coordination Models

Centralized AS Market Model

In this scenario, the DER owner that is directly connected to the DSO grid for AS is contracted by the TSO. Although the DSO can supply and deploy resources to address local grid concerns, the procurement process differs from that of the centralized AS market in terms of timing. Without the widespread participation of DSO, TSO runs a market for both sources tied to the level of transmission and distribution. The most resembling example of the conventional structure is this one.

The prequalification process specified in the DSO role can be divided into two separate processes;

- **Technical Prequalification:** The TSO controls and approves the technical requirements of a unit that wants to join the AS market.
- **System Prequalification:** Approves the participation of distributed energy resources in AS market, provided that it complies with the operating conditions in the distribution grid (URL-4, 2022).

The role of DSO according to the centralized AS market model is limited by its role in the system pre-qualification process. Consequently, according to this model, DSO must provide the TSO with the necessary data, or the TSO must provide full observability of the DSO grid. Full observability means that real-time / near-real-time telemetry data of DERs are transmitted to TSO infrastructures instantly (SCADA etc.).

Local AS Market Model

The main principle of the local ancillary market model is the establishment of a local market and its management by DSO. After DSO has aggregated these resources and transferred them to the TSO AS market, TSO can sign a contract with DER indirectly from the local markets.

DSO organizes a local market for DSO-connected resources and, after resolving local grid restrictions, collects the remaining offers and makes them available to the TSO.

The local AS market model deviates from the centralized AS market model by promoting a local market. The implementation of such a market model shifts the priorities to DSO. In case of compliance with the distribution grid restrictions, all AS that are not needed / procured in the local market are included in the central market under the control of the TSO in bulk. AS offered to the central market by DSO collectively provide an advantage to TSO in terms of manageability.

Shared Balancing Responsibility Model

The TSO passes the “balancing” duty of the distribution grid to the DSO in accordance

with the shared balancing responsibility paradigm. To carry out the DSO balancing duty, it executes DER's Daily Production Programs in accordance with a "predefined program" that takes into consideration demand and grid loss estimates for the territory under its jurisdiction. To carry out its balancing duties, DSO adheres to this predetermined program and makes use of DEKs connected to the distribution network via the regional AS market (Gubina, 2015).

The predetermined program is based on the fact that DERs are proposed (for the entire DSO region) in accordance with daily production plans, their offer to the market (i.e., merit order) as balancing units, and historical data projections at each TSO-DSO interconnection point. The predetermined program is currently only expressed in terms of the outcomes of the energy markets, and TSO and DSOs do not alter this program in order to control congestion. This predefined program means that it is determined at the level of the entire DSO area, not at the TSO-DSO interconnection point, because candidates are not specifically made to enter Merit Order for every TSO-DSO interconnection. Alternatively, TSOs and DSOs could determine the pre-defined schedule, using historical forecasts for each TSO-DSO interconnection point, together with constraints for both the transmission and distribution grid. In this second option, the pre-defined schedule is determined for each individual TSO-DSO interconnection point (URL-4, 2022).

In summary, TSO and DSO balancing responsibilities are fulfilled individually, using resources available on each grid. While DSO organizes a local market taking into account a balance program agreed with TSO, TSO does not have access to resources connected to the distribution grid.

The only coordination model in which TSO does not have access to connected resources in the distribution grid is the shared balancing responsibility model. Only the DSO is permitted to use the distribution grid's flexibility in order to carry out its duties related to balancing and addressing local grid restrictions.

[Common TSO-DSO AS Market Model](#)

The common TSO-DSO AS market model develops a common flexibility market for SOs. The main purpose of this coordination model is to minimize the total procurement costs of flexibility. This model requires incentives to improve the system as a whole, rather than focusing on minimizing the costs of TSO and DSO separately, regarding the revenue requirement of TSO and DSO.

The cost of the resources TSO and DSO require must be reduced. This shared objective can be accomplished by the coordinated efforts of a common market, the dynamic integration of a local market run by DSO, a central market run by TSO, or both (Enerquire, 2017).

The common TSO-DSO AS market model can be seen as an extension of both the local AS market model and the centralized AS market model. By combining the resources

connected to the transmission grid and distribution grid, the optimization is still set up in the centralized variation. However, in this model, DSO grid restrictions and prospective local flexibility requirements are also included in the common markets. In contrast to the decentralized variant, the local AS market model does not give priority to exploiting flexible resources in its distribution grid. Based on a combined optimization of the needs for flexibility at both the distribution level and the transmission level, the DSO will decide which resources to deploy to meet local restrictions. (Atzeni, 2012).

Integrated Flexibility Market Model

The integrated flexibility market model encourages a regulated market (TSO and DSO) and commercial market parties to provide flexibility in a common market. This market is open to both TSO and DSOs and balancing units, aggregators etc., and requires the use of an independent market operator to ensure neutrality. As a result, the boundaries between balancing markets and AS can disappear.

The integrated flexibility market concept puts forth a market mechanism wherein SOs and commercial market players can both purchase available flexibility under the same terms. Actors that are controlled and those that are liberalized are interchangeable. The distribution of flexibility is decided by market forces. But this distribution will account for grid constraints at all voltage levels.

Evaluation of Coordination Models

All these models have different strengths and weaknesses. There is a lot of disagreement about which model to choose under which conditions. The advantage-disadvantage information about TSO and DSO coordination models described above are summarized in the table below.

Table 9. Comparison of Coordination Models

Coordination Model	Advantages	Disadvantages
Centralized AS Market Model	- Only suitable for TSO to purchase AS - Supports standard operations with low operating costs due to a single market - Compatible with many of the existing regulations	- DSO does not have real participation in the market - DSO grid restrictions are not always taken into account
Local AS Market Model	- DSO takes priority in the use of local resources - DSO actively manages the procurement process - Less barriers to small-scale DER participation in the market	- TSO and DSO market are balanced in order - Local market may have low liquidity - Comprehensive communication may be needed between the TSO market and the DSO market

Shared Balancing Responsibility Model	• TSO will require less AS in the future. • Less barriers to small-scale DER participation in the market • System operating limits are clear between TSO and DSO	• Total amount of AS to be supplied by TSO and DSO will be higher • Balancing units may face higher balancing costs • Small local markets may not have enough liquidity to provide adequate resources to DSOs • The predefined program methodology adopted by both TSO and DSO can be difficult to define
Common TSO-DSO AS Market Model	• Total system costs of AS are minimum • TSO and DSO collaborate closely to take advantage of the most out of available resources	• TSO and DSO may have higher individual costs than other models • Costs between TSO and DSO can be difficult to allocate
Integrated Flexibility Market Model	• Opportunities for balancing units to address their portfolio imbalances are expanding. • There are many buyers and sellers, which leads to high liquidity and price competition	• Independent operator is required to operate the market platform • A detrimental effect on the growth and liquidity of intraday markets • TSO and DSO need to share data with independent market operator

As a result, it is recommended that each distribution grid operator should act as an aggregator in the flexibility of its region and use it in the distribution grid according to need or offer it to the transmission AS market, as the distribution regions differ (in terms of DERs, in terms of needed AS, size of distribution grid etc.) in each other. As a first step, it is considered appropriate to prefer the local AS market model, and then to pass to the common TSO-DSO market model.

New Roles of Distribution SOs

In the future, the new roles of DSOs will need to be defined in the legislation as follows;

1. DSOs, as neutral market facilitators, should be able to control, use and coordinate the impact of AS operations on their grids. DSOs can allow a distribution grid user to be activated by a TSO or a market player. However, it should ensure that control architectures as part of DSO's active system management responsibilities and, among other tasks, to provide for prior notification, supervising, evaluation and blocking potentially harmful control signals.
2. Cooperation and coordination between TSOs and DSOs is an important factor when DERs play an important role in providing real-time AS. It is especially important that the services are offered to the TSO and that all systems, as well as the local distribution networks to which they are connected, affect safe operation. Although it is appropriate for TSOs to be responsible for providing balancing services, they may still need to share some of this responsibility with DSOs, when it is considered that the share of the distribution-related organizations will increase in importance (Migliavacca, 2019).

3. TSOs and DSOs should work together to realise the efficient and non-discriminatory utilization of the capabilities of distribution connected generators and demand resources (wherever its connection point) to provide system services (e.g. voltage, frequency, inertia, etc.). As a first goal, relevant responsibilities for each system service should be stated.
4. DSOs should be allowed to use AS to manage their grids and optimize the capacities they can operate. DSOs should be allowed access and use of AS by DSOs such as technical solutions of their own assets, connection agreement, grid tariffs and market-based supply. Regardless of the AS model used, it should be financially viable for all interested parties.
5. The analysis made in the distribution grid of Meram Elektrik Distribution Company, with the spread of DERs, revealed possible problems in the distribution system; it should be able to provide AS from DERs in order to eliminate the effects of voltage rise, grid congestion and to deferral grid investments.
6. Because distributed resources are having an increasingly significant impact on the system's overall operation and planning, TSOs should collaborate with DSOs and regulators to determine the requirements for observability and active power management of distributed generation and demand side response.
7. Since DSOs need more tools to operate their grids (e.g. agreement with flexible resources) segmentation of markets should be avoided, there should be a single market for flexibility and balancing. TSOs, DSOs, regulators and market players should collaborate. A unique set of market rules should be developed to support the active participation of flexible resources of both TSOs and DSOs and to ensure their efficient supply. This situation will enable DSOs to provide flexible resources connected to their grid to manage local congestion and provide voltage control.
8. DSOs must be enabled to select the best and most cost-effective technology to operate the distribution system. Legislation should not limit the choice of technologies DSOs can use to fulfill the legal obligations of DSOs. Nevertheless, DSOs should ensure that the use of these technologies does not cause discomfort in the market. As long as it is efficient, a market-based solution should be preferred. Especially for grid-scale storage, DSOs should be allowed to own and operate such devices to secure the technical operations of the grid within the approved requirements.
9. The development of new distribution network tariff structures based on more capacity for efficient use of distribution system capacity should be supported.
10. In addition to the TSO-DSO coordination model, the types, features and arrangements for the provision of AS will need to improve to enable more participants to participate and use these new business opportunities. Therefore,

since potential flexibility providers are mostly small DERs, the regulation will need to take full account of the features of potential flexibility providers connected to the DSO side. In particular, the importance of market design for AS should not be ignored. However, if the architecture of real-time markets can fully take into account the characteristics of potential flexibility providers connected to distribution grids, it can offer its parties the opportunity to gain significant participation.

11. When making decisions on the TSO side, side effects on the DSO side should be taken into account to avoid lack of resources for alternative purposes or stimulated grid problems in another grid.
12. TSOs and DSOs should get enough information from each other. TSOs and DSOs must receive sufficient data (eg grid user data) to efficiently monitor and operate their grids. When considering for additional observability, level of detail and transparency demands expected by policymakers, data collection requires improvement.
13. DSOs should be encouraged to use AS for congestion management (cost effective for this). DSOs should be able to decide on the best solution to overcome specific challenges, either through ancillary solutions or grid improvement / empowerment.
14. Battery type storage systems respond to frequency faster than conventional production facilities and the success rate in providing frequency control service is close to 100% without deviation. Distribution grids should offer the ancillary service provided from storage systems to TSO as a different frequency control service category.
15. Storage systems can play a very important role in ensuring the production-consumption balance in microgrids.
16. All barriers to aggregators must be removed to ensure that the demand-side participation is placed on the market. This means that consumers can aggregate regardless of their connection points and will increase the gathering potential of consumers for each DSO marketplace.
17. The function played by the collector is crucial: Aggregators must be able to create a market interface that is streamlined and hide the intricate intricacies of a single flexibility provider's characteristics. Aggregators should provide competitive pricing to entice flexibility providers to participate.
18. All market actors, including DERs, aggregators, and other customers, must have access to coordination models. This is anticipated to potentially involve additional rules, such as the development of the appropriate incentive schemes, as needed.
19. To lower the risk of clearing assets, grid planning will need to maximize the use

of RESs while minimizing infrastructure investments or deferral investments.

20. Finally, technical optimism should be supported by a full cost-benefit analysis, and necessary arrangements should be made in the electricity grid regulation, distribution grid regulation, and balancing and settlement regulation, in particular the AS regulation.

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