Digitalization and the Energy Transition:

Use of digitalization to optimize grid operation utilizing AI and Big Data collected from DERs

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Executive summary

This study deals with the use of smart grid technology and other digital technologies to harness Distributed Energy Resources (DERs) in order to enable integration of a higher share of Variable Renewable Energy Sources (VRE) in the distribution grid, combined with increased use of green electricity in heat production and transport (sector coupling). Full utilization of digital technologies such as Artificial Intelligence (AI) using big data provided by Internet of Things (IoT) devices is essential for the effective use of DERs. The examination of the functions of grid and flexibility operation needed to avoid grid congestion/bottlenecks showed that these functions are well defined conceptually. They are specifically; 1) improved demand forecast; 2) improved VRE, wind and solar, generation forecast; 3) maintaining grid stability and reliability; 4) efficient demand-side management; 5) efficient management of power generation from VRE; 6) optimized energy storage operation; and 7) optimized market design and operation. It was also found that each of the functions identified can be associated with the recent development of digital technologies, particularly the IoT and AI with big data, but also grid models, smart meters, smart markets and contracts, and blockchain.

For this study, digital business models in Japan and in Germany as well as experiences to date and current developments/trends were analyzed. In Japan, a demonstration project with a DERs management platform associated with a range of digital technologies conducting centralized management of DERs by DTSOs for optimization of the distribution grid has just been initiated in the Tokyo area. Currently, the demonstration project extensively focuses on the technical aspects of the functions of the DER management platform. Economic aspects, such as the regulatory environment for utilizing DERs via price signals and realization of local/regional flexibility markets, are currently out of the scope of the project. The study concludes that a well-considered reform and expansion of the existing regulatory framework would be necessary in Japan for full use of DERs as flexibility resources by grid operators.

The demonstration projects in Germany over the past, particularly the SINTEG showcase program, have developed and tested in principle all the technical and economic solutions needed. Some are already commercially available, while others still need to become easier to apply or more standardized and secure before mass roll-out. In Germany as well, it was shown that for enabling the full use of DERs for maintaining grid stability and reliability, the regulatory environment for using DERs would need to be created or improved, and Smart Meter roll-out accelerated. However, more analysis and testing will be needed to determine 1) if incentives should be provided via price signals and/or regional flexibility markets, 2) if DER owners or DSOs should control the use of DERs, and 3) if the optimization of the grid should happen at DSO grid or sub-network level. Notwithstanding, it is recommended to simplify market access for small plants; to create incentives for grid-serving behavior e.g. through redesign the system of levies, charges and fees, initial investment incentives, and the offer of flexible grid fees; to commission area-wide flexibility potential and feasibility analyses and roadmaps to finally cover all DSO areas in Germany; and to develop the standardization of interfaces and processes. These measures would

serve both further electricity market integration of DERs to balance supply and demand, and grid stability.

1 Introduction

The power system is facing a major transformation due to changing consumer demands, more flexible loads and storage, and an increasing share of variable Renewable Energy Sources (VRE), i.e. PV and wind power. This study deals with integration of a higher share of VRES in the distribution grid, combined with increased use of electricity in heat production and transport (sector coupling) using smart grid technology and other digital technologies and Distributed Energy Resources (DERs). Full utilization of digital technologies such as Artificial Intelligence (AI) and big data with Internet of Things (IoT) devices is essential for the effective use of DERs, such as distributed solar PV systems, energy storage, Electric Vehicles (EVs), heat pumps, industrial plants, building systems, or even smart home appliances, which can function for Demand Response (DR). Since DERs are directly connected to the distribution network and an increased deployment of DERs may either ease congestion or cause additional congestion in the distribution grid as well as the transmission grid, the role of the Distribution System Operator (DSO) is particularly important to effectively utilize DERs as flexibility resources with digital technologies. The use of flexibilities from DERs would enable DSO to optimize their own network, maintaining security and supply quality, as supply and demand could be balanced within the distribution network, which could reduce network congestion at the Transmission System Operator (TSO) level.

VRE do not offer much flexibility in themselves to match demand, so their system integration needs other flexibility options to avoid grid congestion and bottlenecks, which is relevant to both Japan and Germany. Digital technologies are essential to improve forecasts of both demand and supply from VRE, and to organize the effective use of flexibilities of DERs in full potential. Big data collected by IoT devices from DERs include real time information on each DER type and connected capacity, consumption pattern, system characters; more specifically, on PV production profile, EV/battery storage charging profile, consumption profile, weather forecasts that are processed by AI combined with other relevant information such as electricity market prices, and network congestion data to provide optimal solutions to avoid congestion and bottlenecks. Also, some sector coupling technologies, such as heat pumps, battery electric vehicles, or electrolysis, may both contribute to grid congestion and offer flexibility. Full utilization of digital technologies is crucial to optimize their operation too.

This study focuses on the use of digitalization for the optimization of distribution/transmission grid operation to avoid congestion and bottlenecks, utilizing AI and big data collected from DERs with IoT devices. The paper progresses as following:

- **Chapter 2** will outline the functions of grid and flexibility operation needed to avoid congestion/bottlenecks, such as forecasts of both demand and supply from VRE, and organizing the use of flexibilities of DERs (2.1), the uses of digital technologies for each of these functions, in particular AI and big data with IoT devices connected with DERs to utilise their flexibilities and sector coupling (2.2) and the roles of DSO, TSO, DSO/TSO interconnection, DER owners, aggregators and other relevant third parties, in relation to possible business/market models for the functions (2.3).

- In **chapter 3**, experiences to date and current developments/trends, with whatever digital business model, in both countries are described.
- In **chapter 4**, a qualitative discussion of use cases and business/market models identified is conducted.
- **Chapter 5** comprises recommendations that may be possible on policies and regulations.
- **Chapter 6** ends with a conclusion and further research needs.

2 Optimizing grid operation utilizing AI and Big Data: conceptual background

2.1 Functions of grid and flexibility operation needed to avoid congestion/bottlenecks

In smart grids, information and communication technology (ICT) is used to continuously collect data on grid operation, load, and supply, and to automate grid control. The term is related to the distribution system level, since this level traditionally has a lower degree of monitoring, control and automation than the transmission system level. Due to the historical requirement for the distribution system operator (DSO) to distribute power generated in centralized large power plants to customers, the structure and dimensioning of the system is oriented towards the aggregated load of the customers. This practice is currently changing, as customers are changing their load profiles, and variable renewable energies (VRE) are increasingly feeding into the distribution grid. Consumers increasingly participate in prosumer behavior, i.e. the use of their own PV power, and consume additional power by using electric vehicles and heat pumps. As a result, the flow of energy in the distribution grids is becoming highly volatile and, compared to the past, more difficult to predict. This leads to conflicts. For example, market-oriented behavior such as charging the electric car at the most favorable hour is unproblematic in individual cases, but in concentrated form it may endanger the stability of the grid. A first step towards solving the conflict is to gain a better knowledge of the consumers' power demand and of the generation of VRE by distributed energy resources (DERs). Both demand and DER generation forecasting is needed (1) within the DSO system; (2) within the transmission system operator (TSO) system and for the flows between TSO and DSO level.

This chapter analyses the functions in the operation of both the grid and the flexibility options that are needed to avoid congestion and bottlenecks, which will require the use of ICT. Improved forecasting of power demand and of the supply from VRE is one of these functions. Monitoring the status of the grid and coordinated efforts to maintain grid stability and reliability, including the use of the options within the grid to contribute to these targets, is the second broad area. The third broad area of functions is organizing the use of flexibilities of DERs for grid stabilization, which includes both technical aspects of control and metering, and economic aspects of market/incentive, selection, and billing.

Figure 1 shows six emerging functions where the digital technologies, particularly IoT technologies associated with big data and AI, have already been employed or at least tested for flexible grid operation with higher share of VRE to avoid congestion/bottlenecks (IRENA, 2019b). They are specifically; improved VRE, wind and solar, generation forecast; maintain grid stability and reliability; improved demand forecast; efficient demand-side management; optimised energy storage operation; and optimised market design and operation. In addition, efficient management of solar and wind generation should not be forgotten, to be added on the left side of the figure at the same level as demand-side management on the right side. Although the curtailment of reduction of solar and wind generation should be avoided to the extent possible, it needs to be available as a flexibility in reserve.

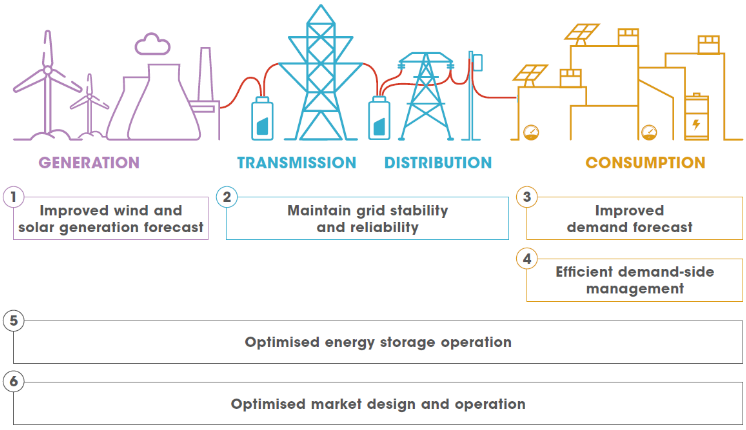

Figure 1: Emerging six functions where the IoT, big data and AI are applied for grid with higher share of VRE. Source: IRENA (2019b)

Forecasts of both power demand and supply from VRE

There are various reasons to improve the **forecasting of power demand**. It is an important issue of economic and safe operations planning in power distribution systems. Basic operations of the power systems such as economic dispatch, unit maintenance, fuel scheduling and unit commitment can be performed more efficiently by having more accurate demand forecasts. There are three basic time scales when it comes to the forecast of power demand, comprising short-term, mid-term and long-term forecasting and related applications (see Table 1).

Time scale	Application
Short-term forecasting (an hour to a week)	Scheduling and analyses of the distribution network
Mid-term forecasting (a month to 5 years)	Planning the power production resources and tariffs
Long-term forecasting (5–20 years)	Resource management and development investments

Table 1: Demand forecasting time scales and applications. Source: own illustration based on Ghalehkhondabi et al. (2017)

Obviously, short-term forecasts are most relevant for the daily operation of a DSO system. However, mid- and long-term forecasts are important for forecasting and planning the need of upgrades to the grid and/or the flexibility options. These will, in turn, enable a secure daily operation of the grid in the future.

Forecasting methods can be further divided into causal and historical data-based methods. In the causal methods, the energy consumption serves as the output variable while economic, social, and climate factors serve as input variables. Artificial neural networks (ANNs) and regression models are the most frequent causal methods used to predict the energy demand. Methods based on historical data use the previous values of a variable to forecast the future values of that variable. Time series, grey prediction and autoregressive models are among these methods.

According to a literature review conducted by Ghalehkhondabi et al. (2017), the most-applied energy demand-forecasting models for short-term electricity demand are: Artificial neural network models; fuzzy logic; time series models; ARMA, ARIMA, SARIMA; regression models; and support vector machines. Other models, such as grey (gray) prediction; genetic algorithm; econometric models; and system dynamics models are more relevant for mid- and long-term forecasting.

New loads, such as battery electric vehicles or storage, and heat pumps, add to the complexity of load forecasting, and require adaptation of results from methods based on historical data.

Forecasts of the generation from VRE units are needed in order to know in advance the amount of power that wind turbines or PV modules will feed into the grid over the next hours and days. The VRE forecasts are generally based on forecasts of the weather conditions at the site locations. To match the different requirements, several time scales of forecasts are used (see Table 2).

Different kinds of stakeholders make use of the predictions: Energy traders, who have a contract to sell VRE for the plant operators, use the forecasts for trade on the intraday and day-ahead energy market, control of curtailment due to negative market price, correct activation of regulation power and participation in the regulation market. Together with speculators, they can also use forecasts to predict the influence of VRE on the market price. The main fields of application for grid operators, load dispatch centers and independent system operators are balancing, unit (re-)dispatch, curtailment of power plants, load flow calculations, Day-Ahead and the Two-Days-Ahead Congestion Forecast (DACF and 2DACF) and week-ahead planning. The last group of stakeholders are VRE operators. They use supply forecasts for day-ahead and medium-term planning of maintenance. Owners of a roof-top PV installation also plan the consumption of their households by means of the forecasts to raise the share of internal consumption of the produced energy.

Time frame	Application	Stakeholders
Shortest-term forecast (0 – 6 hours)	Trading on intraday energy market, control of curtailment due to negative market price, correct activation of regulation power	Traders
	Influence of VRE on market price	Speculators
	Balancing, unit re-dispatch, curtailment of power plants	Grid operators, load dispatch centers, independent system operators
Short-term forecasts (6 – 48 hours)	Trading on day-ahead energy market, participation in regulation market, Influence of VRE on market price	Traders
	Unit dispatch, load flow calculations, DACF congestion forecast	Grid operators, load dispatch centers, independent system operators
	Day-ahead planning of maintenance	VRE operators
Medium-term forecasts (2 – 10 days)	Trading on long-term markets	Traders
	2DACF congestion forecast, week-ahead planning	Grid operators, load dispatch centers, independent system operators
	Medium-term planning of maintenance	VRE operators

Table 2: VRE forecasting time scales, applications and stakeholders. Source: own illustration based on Zieher et al. (2015)

For most applications, there are specialized forecast service providers. They operate on a commercial basis and supply regular VRE power forecasts, similar to weather forecasts. In contrast to this, in-house concepts require a lot of effort in terms of meteorological know-how and resources (human as well as IT infrastructure) to achieve a high forecasting accuracy.

To realize a service solution, it makes sense to establish a centralized approach where one responsible stakeholder, e.g. grid operator, ISO or trading company, receives forecasts for all VRE units of the portfolio from one or more forecast service providers. Hence, the forecasts are not collected from the individual VRE operators. Experiences from other countries show that only a centralized forecasting approach ensures high quality across all VRE units. Especially for large portfolios it is good international practice that all required data from the VRE units, i.e. power production, availability information etc., are collected by the buyers of the power, such as aggregators/traders on the market, DSOs or other customers, and are then made available to the forecast service providers.

There are two steps to be taken to forecast the power supply of VRE. First, the weather for the relevant VRE units has to be predicted. Then the meteorological variables have to be translated into predictions for power generation.

Established wind and solar power prediction systems generally use numerical weather models (NWP) as input. NWP models divide the atmosphere into little boxes (grid cells) with finite spatial extension. They represent on average what is happening inside this box. In horizontal direction, the size of grid cells can vary between a few hundred meters and 20 kilometers. The vertical direction is important to consider as well. In general, the lower levels, which are important for VRE forecasting, are covered by non-equidistant steps, typically around 10 m, 30 m, 100 m or 200 m. For wind power forecasts it is very crucial to calculate the wind speed at hub height of the wind turbines as precisely as possible. The forecasting systems differ widely in the way they perform this vertical interpolation.

The crucial second step of wind and solar power forecasting is the conversion of the meteorological variables, e.g. wind speeds or solar irradiance, into power output of VRE units. There are two main approaches to carry out this conversion: the statistical approach and the physical approach. In statistical systems, a mathematical relation between numerical weather predictions as input and measured power output is “trained” or “learned” based on the available data. In contrast to this, physical systems use methods from boundary layer meteorology and irradiance transfer schemes to calculate the right meteorological input, e.g. wind speed at hub height, and then use power curves to transfer it into power.

Compared to PV and wind, the power generation from other DERs like combined heat and power (CHP) plants, biomass and hydroelectric power is typically more predictable and also able to provide a higher flexibility in most cases.

Monitoring the status of the grid

Matching supply and demand in a DSO system based on improved forecasting, as discussed in the previous section, is an important step to avoiding grid congestion or bottlenecks at the connections with the transmission system or neighboring DSO systems. Still, the status of the connections may be different, and there may also be internal differences in substations and imbalances at the low-voltage level. Therefore, monitoring the status of all grid components is an important additional function.

Maintaining grid stability and reliability

In order to maintain grid reliability, the monitoring data on the grid status has to be processed and assessed in regard to stability and risks. Only then there can be a proper reaction to stability risks by activating resources in the grid itself, such as switching, controllable transformers, or allowing higher power line temperatures depending on weather circumstances, as well as flexibilities of both DERs (see below) and conventional plants. For example, an Active System Management (ASM) is a key set of strategies and tools performed and used by DSOs and TSOs for the cost-efficient and secure management of the electricity systems. It involves the use and enhancement of smart and digital grids, operational planning and forecasting processes and the capacity to modulate, in different timeframes and distinct areas, generation and demand encompassing flexibility instruments to tackle challenges impacting system operation. It thus ensures proper integration of Renewable Energy Sources (RES) and a high share of Distributed Energy Resources (DER), as well as the integration with energy markets.

Organizing the use of flexibilities of DERs

The term smart grid is often understood comprehensively and includes not only IT-supported transmission and distribution of electricity but also power generation, storage and consumption. In this context, distributed energy resources (DERs) are of central importance. The term comprises small-scale distributed generation (DG) and energy storage units as well as demand response (DR) tools connected to the distribution system. DERs could be actively incorporated in the operation of distribution grids providing certain flexibility. Such DER flexibility is generally associated with temporal shifting of energy, i.e. for consumption or injection, in reaction to an external signal (price signal or activation).

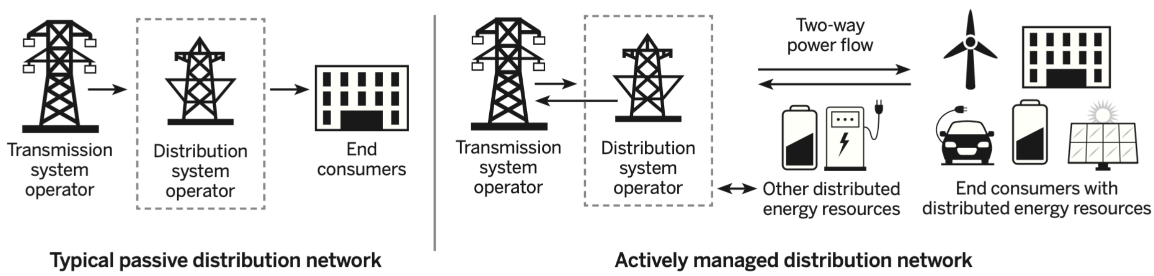

Figure 2: Traditional and modern distribution networks. Source: IRENA (2019a)

Types of DERs and flexibilities

Distributed generation

Small-scale distributed generation technologies include: Wind and PV (VRES), biogas and biomass power plants, small-scale hydro (usually run-of-the-river), and CHP plants (Ecofys et al. 2015).

Wind turbines and PV installations have the technical capability for providing fast response to regulation signals. By curtailing power production, these installations can provide down regulation. Up regulation can be provided by operating units at generation levels below their potential generation value at a given time, and increasing to the normal level if needed. Both operations come at the expense of an overall reduction in VRE output. A similar potential and trade-off is connected to **run-of-the-river hydro** power plants without a possibility for water storage.

The electricity production via **biogas plants** makes use of Gas-Otto-engines which can ramp up and down in seconds. [*But flexibility in the biogas production itself is very limited.*] The reaction time expands over several hours to days. It could be ramped to about 50% of the capacity. Biogas storage facilities are usually constructed to store 3 – 6 hours of biogas production and could be enlarged for provision of flexibility. **Small-scale hydro** power plants with an upper reservoir hold similar characteristics to biogas.

CHP plants produce electricity by heat that is generated from a central process. CHP plants using internal combustion engines and gas turbines, which is typical for small to medium CHP plants, are typically inflexible resources for the power system as their electricity output is constrained by the heat requirements of the process connected to the CHP. CHP can become provider of flexibility with the integration of heat storage, in order to decouple the generation of electricity and heat to a certain extent.

Demand response

The organized energy market places typically have strong and active supply sides (generators), but rather weak and inactive demand side (customers). The involvement of the customers, independently of whether they are prosumers or pure consumers, is likely to be vital for the successful integration of DERs. The key will be to enable participation of the customers that have the underlying potential for flexibility, e.g. factories with their production processes and heat, cold, or compressed air supply, frozen or chilled food warehouses, or large buildings with electric heat pumps or significant cooling demand.

In the residential and in the commercial sector, demand management can especially be applied in cross-section processes such as providing heating and cooling. This includes different levels of electricity demand, e.g. selective timing of the cooling of cold storage warehouses as well as automatic adjustments in the demand of refrigerators. Other potential demand management technologies include air conditioning, compressing air for mechanical use or even rescheduling of washing processes in households. However, although the high number of residential customers may yield a high total potential, it is usually less cost-effective to harness it than the potential that exists with industrial and commercial customers.

Distributed storage

Small scale storage options can provide flexibility on distribution grid levels by enabling time-shifting of local demand and supply.

Pumped hydro storage (PHS) stores energy mechanically. Electricity is used to pump water from a lower reservoir to an upper reservoir and recovering the energy by allowing the water to flow back through turbines to produce power, similar to traditional hydro power plants. Pumped hydro storage power plants are common technology and by far the largest-capacity form of grid energy storage available today. Because of their cost-optimal size, they are typically connected to the transmission network.

Power to gas refers to chemical energy storage, namely the use of electric energy to create fuels that may be burned in CHP or even conventional power plants. Key fuel expected for the future is hydrogen (and synthetic methane produced hydrogen to some degree). Methane is the main constituent of natural gas and therefore can be injected to the existing infrastructure for natural gas (grid and storage). The high storage capacity of the gas grid could then be used for medium- and long-term storage purposes. Alternatively, parts of the gas grid could be converted to a hydrogen grid. Power to gas allows long-term storage, e.g. of PV power from the summer to flexible power production in winter.

Furthermore, **battery technologies**, e.g. conventional (lead acid, lithium ion), high temperature batteries and flow batteries, can provide power storage options. Batteries have a very fast response time and high efficiencies, but they have high capital costs. Similar to those battery technologies, fleets of EVs can be used as a flexibility option for the power system. There are two key operational modes: **Grid-to-Vehicle** (G2V), where fleets of EVs are operated as a demand side management option, enabling a shifting of the charging times or **Vehicle-to-Grid** (V2G), where in addition to charging, the batteries of EVs could be discharged and feed power to the grid. Due to their primary use as means of transportation, the provision of flexibility from EVs is subject to many constraints and is inherently uncertain.

Smart grid technologies

In addition to DERs connected to the grid, there are also flexibility options through smart grid technologies, such as controllable local transformers or high-temperature power cables. These are not in the focus of this report, but should still be mentioned.

Functions for the use of flexibilities from DERs for grid stabilization

There are several technical and economic functions needed for the use of flexibilities from DERs and grid stabilization.

Technical functions include **control** and **metering**. Obviously, in order to use flexibilities, they need to be put in operation or stopped again by a technical control. Control can either be conducted by the DER operator based on a contract and a financial incentive, or by the grid operator. DERs are either under remote/automatic or under manual control. Direct control methods are well-suited for short-term provision of flexibility services, particularly of those which require a very precise location of activation like voltage control and congestion management.

In any case, the impact of the use of a flexibility on power generation, demand, or storage needs to be metered. In addition to traditional costly load metering, the future metering technology appropriate to cover the use of flexibilities is expected to be **smart metering**, which includes load metering and gateways for real-time transmission.

These technical functions are a precondition to make full use of **economic functions.** These include the **design, installation and operation of flexibility markets or incentive programs**; and for their operation, the **offer and selection or activation of flexibilities** in these markets or following these incentives; and the **billing** of the flexibilities used.

If flexibilities of DERs are established via a flexibility market organized by or for the DSO, prequalification of flexibilities will be the first step; offering or tendering by the DER operators will be the second; and selection of flexibilities using certain routines will be the third.

Regarding the details of how to establish the function of optimized market design and operation, it may be possible to learn from markets for balancing and ancillary services that are already established at the transmission system level (Ninomiya et al. 2019). Ancillary service markets are in place in order to manage transactions for upward or downward adjustments in the short to very short term. These markets are organized very close to real- time and require automated load adjustment. Markets for balancing services are arranged longer before real- time than ancillary services. Due to the fact that individual DERs do not provide sufficient reliable electric flexibility to be tradable in markets and their size is usually small and hence, transaction costs are too high for them to participate in the market individually, aggregation is required in order to trade in organized markets. At high voltage levels under responsibility of the system operator, trading mechanisms like contracts for ancillary services and balancing markets already provide opportunities for economic efficient supply of system flexibility services. In a situation with smart metering and real-time management of distribution networks, similar arrangements could be enabled for medium- and low-voltage levels.

With controllable DERs, the system operator, aggregator or even retailer could make the end user agree to automatic control (upward or downward) of the operation of the DER equipment. This control could be price-driven in the offering/tendering and selection phases, like in wholesale or balancing market trading of flexibility. Finally, all of these events of flexibility use will need billing, which can be based on smart metering data.

An alternative to a regional flexibility market could be time-dependent grid tariffs or even real-time pricing for the grid tariff, and self-selection of flexibilities by DER operators in reaction to these price signals. Possibilities with smart metering and real-time pricing allow for the increase of cost causality with tariff design, meaning that the electricity prices reflect the actual costs for delivering the service, which may become very high in times of grid congestion. However, if consumers have to react individually to price signals, the potential for aggregated DR flexibility will be very low. Billing will not be needed in this setting to incentivize the flexible reaction of DERs, since they react to price signals.

The actual reality of pricing is quite complex, as shown in Table 3 below. Depending on time span and purpose as well as TSO or DSO level, there are a variety of different pricing models available.

For grid interactions which require response between 1 to 30 min before real-time, direct load control would be suited in order to secure response of this DER. Appropriate DER for such short notification time periods would be most DER except for CHP units due to their longer ramp-up times, although capacity-type DERs would be more efficient than energy-type DERs. Furthermore, PV units would not be dispatchable as positive flexibility due to their generation dependence on weather conditions; however, in combination with storage, flexibility trading could be enabled. For longer notification times of 30 min to 1 h, all other pricing methods could be suited (see Table 3) and decisions should be further dependent on socio-economic factors like user characteristics of price elasticity and the availability of home automation. All DER types would be appropriate for supplying flexibility for longer than 1 h of activation time, except for short-term duration batteries or other short-term energy storage. For the very long term, critical peak pricing and time of use pricing are appropriate due to the possibility to settle those prices on a yearly basis (Eid 2016).

Notification time before real-time	Appropriate incentives or control method for DER management	Related markets for electric flexibility trading	Appropriate DER
< One minute	Direct control	Frequency control (primary, secondary, tertiary reserves), voltage control	EV, continuous loads (heating/cooling, light-ning), EES
1–15 minutes	Direct control	Network restoration, voltage control	EV, continuous loads (heating/cooling), EES
15–30 min	Direct control	Network restoration (HV/LV), balancing market, portfolio balancing	EV, EES, CHP units continuous loads (heating/ cooling), dispatchable loads
1 hour	Direct control, ICAP*, emergency demand response, real time pricing, peak time rebates, critical peak pricing	Balancing market, network congestion management	EV, EES, CHP units continuous loads (heating/ cooling), dispatchable loads
1 - 48 hour	Direct control, ICAP*, emergency demand response, real time pricing, peak time rebates, critical peak pricing	Spot market (day ahead and Intraday market)	EV, EES, CHP units continuous loads (heating/ cooling), dispatchable loads, PV units with storage
Year ahead	Critical peak pricing, time of use pricing	Deferring network investments (HV/ LV), generation investment peak reduction	EV, EES, CHP units continuous loads (heating/ cooling), dispatchable loads, PV units with storage

*Interruptible capacity programs

Table 3: Relationship between notification times, appropriate incentives and markets for DER flexibility trading. Source: Eid (2016)

2.2 Uses of digital technologies for each of these functions

This section overviews digital technologies employed for the various functions of flexible grid operation to avoid congestion/bottlenecks analyzed in the previous sections. Decisions on grid management have been traditionally taken on a manual basis by skilled operators, in some cases, augmented by elementary automation systems. However, as mentioned in the previous section, substantially rapid growth of distributed RE plans and other DERs have brought increasing difficulties in decision making on grid operation in the traditional manner. Therefore, increased use of digital technologies is needed. There are many different types of technologies that can be used for the functions of flexible grid operation to avoid congestion/bottlenecks. However, due to the increasing complexity and decentralization of the grid with the increasing number of DERs, the Internet of Things (IoT) and Artificial Intelligence (AI), using big data stand out in importance. This is why we first address these two types of digital technologies and their potential uses for the functions of flexible grid operation, before we conclude with an overview of the technologies that can be used for each function.

The IoT (Internet of things)

The IoT technologies are essential to enable the functions being realised. IoT technologies can provide connectivity between physical devices such as power plants, power grid, energy appliances and industry equipment, employing sensors and communication technologies for monitoring and transmitting real-time data which enables fast computations and optimal decision-making (Schulz et.al., 2020). In addition, actors and data transmission for changes in operation are equally important parts of the energy IoT. The IoT is a general concept which captures a range of individual technologies for monitoring, networking, computing and control devices as an automated integrated system. The often-heard notion of “smart grids” can be considered as an advanced power grid empowered by the IoT technologies. In other words, the IoT is a key element of smart grids.

The IoT is expected to enormously contribute to grid stabilization with higher a share of VRE by optimizing the grid through monitoring/controlling supply and demand side. Demand-side management, also known as demand response, is of particular importance, since a greater potential of flexibility concealed in demand-side could be unlocked only by broad application of the IoT. In order to harvest the demand response potential, particularly the tremendous but dispersed residential potential, investment in information and communication technologies (ICT) is necessary. Smart appliances and equipment, home/ building/ plant automation and smart meters are the main instruments to tap this potential. ICT technology can facilitate the interoperability of smart devices. Interoperability will depend heavily on standardization of appliances and of the different communication devices.

Hardware of the IoT technologies is divided into four categories; systems for data collection; systems for communicating data; systems for computing and analysis based on the data; and control devices. The first includes smart meters with high-resolution metering data/sensors, sensors installed in different devices. The second includes ICT infrastructure such as fibre cables, internet, wireless communication, etc. The third comprises all kinds of models of the grid or the markets and their assets. The fourth category, for the energy IoT, includes all kinds of flexibilities in the grid and in demand, generation, and storage, such as battery storage devices at distribution level, upgrading network assets to handle unexpected large reverse of power flow, active network devices such as automatic on-load tap changers for transformers, static synchronous compensators, static var compensators and others (IRENA,2019c).

Software is also necessary for data collection, data pre-processing including smart meter data acquisition software and SCADA software. In addition, communication protocol is indispensable for data transfer between different parties involved. Therefore, it is required to develop common interoperable standard for both the physical/information/ICT layers and cybersecurity protocol (IRENA, *ibid.*).

Not only hard/software, but also relevant policies and regulations are needed for development of the IoT (see chapter 5). For instance, it is vital to encourage DER owners to participate in the market so that DER owners are incentivised for installation of the IoT devices in their DERs. It is also important to encourage data exchange and improved communication on a transparent basis. In parallel to these, appropriate policies/regulations for end consumers private data also need to be established to protect their privacy but enable energy service providers to use the data. An interesting development in this direction is the Estfeed platform operated by the state-owned TSO Elering AS in Estonia (https://www.estfeed.eu/en/technology). The platform enables consumers to give consent to energy service providers to use their smart meter data and to the data hubs to send the data to the service providers. One of the first services offered making use of the Estfeed platform is price incentives to consumers with electric heating to allow control of loading times that enables contributing to system and grid stability. While such control of electric heating is nothing new in principle, the smart meters combined with the new data management platform enable new providers and uses of the load control, which in the past was only possible for the DSO.

AI and big data

Once the IoT devices are installed on a larger scale, a massive amount of raw data could be collected by them. Such a dataset is called "big data" which does not have much value itself. The big data need to be processed by Artificial Intelligence (AI), e.g., under a cloud computing service, in order to be utilised effectively as valuable figure to control DERs as flexible resources for the power grid. Having a large amount of big data collected by the IoT, AI could automatically provide insightful information for decision making on generation, grid and DERs simultaneously to avoid congestion and bottlenecks effectively which has been almost impossible without the IoT, big data and AI.

In fact, none of the IoT, big data and AI works alone for optimization of grid with higher share of VRE. They have to be integrated with each other as a system. AI without big data simply does not work, since AI needs big data collected by the IoT ideally installed at entire power system in order not only for decision making on grid operation but also for self-learning process by AI itself. Similarly, the IoT generates big data which alone itself does not mean anything for grid operation as mentioned above.

Apart from a large amount of big data, AI obviously requires a particular software, which is specific to the AI technology used in a system and is operated on a cloud computing platform in most of the cases. In addition, human expertise of data scientists who develop machine-learning algorithms and continuously improve models as the share of VRE increases is vitally important. Similar to the case of the IoT, development of cybersecurity protocols is also necessary as electricity grid and digital technologies further interconnected are implying that cyberattacks could become enormous risks on the essential social infrastructure.

Given the recent development of DERs and the increasing complexity of grid operation, the IoT, big data and AI would enable a large number of RE plants and DERs to be flexible resources not only for optimization of grid operation but also for optimization of RE plants, electricity consumers, hence a higher share of VRE can be accommodated in the grid while maintaining a secure supply.

Among the functions illustrated in Figure 1 and chapter 2.1, improved VRE generation forecast is one of the main applied areas, in which the IoT, big data and AI have been employed. The IoT technologies used in this application are, for example, various sensors installed individual RE plant for real time measurement of parameters related to power generation such as wind speed and solar irradiance at the location of each plant. These sensors seamlessly produce big data, which is fed into AI with other relevant data including meteorological data, earth observation satellite data and sky image data and other relevant public sensors data if any available. Having big data and other relevant information, AI could more accurately forecast generation, which can be utilised by grid operators to improve unit commitment, increase dispatch efficiency and reduce reliability issues and operating reserves (IRENA, 2019c).

Uses of demand-side management are another important area of application for AI. For high impact through mass uptake of services such as control of cogeneration plants, fuel cell heaters, heat pumps and direct or storage electric heating, or of vehicle-to-grid services, this control would need to be automated in a way not interfering with daily routines and practices of consumers—e.g. through using AI. For the heat-based options, it would also need heat storage, just as there is battery storage in the vehicles.

Since all of this will require an enormous number if small and short-term economic transactions, smart contracts are probably indispensable for its implementation (Ninomiya et al. 2020).

Summing up: Uses of digital technologies for the smart grid and related market functions

The following table sums up what the uses are of digital technologies for each of the functions of grid and flexibility operation needed to avoid congestion/bottlenecks identified in chapter 2.1. Among the digital technologies used for these functions are different forms of IoT and AI, including for example grid models and smart meters, and their accompanying infrastructure and software.

Functions of grid and flexibility operation needed to avoid congestion/bottlenecks	**Uses of digital technologies for these functions**
Improved demand forecast	IoT (to collect smart meter data with high time resolution) and AI to recognize patterns and improve forecasts
Improved wind and solar generation forecast	IoT (to collect generation and weather data with high time resolution) and AI to recognize patterns and

Functions of grid and flexibility operation needed to avoid congestion/bottlenecks	Uses of digital technologies for these functions
	improve forecasts; possibly also physical approaches
Monitoring the status of the grid	IoT (to collect status data from grid components in real time)
Maintaining grid stability and reliability	Grid models able to integrate and assess demand, generation, and grid status data and to calculate trends and forecast risks of congestion, including through AI
Control of DERs: efficient demand-side and solar and wind generation management; optimized operation of energy storage and further flexibilities	IoT to collect status data and to activate changes in operation, if these can be activated automatically; otherwise, safe and reliable control data transmission to decision-makers
Smart Metering	Smart meters and safe data transmission (which are a part of the IoT) as well as safe but easy data and consent management for energy services
Optimized market design and operation	Server infrastructure and software for optimized market operation
Offer and selection or activation of flexibilities	Protocols or smart contracts and software (e.g. using AI) for offer, selection, and activation of flexibilities
Billing	Software (e.g., blockchain) for billing

Table 4: Uses of digital technologies for the smart grid and related market functions

2.3 Roles of DSOs, TSOs, DSO/TSO interconnection, DER owners, aggregators and other relevant third parties in relation to possible business/market models for the functions[1]

Roles of DSOs

As repeatedly mentioned, VREs, batteries, EVs and other DERs have rapidly increased over the past years. They brought less-predicted power flow in the grid. Some of them may be used to contribute to maintaining grid stability and reliability, some may cause events of grid congestion in the distributed area, and sometimes both effects are possible. In this circumstance, DSOs are expected to change their role from conventional one-way power flow operation to two-way operation shown in Figure 1. DSOs could benefit from the flexibilities of DERs by taking their advantage of directly connecting to DERs. With digital technologies, DSOs could monitor and collect real time/past data of DERs which can be processed by AI and used for their grid management. When the regulatory framework and the contract allows, as part of optimization of the distribution grid, DSOs are expected to procure flexibilities from DERs and even directly control DERs.

In relation to the functions of gird operation needed to avoid congestion/bottlenecks discussed so far, the expected roles of DSOs can be; 1) establishment of contracts between DSOs and DERs owners for installation of the IoT devices on each DER; 2) installation of the IoT devices on DERs and monitoring/collecting real-time data from DERs; 3) processing the data or providing the data to TSOs or the third-parties such as aggregators/Energy-as-a-Service (EaaS) to be processed by AI; 4) use of flexibilities offered by DERs to optimize the distribution grid according to the result given by AI or acting as neutral market facilitators and providing high-resolution price signals to the DERs owners, or possibly by organizing a regional flexibility market.

Consequently, DSOs could increase flexibilities in their distribution grid, leading to reduction of their investment in grid reinforcement/expansion. In addition, the data collected from DERs could be fully utilized by TSO and the third-parties allowing even higher share of VRE.

Roles of TSOs and DSO/TSO interaction

A massive increase in DERs and shift to two-way power flow have brought an impact not only on distribution grid, but also on transmission grid since the distribution grid is one of the components of the transmission grid. TSOs only indirectly connect to DERs through DSOs as shown in Figure 1[2]. Therefore, the roles of TSOs in connection to usage of DERs can be extremely limited without an interaction between DSO and TSO. Not having any information on DERs, TSOs would face a difficulty in accurate forecast of the generation from VRE and power demand of the final consumers, and lose the opportunities to utilize DERs as flexibility resources. If potential

[1] This section largely refers to IRENA (2020a, 2019a, 2019b).

[2] Some renewable energy generation facilities are directly connected to the transmission system, such as offshore or big onshore wind farms. However, these are then not considered DERs, so the statement that TSOs are only indirectly connected to DSOs remains valid.

flexibilities of DERs can be fully utilized for the power system, or not, can be highly depending upon efficient coordination between DSO and TSO. The critical factor here is efficient data exchange between them on capabilities of DERs. Figure 3 presents some of key areas of coordination between them (IRENA, 2020a).

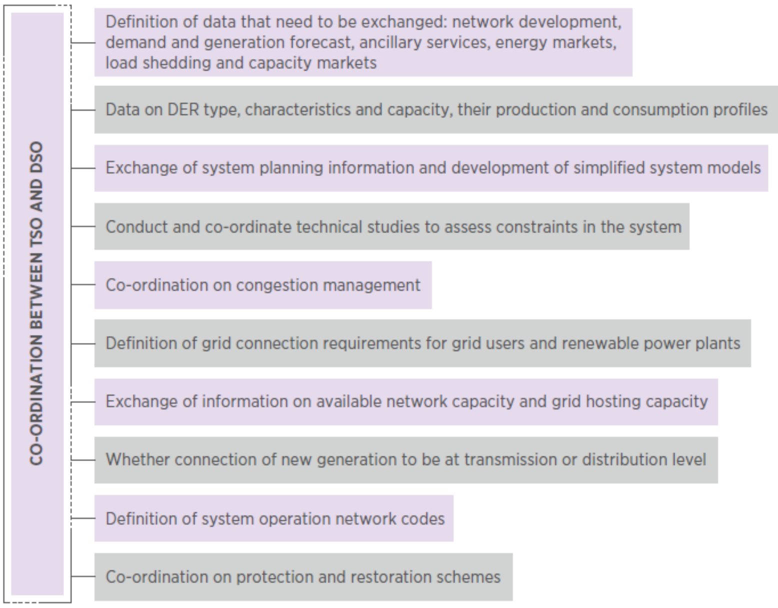

Figure 3: Key areas of coordination between DSOs and TSOs. Source: IRENA (2020a)

In this framework, DSOs are expected to be a data exchange platformer between DERs and TSOs and other relevant parties to provide the required information of DERs to TSOs.

When DSO and TSO interact, the role of TSOs can be 1) definition of the required data collected from DERs to be exchanged between DSO and TSO such as type, characteristics, capacity, their production/consumption profiles of DERs; 2) exchange of the required data which could be fed into AI; 3) use of flexibility offered by DERs to balance the transmission grid according to the result given by AI. In addition, TSOs may be given the task to organize the reserve control markets, as it is the case in Germany, and can directly include DERs at least in this way. As the Elering / Estfeed example from Estonia that has been discussed in chapter 2.2 shows, TSOs can also adopt the role of an impartial manager of data access rights.

Using the flexibility of DERs in coordination between DSO and TSO, the benefits gained by TSOs are significant so that they can increase their system flexibility and differ their investment on grid reinforcement/expansion as the system could accommodate increasing number of VRE without additional investment.

Roles of DER owners

The role of DER owners is also expected to change significantly. Most of DER owners have been in a position like “install DERs and do nothing” so that DERs have hardly ever been recognized as flexible resources. Under the new environment where VRE and DERs substantially increase, at least some of them are likely to change into active market players to react to market conditions and making profits by changing their demand, namely demand response, and generation pattern with the support of digitalization technologies. An installation of IoT devices under the contract to DSOs or aggregators would be a starting point. The data collected by the IoT devices are fed into AI providing the solution for decision making on changing their demand and supply profiles to maximize their profits, which could be automatically executed by IT. This would increase flexibilities in the grid system which may be a benefit for DSOs and TSOs as already discussed. However, if DER owners and aggregators only react to the price signals of the energy markets, this will not take grid constraints into account, as discussed in our study on P2P energy trading and PPAs (Ninomiya et al. 2020). The regulatory and practical preconditions need to be created to make these DERs beneficial for the DSOs and TSOs as well.

The roles of DER owners, in relation to the functions of grid operation needed to avoid congestion/bottlenecks, can be 1) changing their position from "humble ratepayers" into active market players to maximize their profits by fully utilizing their own DERs as flexible resources; 2) installation of the IoT devices on their DERs under the contract with DSOs or aggregators allowing them to collect real-time data of DERs behaviour and feed it into AI process; 3) undertaking actions as active market players reacting to the price signals in the markets based upon the solution given by AI. In this case, DSOs or aggregators are expected to act as market facilitator to provide appropriate solution given by AI to DER owners.

Roles of aggregators

Aggregators who aggregate DERs and operate them on behalf of DER owners to trade their flexibilities in the market are also important actors in relation to the functions of gird operation needed to avoid congestion/bottlenecks. At the present, most of aggregators engage with a limited number of relatively large scale of DERs, for instance more than 100 kW capacity in the case of Next Kraftwerke in Germany. Therefore, flexibility resources of these large scale DERs have already been utilized at least in the grid management of TSOs in a certain extent. Nonetheless, when the costs of digital technologies – in particular, of smart meters – significantly decrease in the future, the threshold, say 100 kW, is likely to be much lower, suggesting that a far greater number of small-medium size of DERs such as EVs, rooftop solar PV and heat-pumps may be aggregated by aggregators. In such a case, the roles of aggregators may be more or less similar to those of DSOs discussed above. The major difference can be that aggregators position between DERs and DSOs as an intermediary to provide flexibilities of DERs to DSOs, but also on electricity, capacity, and reserve control markets. If the coverage of DERs by aggregators considerably widens in this way, DSOs may no longer need to install the IoT devices on DERs and collect big data by themselves. Since installation and operation of the IoT devices on small-medium size DERs can be the costliest elements of the system, the future consequence of "who shall do this", more specially DSOs or aggregator, is still not clear yet at this stage. The result would depend upon the cost reduction of the digital technologies, demand for flexibilities of small-medium DERs and profits margin of trading such flexibilities in the markets. If none of these conditions are met, then economic incentives for installation of the IoT devices on small-medium DERs can be largely diminished.

Roles of other relevant third parties

Other parties are mainly relevant for the market-based functions (such as market operation, offer and selection or activation of flexibilities, and billing) in using DERs and IT solutions, e.g.

- private operators of energy marketplaces
- unbundled energy suppliers or P2P energy trading platformers (Ninomiya et al. 2020), which could take similar roles as aggregators if they engage in connecting DERs and making them flexible.

Finally, regulators also play an important role by allowing or not, and setting the rules, for the use of DERs in optimizing grid operation and avoiding bottlenecks.

Summing up: Roles of actors in relation to business/market models for the functions of grid and flexibility operation

The following table sums up the roles of actors in relation to business/market models for the functions of grid and flexibility operation needed to avoid congestion/bottlenecks identified in chapter 2.1. Different actors make use of these functions: consumers, TSOs, DSOs, aggregators, generators, suppliers, (flexible) DER owners, smart meter operators, and operators entitled or accredited to create and/or operate a market. Sometimes, several types of actors have an interest to use one of the functions for their business models and operations, for example in the case of improved demand forecasting. They all could make use of the digital technologies identified in chapter 2.2.

Functions of grid and flexibility operation needed to avoid congestion/bottlenecks	**Roles of actors in relation to business/market models for these functions**
Improved demand forecast	Consumers for optimizing their bills TSOs, DSOs for forecasting grid status and maintaining stability and reliability; TSOs for the reserve control market Aggregators for optimizing the use of generators and flexibilities Generators for optimizing their generation Suppliers for optimizing their purchasing portfolio and their balancing group
Improved wind and solar generation forecast	Generators for maximizing their revenues/profits TSOs, DSOs for forecasting grid status and maintaining stability and reliability; TSOs for the reserve control market Aggregators for optimizing the use of flexibilities and generators Suppliers for optimizing their purchasing portfolio and their balancing group
Monitoring the status of the grid	TSOs, DSOs for forecasting grid status and maintaining stability and reliability
Maintaining grid stability and reliability	TSOs, DSOs for maintaining grid stability and reliability

Functions of grid and flexibility operation needed to avoid congestion/bottlenecks	**Roles of actors in relation to business/market models for these functions**
Control of DERs: efficient demand-side and solar and wind generation management; optimized operation of energy storage and further flexibilities	DER owners for maximizing their revenues/profits Aggregators maximizing their revenues/profits DSOs or TSOs if they have direct control
Smart Metering	Smart meter operators
Optimized market design and operation	Operators entitled or accredited to create and operate a market, e.g. private electricity exchanges, TSOs for reserve control markets, DSOs for regional flexibility markets
Offer and selection or activation of flexibilities	Market operators Flexible DER owners: offer in markets; activate if not done automatically, or if they self-select in response to incentives from DSOs
Billing	Suppliers, market operators, aggregators, DER owners, etc.

Table 5: Summing up: Roles of actors in relation to business/market models for the functions of grid and flexibility operation.

3 Digital business models in Japan and Germany

3.1 Japan

3.1.1 Experiences to date

In Japan, utilization of DERs for operation of the local distribution grid, particularly for elimination of grid congestion and voltage control, has seen little activity compared to the case of Germany (see below chapters), irrespective of the availability of digitalization technologies. Several reasons can be given for this contrasted status. First, unlike Germany, distribution grids have been owned/operated by TDSOs, which were parts of the monopolized large vertical integrated utilities until recently, in place of local independent DSOs, over the past nearly 70 years after the World War II. This implies that the roles of distribution grid operation have been considered to be subordinate compared to transmission grid operation and often characterized by “connect DERs and forget”. In other words, DERs have rarely been in the situation where local DSOs actively utilize their flexibility for the grid management. Second, the share of VRE in annual electricity generation in Japan, 8% in 2019, is much lower compared to Germany of 28% in 2019. Hence, apart from some exceptional cases in specific areas, congestion of distribution grids caused by a rapid increase in DERs has not been broadly perceived yet as an urgent issue to be addressed as much as the same degree done by Germany. It is no wonder that utilization of DERs for distribution grid management has not been activated in Japan since simply not much necessity for such use of DERs has boosted. In addition, the lower share of VRE conversely means the higher share of non-VRE, indicating that, in Japan, a sufficiently large amount of flexibility resources from conventional power plants, for instance, pumped hydro of 22GW plus oil power plants of around 20GW are still available to provide rapid balancing service. This also has created lesser incentive to use DERs as flexibility resources for grid management, especially for transmission grids. Putting it simply, DERs have not been “desperately needed” for grid management in Japan so far.

However, this situation could would change dramatically in the near future. An accelerated increase in VRE is expected in order to achieve the carbon neutral commitment by 2050 declared in October 2020. Though a detailed roadmap how to reach the decarbonized economy has not been established, a substantial increase in renewables, particularly VRE, will be essential over the next decades. At the same time, not only renewables but also other DERs such as EVs and batteries are also expected to increase substantially. Such increase in DERs would lead to congestion of local distribution grids, for which effective use of DERs by grid operators is likely to become necessary. Moreover, following the recent amendment of the electricity industry law, after 2022, distribution grids can be independently operated by local grid operators with proper legal license, namely DSOs, who may develop incentives to utilize the DERs directly connected to their distribution grids in order to eliminate their grid congestion and provide other services.

3.1.2 Current developments/trends

The recent change in the environment around distribution grid calls for further actions towards effective use of DERs by DTSOs, or possibly DSOs after 2022, for their management of local distribution grids. So far, most of the demonstration projects for effective use of DERs conducted in Japan have mainly focused on the roles/ functions of aggregators rather than grid operators within the framework of VPP and electricity markets. In those projects, it is implicitly assumed that aggregators are acting as main hubs of information gathering taken from DERs via IoT and other digital technologies. In such case, aggregators directly monitor/ control DERs corresponding to the markets, VRE generation forecast and other relevant parameters, whilst grid operators could only indirectly monitor/control DERs through aggregators. While distribution grids physically directly connect to any DERs for power their supply by definition, information on the behavior of DERs is not directly delivered to them, as shown in the following Figure 4.

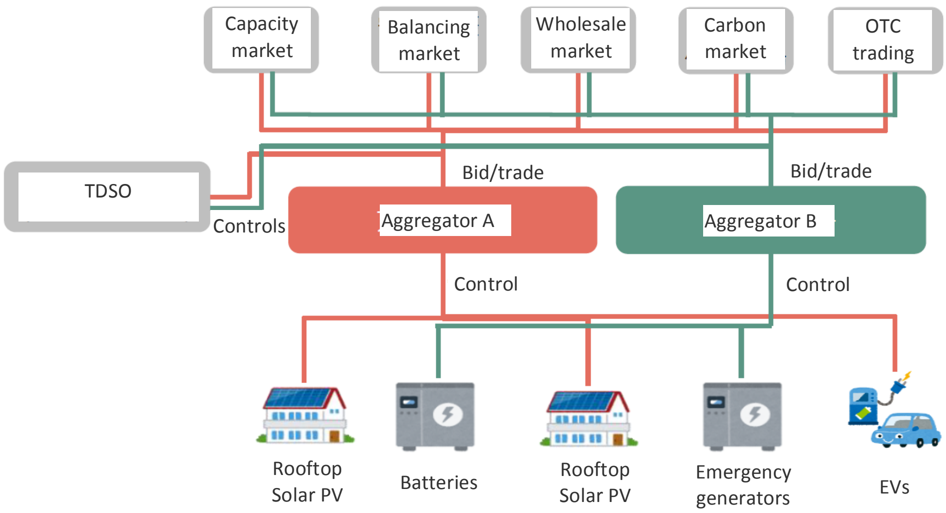

Figure 4: Overview of the existing VPP model: aggregators act as DERs information hub. Source: METI (2020)

In this business model, once again, TDSOs cannot directly monitor the DERs, which may result in facing a difficulty of clear understanding and identification of each DER, and controlling the DER by all means.

In contrast to this existing VPP model, a new framework has been presented where grid operators, TDSOs, or DSOs in specific cases, themselves establish a management platform on DERs for which all of the relevant information on DERs, monitored via IoT embedded each DER, is collected intensively. TDSOs are expected to control the flexibility of DERs, effectively using the DER management platform with AI in order to manage their grid operation, particularly elimination of grid congestion. There are two fundamental differences between the two models. One is "who actually monitors/controls DERs?". It is the aggregator in the former model and the grid operator in the latter model. The other is that optimization of distribution grid is more focused in the latter model in comparison to the former model.

A demonstration project of this framework has just been launched in 2020 by TEPCO Power Grid (TDSO) and others in the Tokyo area financially supported by METI Japan, but any associated results have not been reported yet. Nevertheless, the DERs management platform is expected to deliver notable benefits. First of all, full utilization of available DERs by grid operators would realize much efficient grid management to minimize grid congestion and to control voltage. Moreover, the DERs management platform is not merely employed by grid operators but also by aggregators as well by providing a system platform and bidding/trading on behalf of aggregators.

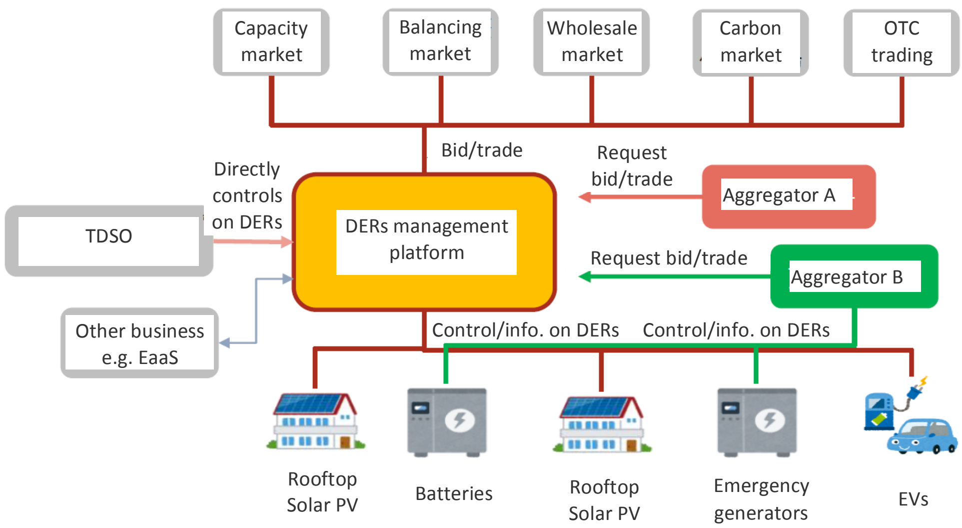

Figure 5: Overview of the DERs management platform model: TDSOs control DERs. Source: METI (ibid.)

The functions of the DERs management platform can be divided into the following three categories; 1) resources/grid management, 2) resource procurement and 3) resource control/ management. Among them, 1) resources/grid management, which encompasses a comprehensive and intensive monitoring/controlling of DERs connected to distribution grid, is seen as the most crucial function of the platform. These functions of the platform in connection to TDSO, aggregators and DERs and are illustrated in the following figure.

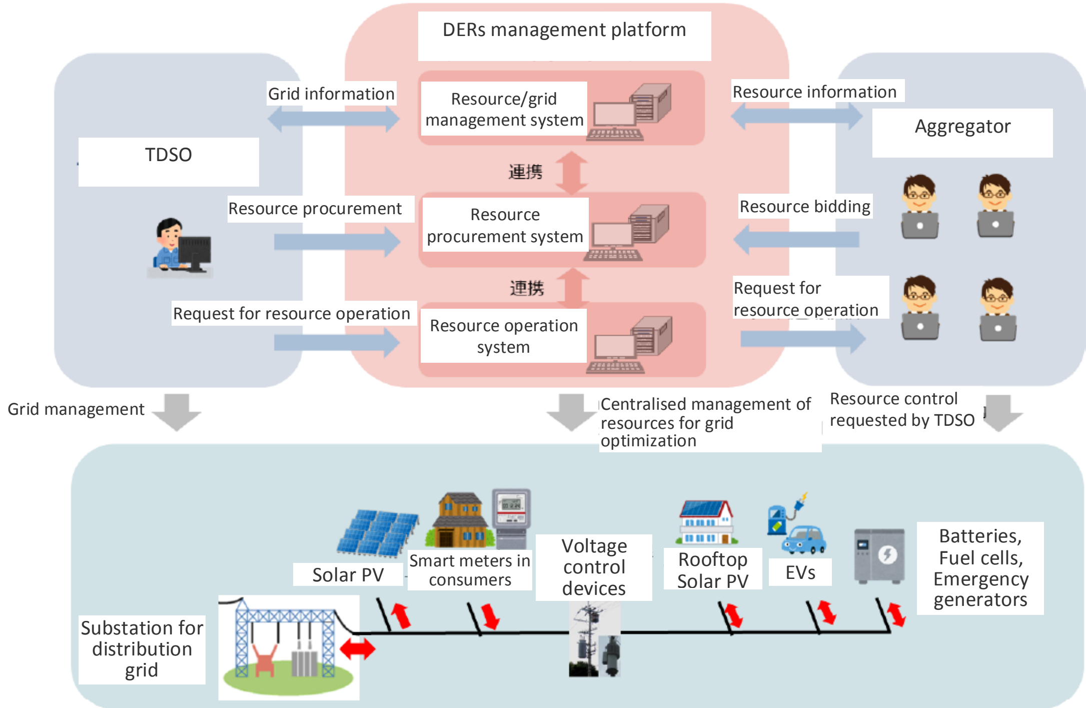

Figure 6: Functions of the DERs management platform. Source: METI (ibid.)

Regarding the use of digital technologies for the functions of grid and flexibility operation with DERs summarized in Table 4 (in Chapter 2.2), this demonstration project primarily focuses on "control of DERs" by DTSO, followed by "monitoring the status of the grid" and "maintaining grid stability and reliability" which are assumed to be achieved by "control of DERs". Almost all attention is paid to the technical aspects of these functions. On the other hand, the economic aspects such as "optimized market design/ operation" and "billing" seem to be out of scope in this project, at least in this stage. Smart meter is implicitly assumed to be completely rolled out, since its penetration rate in the lower voltage consumers was already 74.1% in March 2019 and planned to be 100% by 2020 at Tokyo area, where the demonstration project is currently conducted.

Apart from this demonstration project and the existing VPP projects, model cases of utilization of DERs with digital technologies for grid operation are not commonly found in Japan. An example can be seen in the case of "improved wind/solar generation forecast", which was identified as one of the key functions needed to avoid congestion/ bottlenecks in Chapter 2. In Japan, this function is currently addressed in a way that geological climate data with higher granularity is used, rather than employing big data collected by IoT embedded into each DER. This is because it is pointed out that too much amount of big data with too much higher granularity from each DER is likely to cause inefficiency and increase forecast error, resulting in inferior forecast output compared to the case using climate data obtained by averaging a certain spatial range. This may represent a typical example seen in the country at which big data collected from DERs is not intended to be fully utilized yet.

3.2 Germany

The German cases mostly draw on the results of demonstration projects within the funding program "Smart Energy Showcase - Digital Agenda for the Energy Transition" (SINTEG) by the Federal Ministry for Economic Affairs and Energy. It comprises five large model regions known as showcases, in which model solutions for the energy supply of the future are developed and demonstrated. The focus of the program is on digitalizing the energy sector. Out of more than 300 projects involved, this study is highlighting those who are offering innovative solutions for the monitoring and maintaining of grid status/smart grids as well as the establishing of regional flexibility markets or platforms using IoT, AI and modelling. Special attention will also be given to the aspect of controlling DERs by DSOs.

3.2.1 Monitoring and maintaining of grid status/smart grids

Enera showcase: Simulation platform for the evaluation of flexibility potentials, development of operating scenarios and future scenarios of the network using real flexibility

Enera is a SINTEG showcase in the Northwest of Germany, with high shares of wind power. The work of the DLR Institute for Networked Energy Systems within the enera project shows how the curtailment of renewable generation plants due to bottlenecks in the grid can be avoided or significantly reduced through the targeted use of flexible energy conversion units. Furthermore, scenarios are included in the work, which also represent the future relevance of flexibility options. A simulation platform for the evaluation of flexibility potentials and the development of operating scenarios serves as a starting point. The results obtained from the platform are based on three core elements: On data and insights from practice; on modeling and adaptation based on real measurement data; and on intensive result validation.

The simulation platform determines the grid-serving flexibility requirements that arise due to critical grid situations - for example, due to the overloading of resources during the transport of wind power during a strong wind front. In these situations, grid operators have so far been able to reduce the output of renewable generation capacities by means of feed-in management (“Einspeisemanagement”, short EinsMan) and thus counteract an overload of the grid. Whether or not an overload exists is largely dependent on the current generation or load situation and, in particular, on the topology of the grid. The simulation platform therefore includes not only a detailed model of the high-voltage level of the electrical distribution grid of the enera region, but also extensive models of the energy conversion units that are connected to this grid. The technologies considered in the simulation platform are: wind turbines, electrical storage as large-scale and home storage for photovoltaic systems, power-to-heat for households, power-to-gas with the operating modes "grid-serving" and "full load", and biogas with and without increased nominal power. The models were fed or developed from measurement data of real operating equipment, by means of information provided by cooperation partners, as well as with data from manufacturers and publicly available information sources.

The crucial elements of the simulation platform are:

- Time- and location-resolved quantification of the flexibility demand of the grid due to grid congestion based on the simulation of the vertical grid load

- Determination of the flexibility potential of decentralized energy conversion units for the targeted avoidance of grid bottlenecks
- Inclusion of scenarios for the analysis of the future grid-serving flexibility demand

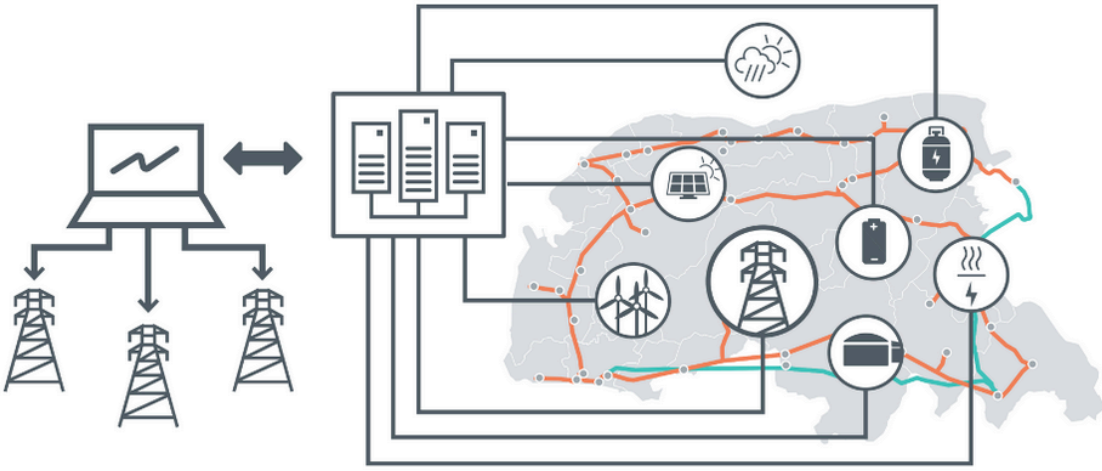

Figure 7: Simulation platform of the enera region in northern Germany. Source: enera (2020a)

During the development of the platform, special attention was paid to the validation of the simulation so that realistic results can be achieved and subsequently used in practice.

Enera showcase: Short-term network condition forecast by machine learning

Forward-looking network management as a basis for better integration of renewable energy sources and the elimination of congestion requires early and precise forecasting of local network load. Such forecasting is expected to become mandatory for DSOs as part of the redispatch and EinsMan reorganization currently under discussion in Germany. Up to now, there is hardly any experience and established solutions for forecasts at the individual substation transformer level, so that the question for all network operators in Germany is how to best meet a forecast obligation. Based on the experience with flexibility markets in the enera project (see chapter 3.2.3), the DSOs EWE AG and EWE Netz took a closer look at the possibilities for forecasts for this use case and to demonstrate the feasibility of a software module in principle. The expected power values of the decentralized feeders are particularly relevant for the network condition forecast. In addition to the feed-in from wind energy and photovoltaics, the grid load also includes the consumption by connected consumers and connected low-voltage grids as well as other feeders such as combined heat and power plants.

For this project, a data-driven forecasting method for the short-term forecast of the vertical grid load at the MS/HS node has been prototypically implemented and evaluated on the data of four substation transformers. The approach used allows to train a forecast model on the time series data itself, so that a relatively complete picture of the vertical network load can be generated.

In summary, it was successfully demonstrated that forecasting by machine learning is possible independent of grid topology and knowledge of the underlying generation structure, and that such a software module can be well applied to different situations. Regardless of the feasibility of the model and the forecast quality achieved, the implementation of a software module would also require integration into an ecosystem at DSOs and hardening of the algorithm for all special cases. If the need for improved forecasts and the avoidance of congestion through the current redesign of redispatch also brings a financial incentive, self-learning forecasting methods can provide significant added value for improving forecast quality as well as for widespread deployment regardless of the exact circumstances (enera 2020b).

Enera showcase: Network-optimizing distribution network automation

As part of the enera research project, Phoenix Contact Energy Automation GmbH demonstrated solutions for distributed, decentralized and partially autonomous grid automation in distribution grids. The self-sufficient automation concept can react independently to critical network situations and control them safely via targeted network interventions. Manual intervention by the utility grid operator is thus no longer necessary.

The demonstrated overall concept of network-optimizing distribution network automation is divided into the two core components of 1) monitoring and 2) control of the network status.

Within the scope of monitoring, the existing network condition is continuously monitored and evaluated. The network status includes on the one hand the network topology, which results from the current switching state of the distribution network, and on the other hand the evaluation of measured values of the measuring points distributed in the network. The monitoring component is called upon and executed continuously. The cyclic call ensures a dynamic update of process values and evaluation results, which forms the basis for the functionality of the network control. With the status information and evaluation results of the monitoring component, the controller component can trigger active network interventions to remedy network status violations in the monitored distribution network area. It is particularly important to correctly identify the specific use cases and to initiate the appropriate and target-oriented measures in each case. Here, controllable systems (e.g., renewable energy generation systems) are used as actuators in the sense of grid-serving management.

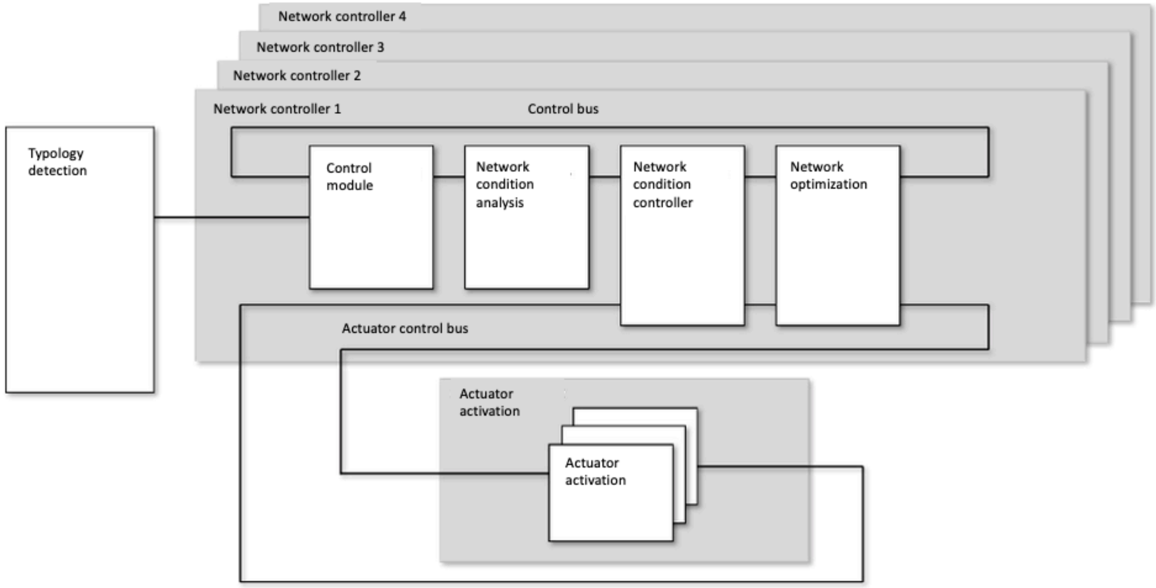

Figure 8: System architecture of the network-optimizing distribution network automation. Source: enera (2020c)

Other examples

Project	Project content
AI4Grids	○ AI-based planning and operational management of distribution grids and microgrids for optimal integration of renewable energy generators and fluctuating loads ○ Digital Grid Lab of Fraunhofer ISE will carry out real-time simulations, since the local generation and consumption structure and thus a network state that is as real as possible can be mapped here ○ In real-world laboratories in Friedrichshafen and at the university of Constance, practical tests will be carried out to determine whether the AI system and its components provide added value for the power grid at both building and neighborhood level ○ For further information see: https://www.ise.fraunhofer.de/de/presse-und-medien/news/2020/projekt-ai4grids-kuenstliche-intelligenz-fuer-stabile-stromnetze.html
Intelligent Grid Platform (IGP)	○ The Intelligent Grid Platform (IGP) is a modular software assistance system that can be used to digitize and automate network planning and network operation management processes for distribution network operators ○ A total of 12 customized applications are available for this purpose in the three main application areas of data quality, network planning and operations management ○ The IGP is already a commercial offer which is provided to DSOs by the company envelio ○ For further information see: https://envelio.de/intelligent-grid-platform/

Table 6: Other examples of monitoring and maintaining of grid status/smart grids.

3.2.2 Controlling of DERs by DSOs

Windnode showcase: targeted use of decentralized generation plants

For a more flexible provision of reactive power from the distribution grid, the creation of control options for wind and PV plants is necessary. The Windnode project of the DSO WEMAG Grid deals with the implementation of such a control, directly from the control system. This is to be used to respond to current requirements from the distribution or transmission grid. These requirements also include the provision of reactive power quantities at a specified interconnection point. In addition, work is being done to ensure that defined target voltages are stabilized directly by automatically provided reactive power.

An essential component of the project is the functional expansion of the network control system to include the so-called intelligent reactive power management system (IBMS), the functional scope of which includes the telecontrol integration of the generation plant, the calculation of node-specific reactive power potentials, the transmission of direct reactive power control commands (setpoint specifications) on request from the distribution or transmission grid, and the visualization of the control potentials.

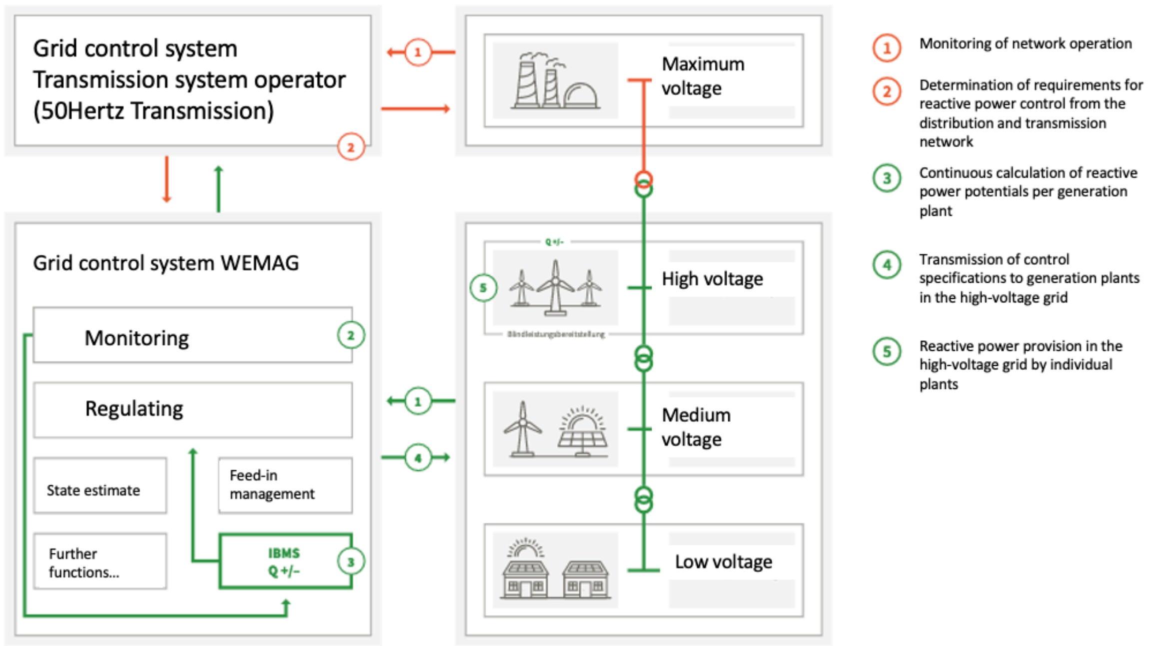

Figure 9: Sequence of the process in the Intelligent Reactive Power Management System (IBMS) in WEMAG's network control system. Source: Windnode (2020, p. 92) © WEMAG Netz GmbH/ WindNODE/ heimrich&hannot

In order for generation plants to participate in the reactive power control of the IBMS, a prequalification is required. The plant pool is currently being expanded through intensive testing of possible generators. By the end of the project, all generation plants connected to the high-voltage grid level of the DSO WEMAG Grid are to be included in the system in order to exploit the maximum control potential from the distribution grid. Due to the focus of the project on the targeted use of decentralized generation plants in the distribution grid, the transmission grid is not addressed.

Windnode showcase: targeted use of decentralized generation plants

Bosch.IO and devolo are working on solutions that allow barrier-free integration of smart home solutions, heat pumps and PV inverters into the existing smart grid concept. In the process, the Windnode partners developed an initial solution approach that makes it possible to create a regulatory penetration of the energy supply companies into home automation. In this way, private flexibilities, such as controllable loads and energy storage, can be offered to interested market players.

The narrow regulatory limits for communication via a German smart meter gateway (SMGW) require an expansion of the solutions established in the Internet of Things (IoT) environment. Currently, access via the SMGW to the home network of an end consumer is only possible via the so-called controllable local systems interface (CLS interface). The current evolutionary stage of the German smart grid essentially allows only two regulatory permissible ways to communicate with customer hardware. On the one hand, protocol conversion or encapsulation of non-smart grid protocols using a virtual or real control box. On the other hand, a natively supported protocol such as http as the communication carrier. Both approaches were rigorously pursued and tested in the visitable sites and laboratory demonstrations. Using the existing smart grid technology, the communication via the CLS channel of the SMGW turned out to be the most barrier-free for the involved partners.

In the first stage, the bridge between smart grid and smart home was built directly via the "Highly Secure Communication Scenario 4" (HKS4) defined by the Federal Office for Information Security for the smart meter gateway: in this scenario, an external market participant (EMP) initiates a secure channel from the EMP via the SMGW to a device in the CLS network. The practical implementation for the customer is that a network-capable device is connected directly via the CLS network socket of the SMGW. The necessary gateway administrator and energy manager solution as an external market participant was implemented by Bosch.IO. To control the customer hardware, devolo implemented a management interface on the Smart Home Control Box. In the test, several loads could be successfully controlled and their consumption measured individually and to the split second. An interesting challenge was the implementation of the HKS4 case according to requirements, as this had not yet been tested much in the field. After successful commissioning, however, this was achieved reliably and smoothly.

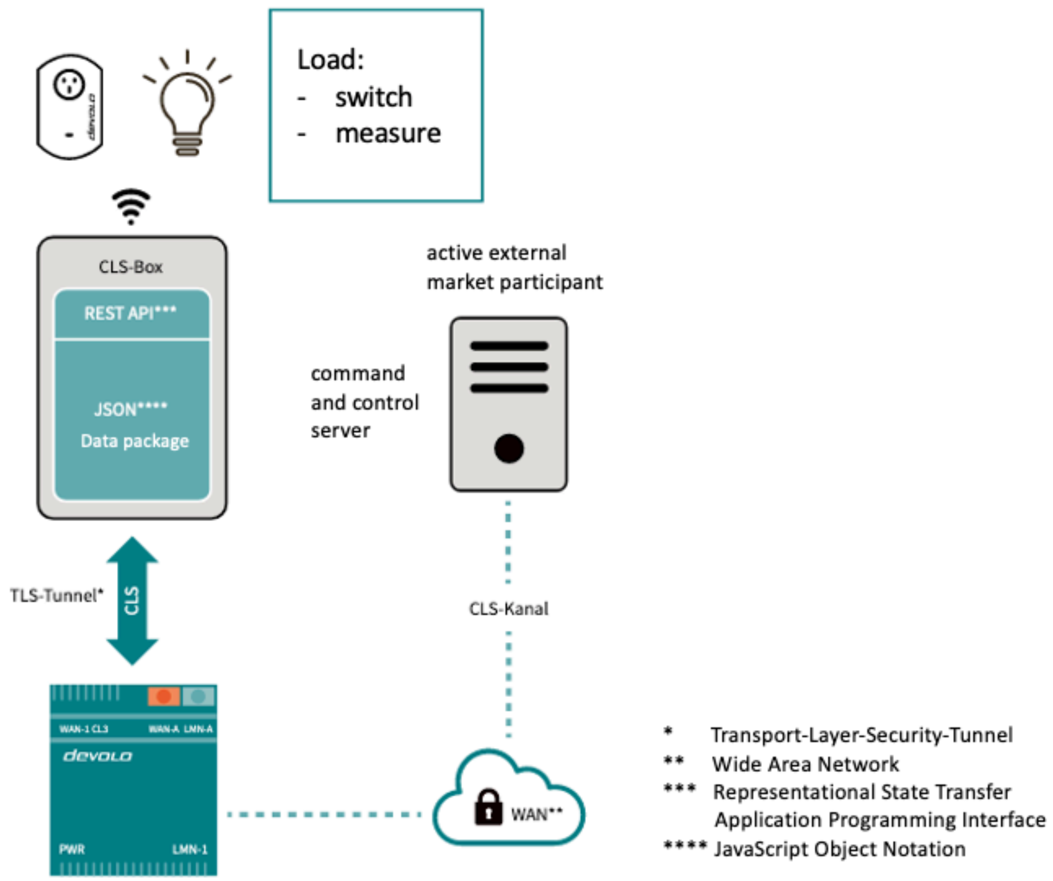

Figure 10: Access to smart home devices within the regulatory framework via SMGW and CLS tunnel: Small-scale flexibilities and load management via control server of an active external market participant. Source: Windnode (2020, p. 113) © devolo AG/ WindNODE/ heimrich&hannot

Another potential added value for customers would be a dedicated IoT-specific interface. In the current form of the SMGW, however, this solution approach is not feasible due to the current regulatory framework conditions. Looking to the future, a solution would be desirable that allows smart home hardware, wallboxes, heat pumps, PV systems or other customer hardware to be connected directly and configuration-free to the SMGW without any additional hardware. Here, direct support of already established IoT protocols on the SMGW would offer ready and available solutions. The customer could then not only obtain information about his or her consumption values centrally, as provided for in the transparency and display software (TRuDI), but would also have an overview of meter values and the status of his or her own hardware via a user interface.

Other examples

Project	Project content
Enera showcase Einspeisevisualisierungsapp ("Feed-in visualization app")	○ Feed-in visualization app for prosumer households: the generation output of the in-house PV system and household electricity consumption are displayed and offset live and in historical curves ○ The resulting recommendations for action enable users to optimize their consumption behavior to the current and forecast future in-house production ○ The smart readout and communication module developed in the enera project collects the required measurement data at the PV generation meter and the grid transfer meter of the test household ○ For further information see: https://projekt-enera.de/blog/einspeisevisualisierungsapp-eivi/
Enera showcase Automation of the feed-in management of RES	○ Automation of the feed-in management of RES in real time carried out by a grid controller ○ Laboratory phase and field test of partially automated grid operation has been conducted ○ For further information see: https://projekt-enera.de/blog/teilautomatisierter-netzbetrieb/
Enera showcase New busines models based on aggregated flexibility	○ New business models based on the aggregated flexibility of micro plants ○ Role of the aggregator of micro plants can be taken over either by the manufacturer of the plants or as a service by VPP ○ For further information see: https://projekt-enera.de/blog/eroeffnung-neuer-vermarktungspotenziale-fuer-aggregatoren-von-kleinstanlagen/
Windnode showcase "StromPager DX"	○ As part of Windnode, a control technology for low voltage was further developed and tested in the real-world laboratory - the "StromPager DX" ○ A first level of coordination function has been created at the operational level. This enables any authorized market partner to send control commands without having to operate a certified control system as an active external market participant (EMT) ○ Hybrid solution of smart metering system and secure broadcast thus also fulfills the door function for value-added services via the future smart meter gateway infrastructure ○ For further information see p. 114f.: https://www.windnode.de/fileadmin/Daten/Downloads/Jahrbuch/WindNODE_Jahrbuch_2020_Web_150dpi.pdf

Table 7: Other examples of controlling DERs by DSOs.

3.2.3 Regional flexibility markets and platforms

Enera showcase: enera Flexmarket and marketplace

At present, network operators mainly use non-market measures prescribed by law to eliminate congestion. In addition to cost-neutral measures, such as switching measures, these are primarily redispatch and feed-in management measures. In order to proactively avoid grid bottlenecks, thus relieving the grids and being able to accommodate further renewable energies in the grid, it is necessary to develop additional local flexibilities for congestion management. Through digitalization and new technical possibilities, this demand is then also met by suppliers who, as active participants in the energy system, can provide this local flexibility with their generation and consumption plants as well as storage facilities. Previously, however, there was no environment in which grid operators could make efficient use of precisely these opportunities. In the SINTEG project enera, the exchange-organized enera flexibility market (enera Flexmarkt for short) was developed and demonstrated for this purpose. It should be noted that this is not yet generally allowed in Germany, but it was allowed as a regulatory experiment in the SINTEG projects. Furthermore, EPEX SPOT designed, developed, implemented and operated the enera marketplace, building on the market design for the enera Flexmarket. The demonstration phase of the flexibility market concept as a whole and the marketplace in particular was successfully conducted from February 04, 2019 to June 30, 2020. During the demonstration phase, six flexibility providers, two DSOs and one TSO operated safely and efficiently in the market, with over 4,000 orders sent and 130 calls completed.

Elements of the enera Flexmarket

Local market areas form the lowest granularity in the enera Flexmarket and comprise network topological regions in which the connected flexible plants act with the same or at least approximately the same sensitivity to all potential congestion. Accordingly, the local market areas are to be selected in such a way that no congestion exists in the corresponding region for any of the network operators. The assignment to market areas makes the flexibilities comparable in their congestion effectiveness and adds a local component to the offers - which is missing on the wholesale market. With the simultaneous **standardization of flexibility products**, flexibility offers also become comparable in price. Automatic comparison and automatic contract execution thus become possible, which significantly increases the efficiency of such a small-scale market. In order to create a high level of acceptance here and thus achieve liquidity on the platform, which is crucial for the success of the market, the **barriers to market entry should be kept as low as possible**. This was achieved in the enera project by basing the market design and the processes required for implementation on the existing wholesale processes for intraday trading of electricity. In addition, in order to be able to use the **greatest possible flexibility potential** for congestion management, the market design should take into account, as far as possible, all generation plants, storage facilities and consumers that can provide a planned deviation from their original, purely market-based schedule. This includes generation plants, regardless of output and whether they are conventional or renewable generation plants. Storage facilities, where at least the charging or discharging process can be influenced, can also be included, as can be consumers (enera 2020d).

The trading process on the enera marketplace

Trading on the enera market opens at 3 p.m. of the previous day (D-1) and ends 5 minutes before delivery starts. This allows flexibility trading until shortly before delivery, which is especially important due to changing forecasts. Analogous to the intraday market, continuous trading is possible on the enera market. In practice, however, the network operators only become active in the market when a bottleneck is expected. They are able to buy renewable and non-renewable flexibility, offered for different delivery times and different delivery periods (15 minutes and 60 minutes).

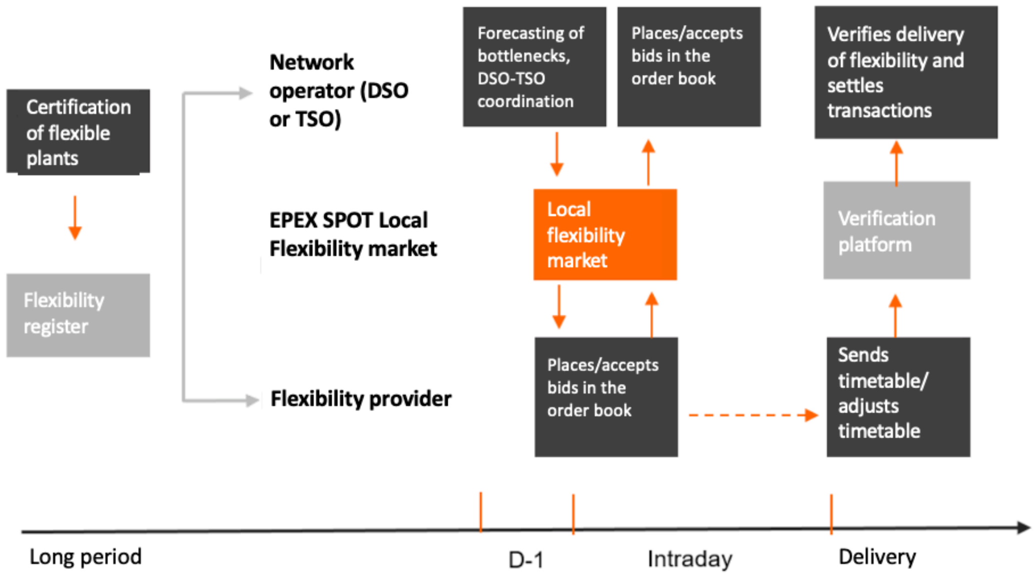

Figure 11: The enera market over time in the short-term markets, source: EPEX SPOT (enera 2020e)

The functioning of the local flexibility market displayed in Figure 11 can be explained as following:

- At the beginning, the **connecting network operator** issues a one-time certification for the flexibility plants, which serves as an authorization to participate in the flex market
- The **network operators** regularly carry out network congestion forecasts in order to detect congestion in their network as early as possible in the intraday time range and to determine the resulting flexibility demand, as well as to coordinate this with the other network operators. The network operators then post their flexibility requirements and their willingness to pay on the trading platform.
- Similarly, **marketers** post their available flexibility as well as offer prices.
- The **trading platform** compares supply and demand and subsequently informs the market participants if both bids are compatible and a transaction has been concluded. Order matching rules ensure that orders are executed at the best price available in the system.
- Subsequently, the **flexibility provider** is obliged to deliver the flexibility according to the product specifications.
- Flexibility delivery has a physical impact on the power grid (injecting or withdrawing power to or from the grid), effectively resolving or mitigating grid congestion. This flexibility provision is verified ex-post by grid operators based on metering data at the point of entry as part of the verification platform processes.

The transmission of schedules and the measurement of actual values can be used to detect undesirable behavior, especially in the form of increase-decrease (inc-dec) gaming. Inc-dec gaming in general is the activity of traders to strategically position themselves in the spot market in anticipation of a redispatch market in order to maximize their overall revenues. Within the scope of the project, market monitoring in combination with appropriate market rules that include corresponding sanction options was developed as a concept for avoiding strategic behavior in the enera flex market (enera 2020f).

The trading system used for the enera marketplace is the M7 trading system, provided by the German stock exchange (Deutsche Börse AG) and already known from the intraday trading of EPEX SPOT. This trading system has been extended with new functionalities and features to reflect the use case of a flexibility market.

Enera showcase: Network operator coordination process

In the run-up to each market use of the enera marketplace, network operator coordination with the respective downstream network operators takes place to ensure efficient and effective use of market-procured flexibility and secure and reliable electricity network operation. Since upstream network operators (e.g. TSOs) do not know the network status of the respective downstream network operators (e.g. DSOs), without coordination there is a risk that an upstream network operator will cause congestion in the downstream network through uncoordinated measures.

The placement of a purchase order or bid on the market platform by a network operator requires the approval of all downstream network operators. It is the task of the respective network operator to obtain approval from the downstream network operators. The network operator willing to contract shall send its request for market use to the network operator directly downstream of it in a jointly defined data format. This request must be received by the respective downstream network operator no later than thirty minutes before market use and no earlier than six hours before the end of the provision of flexibility. In deviation from this, the request must be received by the downstream network operator only 15 minutes before market use if only one downstream network operator is involved in the process. In addition to the time period, the request must contain at least information on the market area(s) in which the upstream network operator wishes to acquire flexibility as well as the forecast quantity of flexibility in MW per 15-minute interval.

The downstream network operator shall calculate any capacity restrictions and notify the upstream network operator thereof. The capacity restriction corresponds to the usable capacity bands that may not be exceeded by the upstream network operator as a result of market usage. By notifying the upstream network operator, the downstream network operator grants the necessary release for the flexibility call for the notified volume. If, as a result of the request, a market area of a further downstream network operator comes into question for a potential flexibility provision, the requested network operator in turn requests in advance any restrictions of the further downstream network operator.

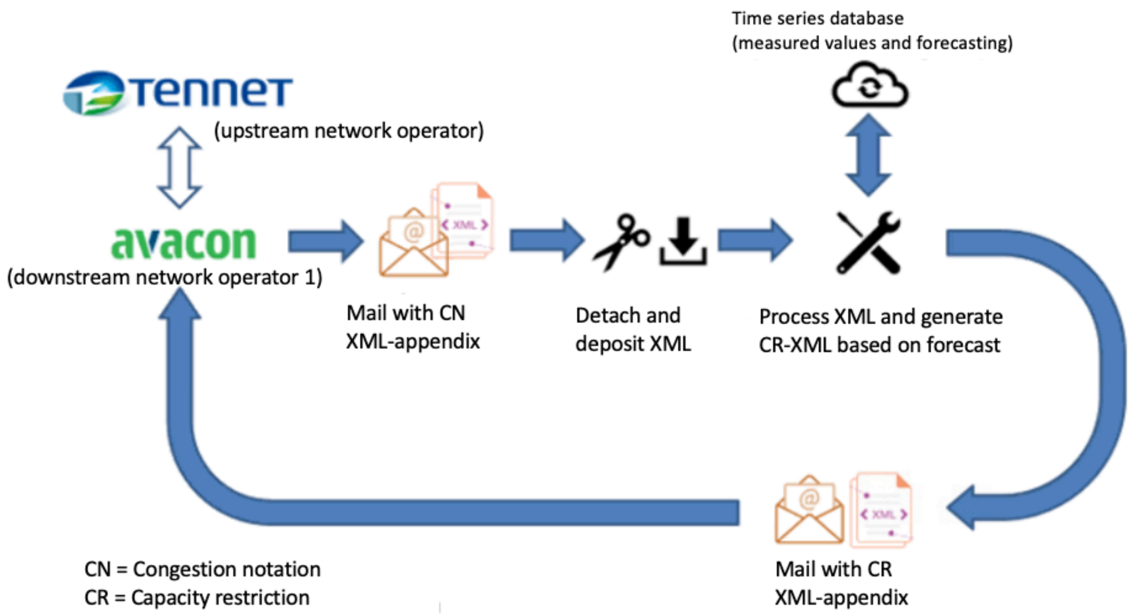

Figure 12: Process flow at EWE Netz (downstream network operator 2). Source: enera (2020g)

Enera showcase: Implementation of an Active Network Management

In cooperation with the DSO EWE Netz GmbH, the conception and implementation of the interface for the generation of files with flexibility demand for the enera market interface were carried out for medium-voltage areas of the enera region and verified in a field test. The feed-in and load forecasts were provided by the consortium partner energy & meteo systems GmbH.

Figure 12 summarizes the functionality of the Active Network Management (ANM) for the implementation of the so-called yellow traffic light phase in the forecast mode. Schedules and forecasts from external data source are fed into the ANM via the interface applications. The ANM calculates the state estimate and determines the traffic light. The subsequently calculated optimization uses the control variables allowed for the traffic light phase. When the traffic light phase is yellow, a flexibility demand is calculated. This flexibility demand is forwarded to an external market interface via an appropriate ANM interface. There it can be converted into a flexibility request to the regional flexibility market (as described above). The activities on the market are included as a result in the schedules of the flexible plants and are transmitted to the ANM via a corresponding interface. This closes the circle.

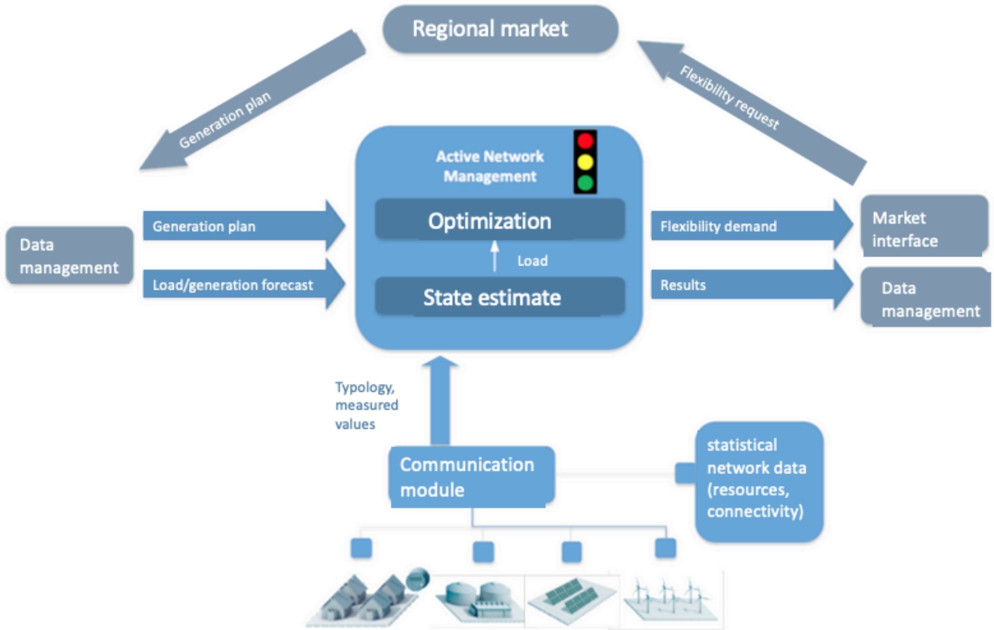

Figure 13: The functioning of the Active Network Management (ANM). Source: enera (2020h)

The laboratory test and installation of the Active Network Management (ANM) was carried out in the network control center at EWE NETZ. Among other things, the field test showed that the application of Demand Response at the distribution network level is technically feasible in principle. However, the following factors, among others, are indispensable for successful operation:

- A sufficient amount of flexibility (especially flexible load) in the distribution grid. The ANM can be used to determine the required amount. The availability of flexibility not only allows for the elimination of congestion, but is a necessary condition for market liquidity.
- Reliable load and feed-in forecasts, from which one can accurately derive the time, level as well as duration of the bottleneck.

Designnetz showcase: PolyEnergyNet

The SINTEG project Designnetz maps the power grid into local and regional energy areas. As far as possible, energy should be consumed or stored where it was generated. Local energy sectors can exchange with each other via regional connections.

For example, Stadtwerke Saarlouis is developing a resilient local network consisting of autonomous sub-networks, so-called "holons". The subnetworks are not static. They adapt dynamically to the respective network situation and reorganize among themselves in order to always guarantee the optimal supply situation. The electricity, water and gas networks were coupled with a fiber optic network to control the holons. Electricity generated by local photovoltaic systems, for example, can be intelligently controlled and converted into heat energy in a power-to-heat plant to stabilize the grid. This avoids high transmission losses and prevents voltage band problems. Sector coupling creates an overall efficient polygrid, the so-called PolyEnergyNet.

In order to realize the holons, the project partners developed various systems that enable the operation of autonomous subnetworks in a critical network infrastructure. These include holon management as decentralized intelligence, integrated measurement concepts, real-time data management, actual-state detection, forecasting procedures, and the associated protocols for overall control. Attack and anomaly detection continuously monitors the ICT network, detects attacks and faults, classifies them and initiates appropriate countermeasures.

This way, PolyEnergyNet has developed a new paradigm for the control of the energy system with the 'holar model'. Previous models envision a rigid, hierarchical or tree-like structure. The holar model, on the other hand, is dynamic. Depending on demand, the 'holar elements', i.e. the generators, consumers, storage units and line elements, rearrange themselves into self-controlling groups, the 'holons'.

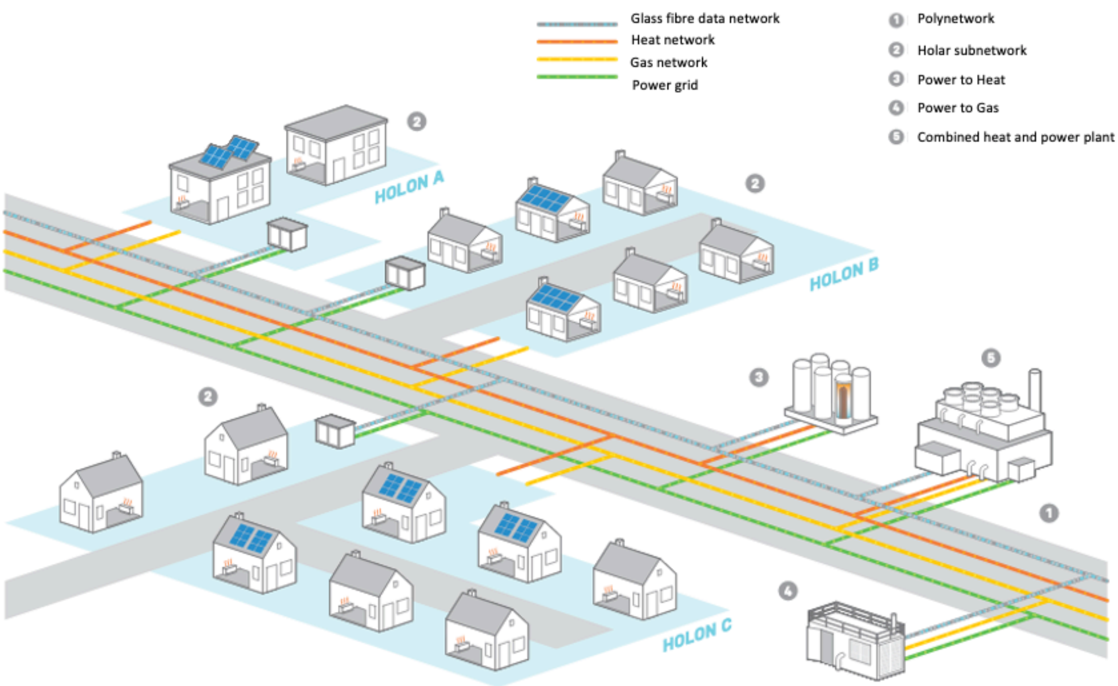

Figure 14: The PolyEnergyNet. Source: Designnetz (2020, p. 17f.)

Windnode showcase: Uckermark integrated power plant

The „Uckermark integrated power plant" demonstrates how the coupling of renewable generation plants, storage facilities and PtX plants can completely replace the functions of conventional power plants in the future. A feed-in grid with a radius of 25 kilometers connects wind energy, photovoltaic and biogas plants, a 20 megawatt battery, a heat storage tank with 1,000 m^3, and a hydrogen electrolyzer.

All components of the integrated power plant are already directly connected to each other electrically and digitally and are coordinated with each other. By connecting all plants, the decentralized and heterogeneous structures are unified with the help of the IT platform ENERTRAG PowerSystem. The platform monitors and controls all individual plants in the integrated power plant and groups them into large power generation units. The goal of the

Windnode project partners was to advance the coupling of the interconnected power plant and make it even more secure against external attacks. Due to the rapid technological development of wind turbines, the technical software requirements for the regulation and control of turbines have also changed significantly. With the support of Windnode, ENERTRAG PowerSystem was therefore further developed as a program that is designed for the formation of renewable power plants and is thus ideally suited for monitoring and controlling the large number of directly coupled plants of the interconnected power plant.

Other examples

Project	Content
Enera showcase: Municipal web application	○ Municipal web application visualizes in real time the electricity consumption of numerous properties in the model region ○ The current consumption of a property could be compared at any time with the values of the previous week or month and thus irregularities, caused for example by a defective terminal device, could be identified quickly and easily. ○ For further information see: https://projekt-enera.de/blog/mit-digitalen-loesungen-zur-kommunalen-energiewende/
NEW 4.0 showcase: ENKO	○ The digital flexibility platform ENKO makes it possible to use more green power in the model region and at the same time relieve the power grid ○ The project comprises the entire development of the digital flexibility platform called "ENKO- ENergie intelligent KOordinieren" ("coordinate energy intelligently"), on which plant operators can offer their flexible loads to grid operators. In addition, innovative algorithms were developed for the forecast of flexibility requirements by the grid operator and continuously improved in live operation. ○ For further information see: https://new4-0.erneuerbare-energien-hamburg.de/de/new-40-projekte/details/ENKO-konzept-zur-verbesserten-Integration-von-Gruenstrom.html

Table 8: Other examples of regional flexibility markets and platforms.

4 Discussion of use cases and business/market models identified

In this chapter, we compare Table 5 on use cases and business/market models in chapter 2.3 to the use cases identified chapter 3. In this way, we can conclude which business/market models are already established or starting to be established on commercial basis and which are in development or demonstration phase only, and the reasons why (lack of technologies or markets/regulation /business cases).

For the establishment of a smart grid, firstly **optimized demand and supply forecasts** are absolutely necessary. As shown in Table 5, according roles of actors in relation to business/market models for these functions are: consumers optimizing their bills; TSOs, DSOs forecasting grid status and maintaining stability and reliability; TSOs for the reserve control market; aggregators optimizing the use of generators and flexibilities; generators optimizing their generation and maximizing their revenues/profits; suppliers optimizing their purchasing portfolio and their balancing group. For many of these business/market models, forecasting is well developed; for example, its use by aggregators such as Virtual Power Plants was discussed in our previous study (Ninomiya et al. 2019). It has also been demonstrated for the function most relevant for this study, i.e. TSOs, DSOs forecasting grid status and maintaining stability and reliability. As described in chapter 3, for example, a simulation platform for the evaluation of flexibility potentials, development of operating scenarios and future scenarios of the network using real flexibility was developed within the enera project region. This is also one aim of the demonstration project currently developed in Japan and described in the previous chapter.

For similar projects in other regions, special attention has to be paid to the validation of the simulation so that realistic results can be achieved and subsequently used in practice. They are then ready to become a (part of) a business model, in which the TSO or DSO monitor the grid status and use grid resources and EinsMan for maintaining grid stability and reliability. However, for enabling the full use of DERs for this purpose, the regulatory environment for using DERs would need to be created or improved in Germany and Japan (see below).

Secondly, the **monitoring of grid status and the forecast of (near) critical status** needs to be advanced as well. As shown in Table 5, TSOs and DSOs forecasting grid status and maintaining stability and reliability are necessary users for this function. As described in chapter 3, for example, the enera project demonstrated a solution for distributed, decentralized and partially autonomous grid automation in distribution grids. Also, a short-term network condition forecast by machine learning was developed and demonstrated within the project framework. In the demonstration project in Japan, monitoring of grid status is viewed as a part of grid management, which can be performed by control of DERs described below. Regardless of the feasibility of the model and the forecast quality achieved, there are still technical and regulatory issues to be solved. The implementation of a software module would also require integration into an ecosystem at DSOs and hardening of the algorithm for all special cases. Also, the current redesign of redispatch needs to bring a financial incentive for improved forecasts and the avoidance of congestion. Despite this need, the example of the Intelligent Grid Platform (IGP) demonstrates that there is already a market in Germany for commercial offers like this one.

As a third function, the **use and control of DERs** for flexibility needs to be advanced. As shown in Table 5, the respective roles of actors in relation to business/market models for the use/control of DERs are: DER owners maximizing their revenues/profits; aggregators maximizing their revenues/profits; DSOs or TSOs using DERs for grid stabilization if they have direct control. For example, as described in chapter 3, the Windnode project of the DSO WEMAG Grid deals with the creation of control options for wind and PV plants directly from the control system. In order for generation plants to participate in the reactive power control, prequalification in the form of intensive testing of generators is required. That is why the project is still in the development phase. Furthermore, Windnode partners developed an initial solution approach that makes it possible to create a penetration of the energy supply companies into home automation for control purposes. However, this project is also in the testing phase. To make use of this solution approach on a big scale, an adaption in regulatory framework conditions of the SMGW would be needed. In general, for enabling the full use of DERs for maintaining grid stability and reliability, the **regulatory environment** for using DERs would need to be created or improved in Germany.

In the Japanese demonstration project, use/control of DERs is considered as the most important feature of the model with which DTSOs are expected to conduct effective grid management. In Japan, although the demonstration project has just been initiated, full use of DERs as flexibility resources by grid operators also requires reform of the existing regulatory framework (see below).

As shown in Table 5, roles of actors in relation to business/market models for the function of **optimized market design and operation** are: operators entitled or accredited to create and operate a market, e.g. private electricity exchanges; TSOs for reserve control markets and DSOs for regional flexibility markets. As an example, in the enera project, the exchange-organized enera Flexmarkt was developed. It demonstrated how suppliers with their generation and consumption plants as well as storage facilities can provide local flexibility to TSOs and DSOs. Within the Flexmarkt context, a network operator coordination process and an Active Network Management was developed as well. However, it should be noted that to realise a flexibility market with such features on a commercial basis, the regulatory framework would need adaptation. Within the project Designetz, Stadtwerke Saarlouis are working on a resilient local network consisting of autonomous sub-networks, so-called "holons". The approach is still in development phase. Within the Windnode project, the „Uckermark integrated power plant" connects different forms of DERs and storage options on a regional scale. However, possible business models for the operation are still under research. In the Japan, optimized market design is somewhat out of consideration since almost all attention is solely paid to the technical aspects of the DERs management platform system. This does not necessarily mean that the market aspect is seen as unimportant, but it would need to be investigated after overcoming the technical challenges.

Further roles of actors in relation to business/market models for **smart metering, offer and selection or activation of flexibilities, and billing** are: Smart meter operators; data hub and data consent management operators, e.g. TSOs; market operators; flexible DER owners (offer in markets; activate if not done automatically, or if they self-select in response to incentives from DSOs) and suppliers, market operators, aggregators, DER owners. Due to the focus on monitoring and maintaining of grid status/smart grids, controlling of DERs by DSOs and regional flexibility markets and platforms, use cases in chapter 3 didn't draw extensively on these functions/business models.

5 Recommendations on policies and regulations

5.1 Recommendations for Japan

As already mentioned, in Japan, the demonstration project with the DERs management platform associated with a range of digital technologies conducting centralized management of DERs by DTSOs for optimization of distribution grid has just been initiated and, to date, no tangible results have been reported. Despite it may be premature to suggest recommendations on policy and regulation at this stage, the discussion based upon the experiences in Germany, which is clearly ahead of Japan in this field, provides valuable policy implications which could be applied to Japan in the similar manner.

Currently, the main concern of the demonstration project extensively focuses on the technical aspects of the functions of the DERs management platform. In other words, the economic aspects, such as the regulatory environment for utilizing DERs via price signals and realization of local/regional flexibility markets, are currently out of the scope of the project. However, it should be stressed that Germany's experiences highlight the importance of consideration on such economic aspects of utilization of DERs. Therefore, it is recommended that, in parallel to the implementation of the demonstration project mainly focusing on the technical elements, the regulatory environment should also be carefully considered with the views of how to create economic incentives to utilize DERs for DER owners, DTSOs/DSOs and aggregators and how and what markets, local/regional markets such as in the cases in Germany should be established and in which regulatory framework. These are still left for further examination.

In a similar context, the experiences in Germany also indicate that a reform of the existing regulatory framework is also necessary in Japan for full use of DERs as flexibility resources by grid operators. Some of the issues were already recognized by the policy makers who recently amended the existing regulations on, for instance, legalization of independent local DSO and aggregators under the electricity industry law, deregulation of the existing measurement law on metering of DERs and an amendment of the grid delivery charge for using the grid. The last one includes a newly introduction of a revenue-cap regulation on TDSO to promote cost-effective grid management. These amendments will be in effect in April 2022, conceivably improving the environment for effective use of DERs.

5.2 Recommendations for Germany

It was shown above that for enabling the full use of DERs for maintaining grid stability and reliability, the regulatory environment for using DERs would need to be created or improved in Germany. However, in this respect, more analysis and testing will be needed to determine, whether the use and control of DERs should be implemented 1) via price signals (e.g. via a shorter-term/interval intraday market plus incentives for control to support the grid), and then a) via control by DER owners, or b) via control by the DSO? Or will 2) a control by DSOs be necessary only in cases of a need to avoid congestion, e.g., via a local/regional flexibility market?

To realise a flexibility market, in which suppliers, with their generation and consumption plants and storage facilities, can provide local flexibility to TSOs and DSOs on a commercial basis, the regulatory framework would need adaptation as well. Offering grid fees dependent on time of use or at least on events of grid constraints will make sense in any case, starting with this incentive for bigger consumers than households due to the current state of establishment of smart meters in Germany, and due to the cost of establishing the control and billing. Initially, investment incentives e.g. for IoT equipment, such as DER control systems, or software solutions may also be needed and should be analyzed further.

Furthermore, it needs to be investigated at which scale the optimization of the grid should happen, e.g., very small cells or holons, or regions of cities and surrounding countryside, or the whole area of a DSO. Also, and as a more general note, it is still unclear whether a balance at DSO grid or sub-network level can be maintained, or how much additional use of TSO grid will be needed/optimal. Future regulations can then build on further insights on these topics.

For example, the SINTEG project C/sells recommends the following steps for promoting, testing and using flexibility and digitalization as enablers of the energy transition, not only but including for serving grid stability (C/sells 2020):

- Simplify market access for small plants and open up new opportunities for action (for example, energy exchange in the neighborhood, autonomously acting self-suppliers and RES communities, but also use in grid congestion management via unbureaucratic participation in the flex platforms)
- Design the system of levies, charges and fees in such a way that a systemically reasonable, interference-free integration of flexibility is made possible and that neither the grid operators nor the flexibility providers incur additional costs for a grid-serving use of flexibility, but rather that incentives are created for grid-serving behavior
- Commission area-wide flexibility potential and feasibility analysis and a further roadmap to finally cover all DSO areas in Germany. These studies would analyze how to appropriately mix various energy resources (solar, wind, biomass, and many others) and demand response to stabilize the use of VRE without depending too much on storage options, aiming for both minimization of GHG emissions and environmental damages and economic system costs[3] while maintaining system security.

Furthermore, it is recommended to develop the standardization of interfaces and processes as well as labels for smart, sustainable buildings and factories with a standardized smart grids interface. For the flexibility proving plant, digital interfaces must be defined that enable control without relays, thus making the gateways a safe communication and control component.

[3] As of today, demand response, heat storage, control of RES are usually cheaper than electricity storage. However, this may change in the near to medium future because of ongoing cost degression of batteries.

6 Conclusions and further research needs

This paper has focused on the use of digitalization for the optimization of distribution and transmission grids operation to avoid congestion and bottlenecks, utilizing AI and big data collected from DERs with IoT devices. The examination of the functions of grid and flexibility operation needed to avoid congestion/bottlenecks showed that these functions are well defined conceptually. It was also found that each of the functions identified can be associated with the recent development of digital technologies, namely the IoT and AI with big data. The importance of these functions with the digital technologies are highlighted by the recent rapid increase in VRE and DERs in both countries Germany and Japan.

Over all, it can be concluded that the concept of the functions and the associated digital technologies are properly defined and developed at least as seen from the technical view point, although the standardization of software and interfaces for easy-to-use control of especially small DERs and its mass roll-out will need further development. For example, vehicle-to-grid technologies are not yet available in Germany on a broad scale. The roles of actors and their potential business models corresponding to the functions of grid and flexibility operation also adequately identified, proving that uses of digital technologies for the functions by each actor are almost ready to be set at the demonstration projects in the both countries.

The demonstration projects in Germany over the past, particularly the SINTEG showcase program, have developed and tested in principle all the technical and economic solutions needed. Some are already commercially available, while others still need to become easier to apply or more standardized and secure before mass roll-out. However, the most important barrier is the lack of a regulatory environment that would allow DSOs, DER owners, and aggregators to make full use of DERs for optimizing the grid, in addition to the general energy and reserve control markets. Considerable research has been made in policy and regulatory options, but policy still needs to conclude on the best solution between implementation via price signals to DER owners or a local/regional flexibility market. The currently discussed option for DSOs to limit charging power to BEV at times of local grid bottlenecks may only be a first partial and not very smart solution. Offering grid fees dependent on time of use or at least on events of grid constraints may be part of an alternative and smarter solution.

In addition, as stated in chapter 5, more research, development and testing is needed to understand at which level a balance between supply and demand while avoiding grid congestions can be achieved, e.g., for very small cells or holons, or regions of cities and surrounding countryside, or the whole area of a DSO. An analysis of area-wide flexibility potential and feasibility seems needed for as many regions as possible.

In comparison to Germany, far less progress has been made in this field in Japan. To date, only one demonstration project has just started and no tangible outcome has been reported. The project is aimed at centralized management of DERs by TDSOs via the DERs management platform employing a range of digital technologies for optimization of grids, particularly elimination of congestion of distribution grids. It was revealed that the focus of the demonstration project is intensively on the technical aspects of the platform system, specifically accurate monitoring and secure controlling of the DERs by TDSOs via the platform. In contrast, the economic aspects, such as the regulatory environment for utilizing DERs via price signals and/or realization of local/regional flexibility markets, are currently out of the scope of the project. However, the extensive experiences in Germany in the implementation of a number of demonstration projects over the past years clearly indicate that profound consideration of these economic aspects is absolutely essential to ensure the project is commercially viable. It is worth recalling that, in Germany, the most significant barrier was identified as the lack of a regulatory environment. It was also emphasized that, once again based upon the experience in Germany, a reform of the existing regulatory framework is also necessary in Japan for full use of DERs as flexibility resources by grid operators. While some of the amendments of the existing regulations have been adopted in 2020 so that independent local DSOs and aggregators will be legalized under the electricity industry law after 2022, further examination for regulatory reform will be needed.

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