ACTIVE DISTRIBUTION SYSTEM MANAGEMENT

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ABSTRACT

The paper highlights the need for an Active System Management (ASM) of distribution networks as a key tool for the efficient and secure integration of a high share of Distributed Energy Resources (DER). The paper provides technical and regulatory recommendations that mainly focus on distributed generation but are also largely applicable to flexible loads, electric vehicles and storage.

INTRODUCTION

With the EU on its way to meeting a 20% target for renewable energy sources (RES) in total energy consumption by 2020, the share of electricity supply from RES is on the rise. RES, including intermittent solar and wind, will be largely connected to distribution networks, mainly at medium and low voltage levels. Some European countries are already experiencing a high penetration of such distributed generation (DG), and in a number of regions, for example Galicia in Spain or Bavaria in Germany, the installed capacity of DG connected to the distribution networks exceeds the area's total peak demand.

KEY CHALLENGES OF INTEGRATING DISTRIBUTED GENERATION

In traditional distribution networks, the massive extension of DER connection, including DG such as intermittent RES, implies the need for increased back-up capacity from conventional generation as well as the construction of new and the reinforcement of existing network facilities. This is not necessarily socio-economically efficient.
DG is not always located close to load and DG production does not always coincide with demand (stochastic regime). Distribution networks have to be prepared to cope with all possible combinations of production and load situations. To this end, they are designed for the most extreme scenario, a peak load that often only occurs for a few hours per year (the so-called fit-and-forget approach). This approach is acceptable in case of low DG penetration: unidirectional and predictable flows require low monitoring and control, and allow for solving all possible constraints at the planning stage.
In the context of expanding DG, this approach might not be the most efficient one. Injections of power to higher voltage levels need to be considered where the local capacity exceeds local load does not coincide with it. This could lead to higher reinforcement costs and thus to a rise in CAPEX for DSOs or to higher connection costs for DG developers. The contribution of DG to the deferral of network investments thus holds true only for a certain amount and size of DG and for predictable and controllable primary energy sources.
DG is mostly connected on a firm/permanent network access basis. Connection studies and schemes for generators are designed to guarantee that under normal operation all capacity can be injected at any time of the year. The necessity of providing an unconditional firm connection may cause delays or increase costs for connecting embedded generation. Moreover, the increased complexity of extending and maintaining the grid may result in temporary limitations in connecting end customers.
In addition, operational problems like voltage variations and congestions already occur today, endangering security of supply and negatively affecting quality of service. This will occur more frequently in distribution networks with high DG penetration, depending on the different types of connected resources, their geographic location and the voltage level of the connection. Injection of active power leads to voltage profile modifications. Reversed power flows occur when DG production exceeds local load or they do not coincide. The more local production exceeds local demand, the stronger the impact. Additional system perturbations like harmonics or flickers can also occur more frequently due to the rise of power electronics connected to the network.
Alternatively, congestions in distribution networks may occur in cases when excessive DG feed-in pushes the system beyond its physical capacity limits ($P_G - P_L > P_{max}$). This may lead to necessary actions to interrupt/constrain generation feed-in or supply. A similar situation can occur in case of excessive demand on the system ($P_L - P_G > P_{max}$).

BUILDING BLOCKS OF ACTIVE SYSTEM MANAGEMENT

The continuous shift to decentralization implies that the 'fit and forget' approach alone is no longer cost-effective. The DSOs need adequate tools for being able to comply with its fundamental tasks of market facilitation, transparency and not discrimination, as well as maintaining security of supply and quality of service in their networks. Therefore, their role and their networks will need to evolve.

In addition to traditional network reinforcement, a move from network connection to optimal system integration requires an innovative approach from both networks and network customers. Network planning, access, connection and operation methodologies need to be revised and system services established at distribution level. Technical development of the grid is necessary to support these processes. Table 1 provides an overview of the different elements of active distribution system management.

Layer	Passive Distribution network	Active distribution system management
Network development (planning, connection & access)	Fit and forget approach: everything 'solved' at the planning stage	*Combined planning and operational solutions:* Active capacity and loss management through commercial interaction with market actors selling flexibility services
Network operation	Low monitoring & control of DG RES, often only by the TSO Missing rules & services for DG contribution to quality of service, security of supply & firmness	Connection and access criteria combined with operation tools to manage DER Flexibility support from DSO to TSO and from TSO to DSO when required New system services for DSOs arranged via commercial ancillary services and grid codes
Information exchange	Little information exchange from TSOs/DER to DSOs (small DER do not send information)	Structured and organised off-line and where needed real-time information exchange (standardised interfaces with DER required)
Technical development – Network	Limited monitoring & control capabilities (usually only HV) Conventional SCADA for HV network	Increased monitoring, simulation and control down to LV via telecommunications Advance Distribution Management Systems (ADMS) – integration of new SCADA and DMS/OMS
Technical development – DER	DG often not prepared for power factor control Storage & EV not developed	Configurable settings: e.g. protection / fault ride through settings, voltage droop Presence of storage & EVs

Table 1 From passive to active distribution networks

Coordinated Network Development & Connection

Traditionally, network operators perform an individual analysis and provide an individual solution for each connection. But with a high demand for DG connection the available network capacity is limited and this approach is not always optimal in terms of overall cost and network development.

DSOs should be able to undertake long-term planning of their grids to prevent bottlenecks in the most cost-effective way. To this end, all relevant actors (including network operators, investors and local authorities) should coordinate and be involved in the analysis of connection requests. The planning process should consider every connection request in order to make best use of the existing network.

In this process, coordination between TSOs and DSOs plays an important role. In some cases, the ability of one system operator to maintain its network performance will influence the other, e.g. connection of MV generation must take HV network saturation into account. Transmission or distribution network conditions which require regular (or conditional) information exchange should be defined, including a standard reciprocal forecast of the generation/load at the different voltage levels and the different network reinforcement needs. If the system is considered as a whole, most cost-efficient network investments in respective voltage levels would be determined in a cooperative manner, also contributing to minimization of total losses in the electrical system.

Congestion management & network capacity management

Operational issues conflicting with security of supply and quality of service may occur in both transmission and distribution networks. Therefore, DSOs as well as TSOs should have visibility of the planned actions of aggregators/independent power producers connected to their networks. Appropriate methodologies and processes should be defined in order to ensure that market schedules do not conflict with network operation. A comprehensive set of necessary actions including basic system states for distribution network operation, e.g. within security standards or grid codes, should be defined at distribution level for different time schedules in order to eliminate such violations. Figure 1 shows interactions between different actors at different stages for this purpose.

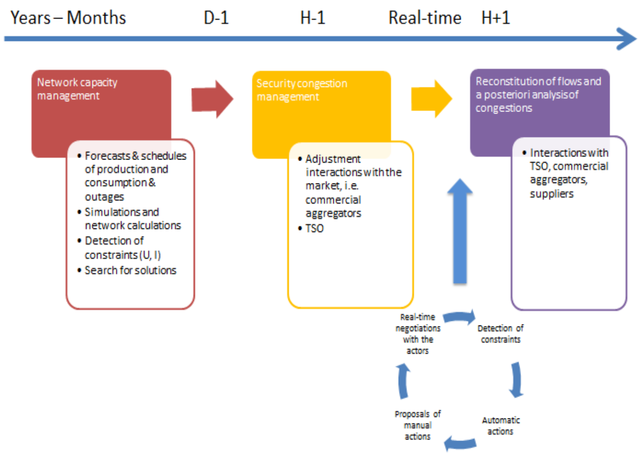

Figure 1 DSO interactions with markets & TSO

Network Capacity Management

To optimize network capacity it is necessary to consider DER already during network planning, including the use of voluntary commercial services from different DER, which could provide an alternative to network development wherever there is a positive business case (i.e.e. when production exceeds load demand by only a few hours a year).

Two different options should be further investigated: (1) firm DG production and load off-take management via tendering for commercial services and (2) variable network access contracts:

(1) Firmness describes the ability of generators to generate whenever distribution systems require. A service tendering mechanism incentivising DG to generate or consumption to

decrease during network peaks would enable more efficient use of existing distribution assets and deferral of grid reinforcement, as illustrated in Figure 2. Providing firm capacity would be rewarded as an extra service for the system.

(2) Alternatively, DG developers could be allowed to select between firm or variable network access contracts based on their own business plan. While firm contract allows for using physical connection to the grid 100% of the time, variable one would allow for network access most of the time but if network is constrained which would be specified under contractual agreement. Variable network access rights could be offered as a discounted connection contract for generation network users, with mechanisms for DG to reduce their output to a predefined limit in predefined infrequent network situations, expected only for a few hours per year.

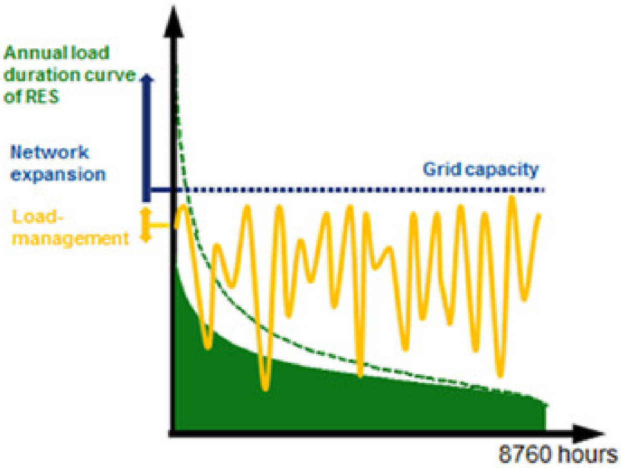

Figure 2 Extension of network capacity for peak load vs. a load management solution (Source: EWE Netz)

Security Congestion Management

Security congestion management could be used to solve the technical constraints at distribution level that arise close to real-time. Market-based mechanisms could be developed for this purpose: DG, flexible loads and possibly decentralized storage connected to distribution networks could (probably via aggregators/VPPs) provide ancillary services to DSOs, either through pre-agreed contracts or in real time at market prices. Newly established flexibility platforms could offer flexibility to DSOs and to TSOs who could use it to manage further balancing and redispatching issues in transmission grids. If the services for TSO purposes are provided by the distribution grid DSOs need real-time visibility to ensure that this activation does not impede quality of service. Last but not least, emergency tools including direct load management (load shedding) and emergency DG curtailment should be available to DSOs, and used only in well-defined emergency states/once the contracted options are exhausted.

Any action on distribution network users requested by the TSO should be agreed with the DSO as system operators. TSOs should not act on any individual DER embedded in MV or LV networks. Any direct order from the TSO to DER embedded in distribution networks targeted at safeguarding operation of the system should be executed by the DSO, not the TSO.

Voltage Control

Voltage control is a system service managed by network operators in order to maintain voltage in their networks within certain limits and to minimize reactive power flows and, consequently, technical losses.

In high voltage networks, DSOs (if they operate such networks) are able to maintain the voltage within the security standards by controlling the reactive power flows. Active power will not cause voltage deviation under normal operation. By contrast, in medium and low voltage levels, active power changes due to DG feed-in cause voltage rises (especially in cables) because of the different R/X ratio (the ratio between the resistance and the reactance of overhead lines or cables). Reactive power may help compensate the active power effect but may not be sufficient to neutralize it [2]. Taking into account the local behaviour of the voltage and the fact that it is not possible to transport reactive power over long distances, DSOs should have the opportunity to explore all local possibilities to managing voltage and choose the most efficient one. The solutions could come from network users (e.g. generators able to absorb reactive power), from network contribution (e.g. power electronics, OLTC for MV/LV transformers), or from a combination of both. Regulation should facilitate these innovative approaches to voltage control in distribution networks.

In cases where user participation is deemed the most cost-effective solution, generators should be required through network codes to comply with minimum connection and operational requirements necessary for managing distribution network stability. In contrast, DG contribution to losses minimisation may be compensated on a commercial basis.

Reduction of active power might sometimes be technically necessary to manage the network voltage and avoid complete generation disconnection, but should be used only when other solutions have been exhausted. Congestion management would apply in this case, with emergency DG curtailment only if necessary.

Last but not least, even though voltage control is a local phenomenon, it requires a system approach that considers both transmission and distribution networks. Coordination between the DSO and TSO at the interface point should follow the reactive power optimisation in order to minimise system investments and losses.

Technical & Information Exchange Needs

The abovementioned tools, including services from DER, will depend on DSOs' ability to actively monitor the grid. Today, DSOs have no systems installed for acquiring data from DG, in particular small-scale DG. In some cases, the TSO receives information from DG in real time while DSOs are not in the loop. There is usually no real-time exchange between the TSO and the DSO.

In a system with a high share of DER, monitoring, simulation, control strategies and advanced protection systems in MV and LV distribution networks will have to develop to enable DSOs to supervise and control power flows and voltage in their networks, to solve incidents rapidly and to unlock the ASM potential as described above. Relevant monitoring functionalities from smart meters in LV should be included in this evolution. However, the technology options outlined in Table 2 should not be considered in isolation from other options such as services from DER.

Function	Medium Voltage	Low Voltage
Monitoring	Current, voltage, fault passage indicators & other sensors	Centralization of information via secondary substations
Control	Remotely controllable reclosers, switches automated protection / fault sectionalisation – remote monitored fault detectors Voltage or power factor set points to DGs	Controllable MV/LV transformers[1] (with centralised or decentralised sensors)
Telcos	Radio, Carrier or GPRS	Radio, GPRS or PLC

Table 2 Technology options for LV and MV networks

In addition, a well-structured and organized information exchange between relevant actors will be necessary to operate the distribution network in real-time or close to real-time (see Fig. 3). DG forecasts, schedules and planned maintenances are key, due to their implications for operational planning. However, it may not be possible for aggregators to profile the forecast down to clusters of small aggregated customers on the same distribution networks as market activities will be at portfolio level. This issue needs to be further investigated, but implies enhanced monitoring and control strategies for distribution networks.

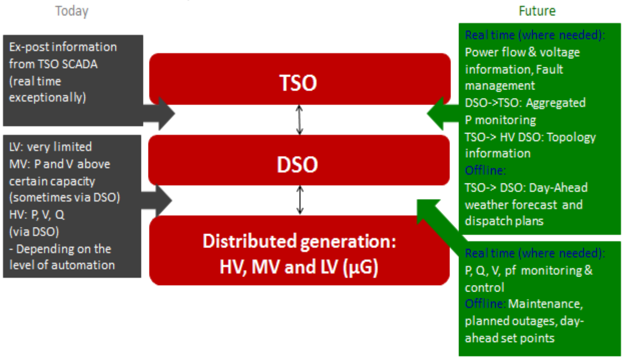

Figure 3 Information exchange evolution for an ASM

IMPLICATIONS FOR REGULATION & OPEN QUESTIONS

In general, a one-size-fits-all solution for distribution networks is difficult to find due to their heterogeneity in terms of grid equipment and DG density at different voltage levels. Every distribution network should be assessed individually as regards its network structure (e.g. customers and connected generators) and public infrastructures (e.g. load and population density). This analysis should provide the basis for a technically acceptable, cost-effective balance between network investments, including both conventional reinforcement and specific intelligent solutions (active resources), and integration of new commercial services from end network users.

Regulation and the flexibility market model should be further developed to address the following issues:

- **Methodologies for monitoring and calculating system states within a 'traffic lights scheme'** defining when the market should operate freely and when system services should be used. Physical boundaries of the individual systems (power and voltage) should be used by national regulation when setting these operation states.
- **Regulation for steering most cost-efficient solutions and innovation.** DSOs need to be provided with adequate remuneration for the most adequate solution: investment or active system management including procurement of services from network users.
- **New roles and relationships between different actors in the market and interaction between the DSO, the TSO and the market**. Aggregators will play the role of a possible middle-man for many small DG and load customers, by offering the options they buy from their clients to TSOs and DSOs. DSOs are in the best position to plan and manage the new opportunities and risks related to the grid: they should act as market facilitators for flexibility platforms where generators, suppliers and consumers can offer services either directly or via aggregators.
- **Establishment of system services for distribution system via ancillary services and grid codes** to be used for maintaining security of supply and quality of service when they are the most cost efficient solution.
- Revision of planning guidelines for distribution network development and establishment of contingency assessment and outage management (organization & coordination of outages) rules for distribution networks and their users.

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