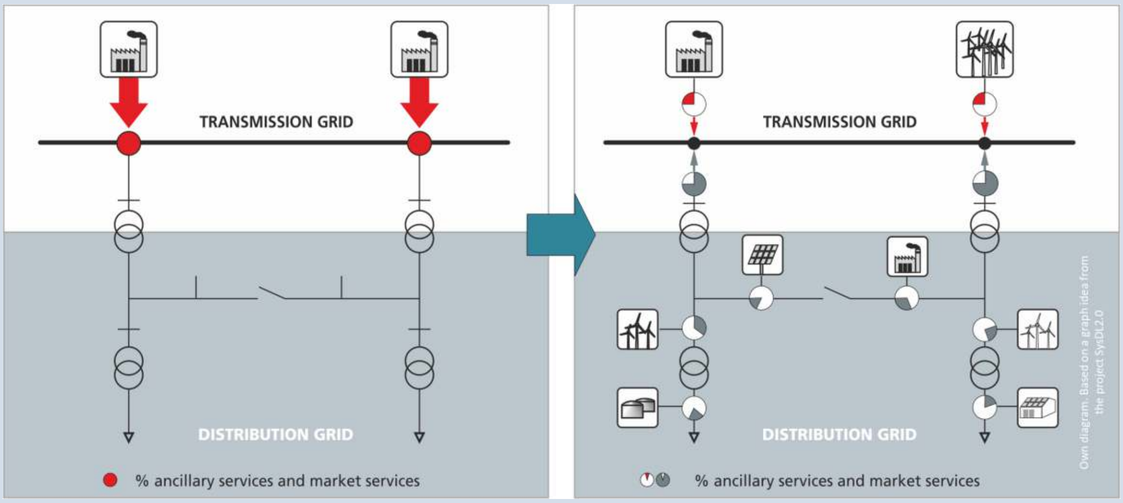
IEA INTERNATIONAL ENERGY AGENCY

International R&D Project Collection – Advanced Cooperation between Distribution and Transmission Network Operation

Summary Report of IEA PVPS Task 14 Activity 2.7 on DSO – TSO cooperation



PVPS

PHOTOVOLTAIC
POWER SYSTEMS
PROGRAMME

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IEA PVPS Task 14 Activity 2.7 Report

IEA PVPS Task 14, Subtask 2.7
Report IEA-PVPS T14-11:2018
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Foreword

The International Energy Agency (IEA), founded in November 1974, is an autonomous body within the framework of the Organization for Economic Co-operation and Development (OECD) that carries out a comprehensive programme of energy co-operation among its 29 members.

The IEA Photovoltaic Power Systems Programme (IEA-PVPS) is one of the collaborative R & D agreements established within the IEA and, since 1993, its participants have been conducting a variety of joint projects in the applications of photovoltaic conversion of solar energy into electricity.

The overall programme is headed by an Executive Committee composed of one representative from each participating country or organization, while the management of individual Tasks (research projects / activity areas) is the responsibility of Operating Agents. Information about the active and completed tasks can be found on the IEA-PVPS website www.iea-pvps.org

The main goal of Task 14 is to promote the use of grid-connected PV as an important source of energy in electric power systems. The active national experts from 15 institutions from around the world are collaborating with each other within Subtask 2 – High Penetration PV in Local Distribution Grids – in order to share the technical and economical experience, to increase the amount of distribution grid integrated PV. These efforts aim to reduce barriers for achieving high penetration levels of distributed renewable systems.

Management Summary

In a power supply system with an increasing share of distributed generation, there is a growing need for generators and demand response units at the distribution level to support the operation of the bulk power system by providing ancillary services and/or market flexibility. PV systems are mainly connected to the distribution level and hence coordinated operation and planning of the transmission and distribution level are of high relevance for electricity grids achieving high photovoltaic (PV) penetration scenarios.

This report is a collection of international R&D projects, with a focus on advanced TSO/DSO cooperation procedures. Therefore, 19 international R&D projects from the United States, Europe, and Japan have been identified and their objectives, key findings, and recommendations have been collected and summarized. The project fact sheets were provided directly by project members or through a detailed literature review. Furthermore, for the following five projects or concepts, detailed summaries are presented in the report:

- **Possible Future DSO Models:** Kristov and De Martini (USA) describe and discuss two main concepts for the future role of DSOs; the total DSO model and the minimal DSO model.
- **SmartNet:** SmartNet analyses five different coordination schemes between TSO and DSO and different architectures for the real-time ancillary services markets with reference to three countries: Italy, Denmark, and Spain.
- **SysDL 2.0:** SysDL2.0 analyses the coordinated provision of ancillary services from DSOs to TSO by means of controllable distributed generators and other controllable equipment (STATCOMs, OLTCs etc.). Case study and field test are performed for a transmission-distribution network in the eastern part of Germany.
- **Q-Study:** In the project Q-Study, new grid planning and new operational concepts for reactive power management at the TSO/DSO interface with the support of distributed generators are developed and analyzed. The case study deals with a Bavarian distribution grid section (Germany) with a very high PV penetration.
- **Next Generation SCADA:** In this TEPCO project (Japan) an integrated SCADA system for the transmission and distribution level is developed.

Scopes and trends in identified R&D projects

The challenges for an advanced TSO/DSO cooperation are multilateral and cover grid operation aspects, grid planning aspects, and the organizational and regulatory framework. Figure 1 gives an overview of the scope of the identified R&D projects. The TSO/DSO grid operation challenges[1], congestion management, balancing challenge and voltage support by distributed renewables are widely addressed in the identified R&D projects. Otherwise, TSO/DSO grid operation challenges on coordinated protection, grid restoration, and black start are only addressed by a few identified R&D projects.

Further important challenges for an advanced TSO/DSO cooperation are: The development of an appropriate market design and regulatory framework for the provision of bulk system services by DER; the further development of the ICT infrastructure; communication protocols for data and information exchange between TSO, DSO, DER and other relevant stakeholders (e.g. DER aggregator); enhanced co-operation in operational and long-term planning between TSOs and DSOs (i.e. integrated modelling of transmission and distribution level).

[1] A detailed description of different TSO/DSO cooperation challenges is provided in the ISGAN Annex 6, Task 5 Discussion Paper [10]

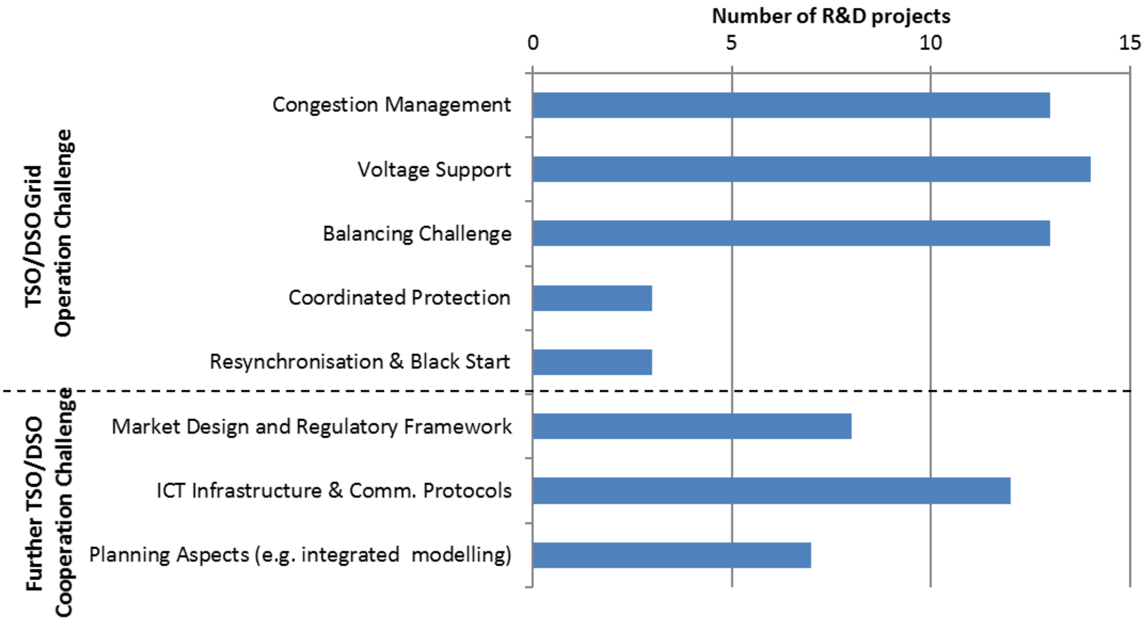


Figure 1: Scope of 19 identified R&D projects on advanced TSO/DSO cooperation (multiple scopes per R&D projects possible)

The following trends in TSO/DSO cooperation are identified in the investigated R&D projects:

- New coordination schemes between TSO and DSO are developed, analyzed and discussed in several R&D projects. The optimal TSO/DSO coordination scheme may differ in different areas depending on regulatory structures, DER penetration and growth, overarching policy objectives and other factors. Nevertheless, the most promising schemes consider an **increased responsibility and a crucial role of DSOs,** for the coordination and provision of ancillary system services by DER.
- The demand for ancillary system services can vary strongly by time and grid location. In order to satisfy these location-dependent needs, **regional markets for ancillary services** are developed in several R&D projects. The developed regional markets can cover services for congestion management, balancing challenge and/or voltage support (e.g. reactive power market).
- Further **standardization and automation of communication between TSO and DSO** is the subject matter of several R&D projects. A widely applied standard for data exchange in European R&D projects is the Common Information Model (CIM) and the Common Grid Model Exchange Specifications (CGMES). In European projects, a strong focus is set on the standardization of communication interfaces between different stakeholders and their management systems. In a Japanese case study, also an integrated SCADA system for the transmission and distribution level is developed, where it is possible to set flexible authority for persons in charge of multiple internal organizations, including future task sharing.
- A key enabler for advanced TSO/DSO cooperation is **advanced automation within the distribution level**[2]. In the investigated R&D projects, especially the improvement of the situational awareness (functionalities: DER & load forecasting, state estimation, and advanced monitoring) as well as system controllability at the distribution level (functionalities: active and reactive power scheduling/dispatch of DER) are addressed in most identified R&D projects. Functionalities (fault location, grid restoration, contingency analysis) concerning reliability and protection are only addressed by a few investigated R&D projects.

[2] A comprehensive overview of advanced distribution automation functions for emerging TSO/DSO functionality is provided by the *CIGRE/CIRED C6.25/B5 Joint Working Group (JWG)* in [11]

- In power systems with a high penetration of DER also a stronger **coordination of operational planning and long-term planning between TSOs and DSOs** is required. One challenge is the development of appropriate grid equivalents for integrated system studies of the transmission and distribution level, for example for stability analysis. Furthermore, joint planning procedures are also required to assess the flexibility potential of DER for bulk system support (e.g. available reactive power flexibility at transmission – distribution interfaces).

An overview of the addressed TSO/DSO cooperation challenges in the identified R&D projects is given in Table 1.

Table 1: Overview – Main TSO/DSO cooperation challenges of R&D projects

Project	Region	Project status	TSO/DSO Grid Operation Challenge: Congestion Management	TSO/DSO Grid Operation Challenge: Voltage Support	TSO/DSO Grid Operation Challenge: Balancing Challenge	TSO/DSO Grid Operation Challenge: Coordinated Protection	TSO/DSO Grid Operation Challenge: Resynchronisation & Black Start	Further TSO/DSO Cooperation Challenge: Market Design and Regulatory Framew.	Further TSO/DSO Cooperation Challenge: ICT Infrastructure & Comm. Protocols	Further TSO/DSO Cooperation Challenge: Planning Aspects (e.g. integrated modelling)
Modelling of DER in Transmission Planning Studies	USA	●		■	■					■
IDE4L*	EU	●	░		░	░	░		░	
evolvDSO*	EU	●	░	░	░			░		░
SysDL 2.0	GER	●	■	■					■	
Q Study	GER	●		■						■
NETZ:KRAFT	GER	◕			■		■			
VOLATILE	SWE, DK	◕		■				■		
PV Regel	GER	◕			■		■	■	■	
PVTP - A live PV testing platform	DK	◕		■	■				■	
SmartNet	EU	◕	■	■	■			■	■	
Next-Generation SCADA	JPN	◕	■	■	Future Appl.	■			■	■
CALLIA*	EU	◑	░		░			░	░	
Real-time optimization and control of next-generation distribution	USA	◑	■	■	■				■	■
TDI 2.0*	UK	◑	░	░					░	
FutureFlow*	EU	◑	░		░			░	░	
TDX-ASSIST	EU	◔	■	■	■	■			■	■
INTERPLAN	EU	◔	■	■	■					■
New 4.0 (Work package 1)	GER	◔	■	■				■		
EU-SysFlex	EU	◔	■	■	■			■	■	

Legend pojekt status 05/2018:

- Initial phase ◔
- Middle phase ◑
- Final phase ◕
- Completed ●

Legend main project scope:

- ░ *based on literature review
- ■ based on fact sheets project members

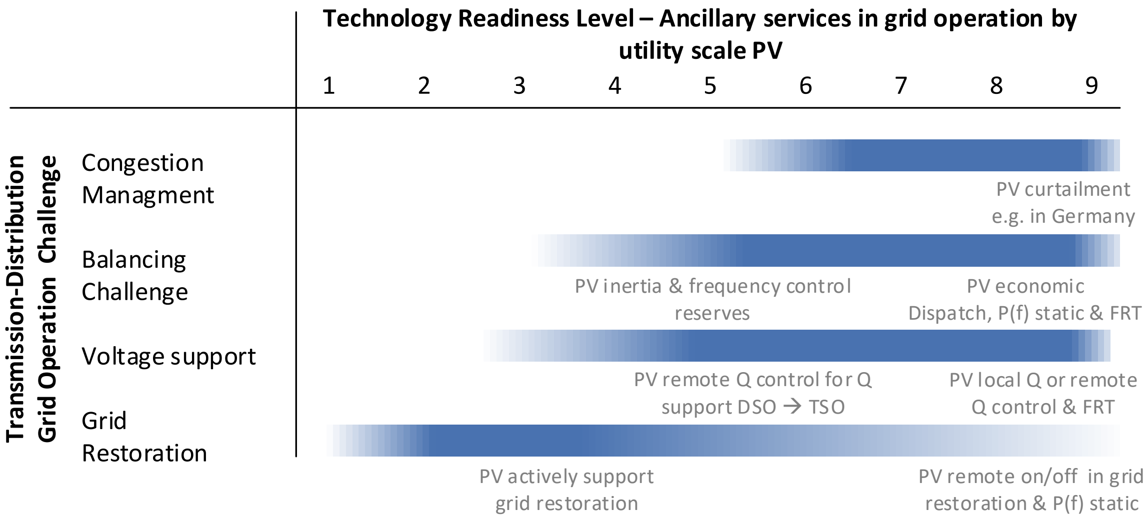
Technology Readiness Level – Provision of ancillary service by PV
Based on the input from the investigated R&D projects and on discussions within the IEA PVPS Task 14 experts, an initial evaluation of the technology readiness of bulk system support by PV is determined. In most cases, the technology readiness for bulk system support does increase with the system size and the voltage level of PV interconnection. Therefore, a separate assessment of the technology readiness is performed in Figure 2 for utility PV (installed capacity > 2 MW, HV or MV interconnection) and in Figure 3 for residential PV (installed capacity ≤ 10 kW, LV interconnection). The technology readiness of commercial PV systems (10 kW < installed capacity ≤ 2 MW, MV or LV interconnection) is usually ranked between these.

A high technology readiness for utility, commercial and also residential PV is usually determined for autonomous control characteristics, such as watt-frequency characteristic P(f), fault ride-through requirements (FRT) and local reactive power characteristics (e.g. Q(V) control). These characteristics are defined in grid codes and are already applied in practice in several countries. For example, a watt-frequency characteristic can provide support for the balancing challenge and the grid restoration process. Nevertheless, R&D demand is still required to fully understand and optimize the impact of these functions on the bulk power system.

For state of the art **utility-scale PV** systems, remote control of active and reactive power output and a remote on/off function is usually available. PV curtailment for congestion management in transmission or distribution level is already applied in practice in several countries (e.g. Germany). Also, economic dispatch of utility-scale PV may already apply in practice, in case the energy market and the regulatory framework provide suitable incentives here. Furthermore, grid operators usually have a direct communication link with the switching field of utility PV parks, which can be used for a remote connect/disconnect within a grid restoration process. Nevertheless, R&D demand for these services is still required to optimize organizational and technical processes.

The provision of frequency control reserves (primary, secondary and tertiary control reserve for balancing challenge) by PV systems is adressed within several R&D projects, besides technical challenges, especially regulatory adjustments are still required to enable a participation of PV systems in these reserve markets. The reactive power support at the transmission-distribution interface by DER is especially adressed in European R&D projects (voltage support DSO → TSO). In field test applications, distributed generators like utility-scale PV plants are used to actively control the reactive power exchange at the transmission-distribution interface.

A rather low technology readiness level (TRL: 2 to 4) is determined for active support of utility PV within a grid restoration process, for example by balancing load variations or generation variations of non-dispatchable DER. Here it should be highlighted, that the focus of this report is set on power systems with a strong synchronous interconnection (e.g. continental European power systems); for island grid and micro grid applications, the technology readiness of PV may be more advanced. Also, a combination of PV with storage systems can further increase the technology readiness and can enable a wide-ranging provision of system services. This aspect is not discussed in detail in this report.



Legend Technology Readiness Levels (TRL)*:

- TRL 1: basic principles observed
- TRL 2: technology concept formulated
- TRL 3: experimental proof of concept
- TRL 4: technology validated in lab
- TRL 5: technology validated in relevant enviroment
- TRL 6: technology demonstrated in relevant environment
- TRL 7: system prototype demonstration in operational environment
- TRL 8: system complete and qualified
- TRL 9: actual system proven in operational environment

*Source Technology Readiness Level definition: https://ec.europa.eu/research/participants/data/ref/h2020/wp/2014_2015/annexes/h2020-wp1415-annex-g-trl_en.pdf

Figure 2: Technology readiness level - provision of ancillary services by utility-scale PV plants (installed capacity > 2 MW)

For **residential PV systems**, a communication infrastructure for remote active and reactive power control by the grid operator is usually not available. Furthermore, a challenge for the provision of bulk system services by residential PV is the very large number of PV units and the usually very low observability in the LV level. Therefore, especially (but not exclusive) for residential PV, a key enabler for bulk system support is the development of advanced distribution automation, including advanced observability and controllability at the distribution level as well as the application of appropriate aggregation measures (e.g. via Virtual Power Plants VPP and/or Distributed Energy Resources Management Systems DERMS[3]).

Overall, the technology readiness level of ancillary services by residential PV covers the full range. A low to medium technology readiness level (TRL: 1 to 6) is determined for services, which require an advanced communication infrastructure within the distribution level (e.g. remote Q control and economic dispatch). An exception here is radio ripple control, which is partly also applied for small PV units (installed capacity < 30 kW) in Germany. This unidirectional communication infrastructure can be used as a contingency measure in congestion procedures.

As described in the previous section, a rather high technology readiness level for residential PV is determined for local control characteristics, such as watt-frequency characteristics P(f), fault ride-through requirements (FRT) and local reactive power characteristics. However, a significant R&D demand still remains in order to further optimize and understand the impact of these characteristics on the bulk power system.

[3] In this context, highly location-dependent services are referred to DERMS (e.g. congestion management, voltage support) and non highly-location dependent services are referred to VPP (e.g. frequency control reserves).

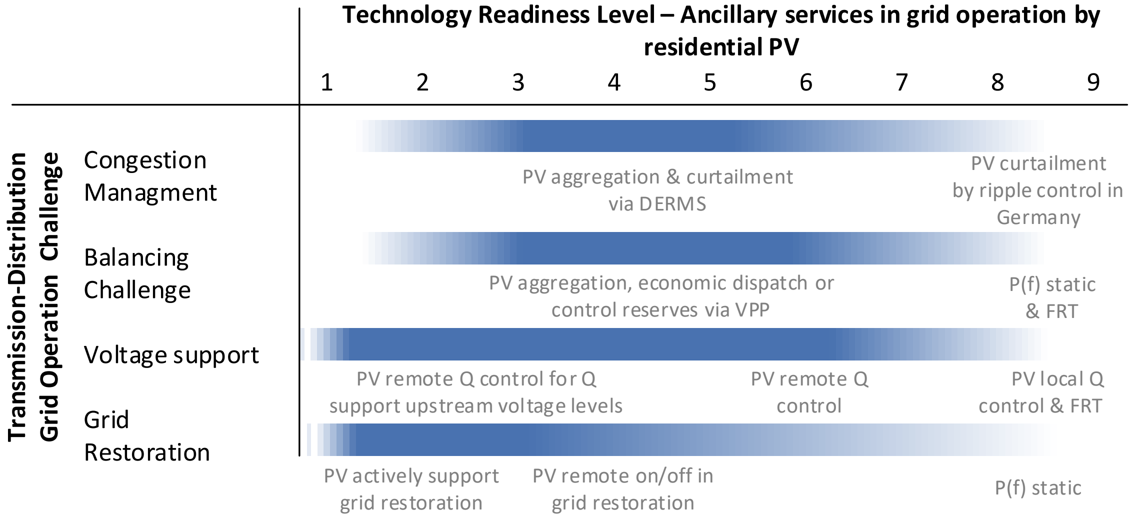


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Figure 3: Technology readiness level - provision of ancillary services by residential PV (installed capacity ≤ 10 kW)

Summary

The report provides an overview of objectives, best-practice examples and key findings of international R&D projects in the field of TSO/DSO cooperation. Nevertheless, it should be highlighted, that the provided project overview does not intend to be exhaustive or complete. In detail, the status and development of TSO/DSO cooperation depends on many impact factors, for example on the addressed grid operation challenges, the applied communication technologies and standards, the addressed voltage levels and DER types (e.g. residential, commercial, utility-scale PV), and especially the national/ regional regulatory framework and requirements and overarching policy objectives. Overall, a major part of the identified R&D projects is ongoing and a significant research and development demand is identified for advanced TSO/DSO cooperation.

Outlook

This report focuses on electric power systems with a relatively strong synchronous interconnection (such as the continental European interconnection, or the Eastern, Western and ERCOT interconnection in the USA). In the upcoming phase 3 of the IEA PVPS Task 14 “High Penetration PV Systems in Electricity Grids”, an expansion of scope on island grids and power systems with a weak interconnection to a wide area grid is planned. Furthermore, with the scope of IEA PVPS Task 14 phase 3 on “Solar PV in a 100% RES Power System” extensive and multilateral bulk system support by RES and/or distribution units are essential. Therefore, a more integrated perspective on transmission and distribution grid planning and operation is planned.

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Contents

Abbreviations and Acronyms

ADA	Advanced Distribution Automation
aFRR	automatic Frequency Restoration Reserve
ANM	Active Network Management
AS	Ancillary Services
BRP	Balance Responsible Party
CEER	Council of European Energy Regulators
CMP	Commercial Market Party
CIM	Common Information Model
CGMS	Content Generation Management System
CGMES	Common Grid Model Exchange Standard
DCC	Demand Connection Code
DER	Distributed Energy Resources
DERMS	Distributed Energy Resources Management Systems
DG	Distribution Generation
DLMS	Device Language Message System
DMS	Distribution Management System
DSO	Distribution System Operator
EDSO	European Distribution System Operators for Smart Grids
ENTSO-E	European Network of Transmission System Operators for Electricity
ESB	Enterprise Service Bus
FIT	Feed-in Tariff
FLISR	Fault Location Isolation and Supply Restoration
HV	High Voltage
HVDC	High Voltage Direct Current
ICT	Information Communication Technology
ICCP	Inter-Control Centre Communications Protocol
ICPF	Interval Constrained Power Flow
IEA	International Energy Agency
IEC	International Electrotechnical Commission
IED	Intelligent Electric Device
IoT	Internet of Things
IP	Internet Protocol
ISGAN	International Smart Grid Action Network
ISO	Independent System Operator
IT	Information Technology
LMP	Locational Marginal Pricing
LV	Low Voltage
MINLP	Mixed Nonlinear Programming
MV	Middle Voltage
NCP	Network Connection Point
NFV	Network Function Virtualisation
OLTC	On-Load Tap Changer
OPF	Optimal Power Flow
PCC	Point of Common Coupling
PMU	Phasor Measurement Units

PLC	Power Line Communication
PV	Photovoltaic
RA	Reserve Allocator
RES	Renewable Energy Sources
RSE	Remote Systems Explorer
RTO	Recover Time Objectives
RTU	Remote Terminal Unit
SAU	Substation Automation Unit
SCADA	Supervisory Control and Data Acquisition
SDN	Software-defined Networking
SGAM	Smart Grid Architecture Model
SOPF	Sequential Optimal Power Flow
STATCOM	Static Synchronous Compensator
TCL	Tool Command Language
TCP	Transmission Control Protocol
T-D Interface	Transmission-Distribution Interface
TSO	Transmission System Operator
UDP	User Datagram Protocol
VPP	Virtual Power Plant

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1. Introduction

1.1. Motivation

"It is essential to take advantage of the opportunity to harness the valuable and increasing amount of resources at the distribution level (solar panels, wind power, DSR, storage, etc.) for providing services for the overall benefit of the power system." European Network of Transmission Systems Operators for Electricity (ENTSO-E) [1]

The relevance of TSO/DSO coordination is gaining importance for utilities, R&D facilities, and regulatory authorities. A major driving force is here the fast increase of renewable energy sources and hence the increase of distributed generation in many countries. Especially photovoltaic (PV) systems are usually categorized as distributed generators (DG), which are mainly connected to the distribution level. Figure 4 gives an overview of installed PV capacity at the distribution and transmission levels for different countries. For most of the selected countries, more than 90% of installed PV capacity is connected to the distribution level. A high share of PV installations is here especially determined for residential and commercial rooftop-PV systems at the MV and LV level. An exception is the Chinese power system with a high share of ground-mounted utility-scale PV systems connected to the transmission level.

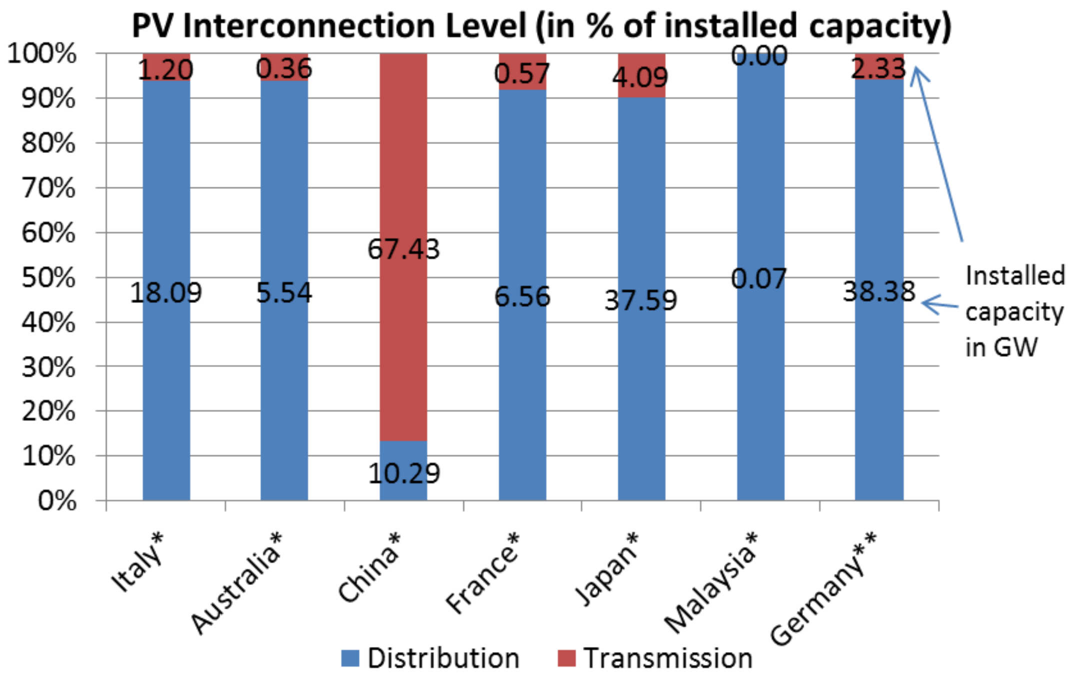

Figure 4: Installed PV capacity in the distribution and transmission level for selected countries. Source: * National Survey Reports 2016 IEA PVPS [2]-[7], ** Bundesnetzagentur, Germany [8])[4]

In a power supply system with an increasing share of distributed generation, there is a growing need for generators (e.g. PV) and also demand response units (e.g. storage systems, heat-pumps) in the distribution grid to take over some responsibilities typically attributed to the bulk power system,

[4] The definition of transmission and distribution level and the related voltage levels can differ for the different countries. For example, in Germany the HV-level (usually 110 kV) is also considered as part of the inter-regional distribution grid. However, in many other countries the HV-level is considered as part of the sub-transmission or transmission level. For simplicity, the PV interconnection at the LV and MV level are considered as part of the distribution level and HV and EHV interconnections are considered as part of the transmission level.

including ancillary services or market flexibility. Figure 5 shows how the provision of ancillary services and market flexibility might change in a power system with an increasing share of distributed generation. However, closer interaction between TSO, DSO and other relevant stakeholders is relevant to access the large flexibility potential of the distribution units.

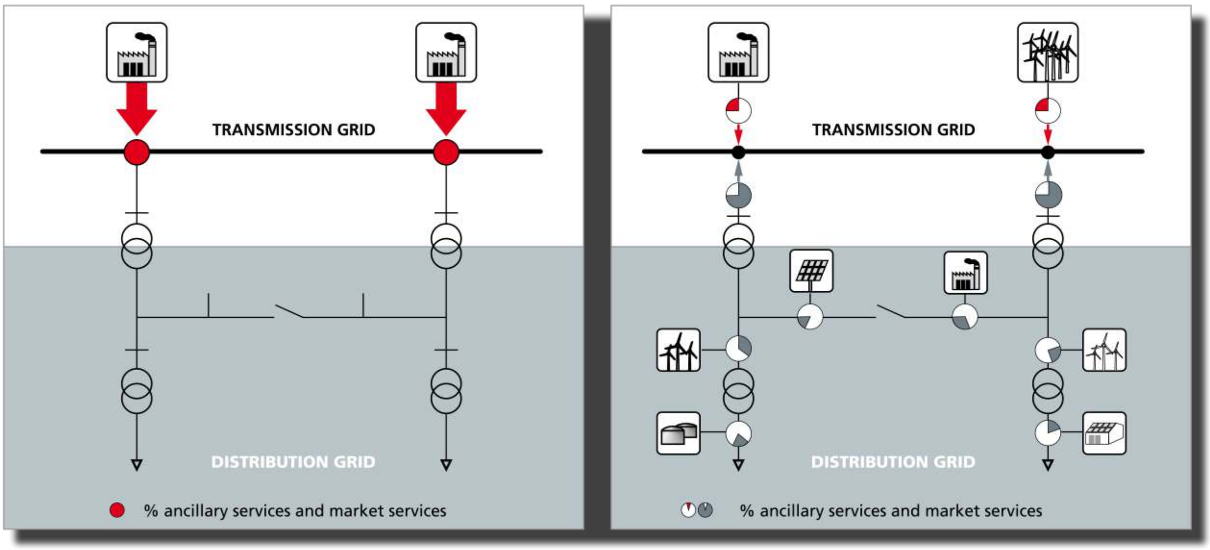

Figure 5: Provision of ancillary services for the bulk power system in the past (left) and for future smart grid applications (right) (source: own diagram, based on a graph idea from the Project SysDL2.0)

As a practical example, Figure 6 shows the curtailed energy of renewable energy sources (RES) over the past years according to the German Renewable Energy Source Act (EEG) §14. This paragraph allows the grid operator RES curtailment for congestion management. Nevertheless, several grid measures and market-related measures (e.g. grid reconfigurations, economic dispatch) have to be given priority by the grid operators, if reasonable. Figure 6 shows a significant increase of the curtailed RES energy in 2015 and 2016 compared to the previous years, which indicate an increase in tense grid situations and interventions by the grid operators. Drivers for this development are especially the ongoing increase in RES capacity and not yet completed grid optimization, reinforcement and expansion in the German power system [9]. Especially of interest is that 82% of RES energy curtailment in 2015 and 85% in 2016 was caused by congestions in the transmission level, but was resolved by RES curtailment in the distribution level. Therefore, TSO/DSO cooperation has already achieved a high practical relevance for the safe and secure operation of the German power system.

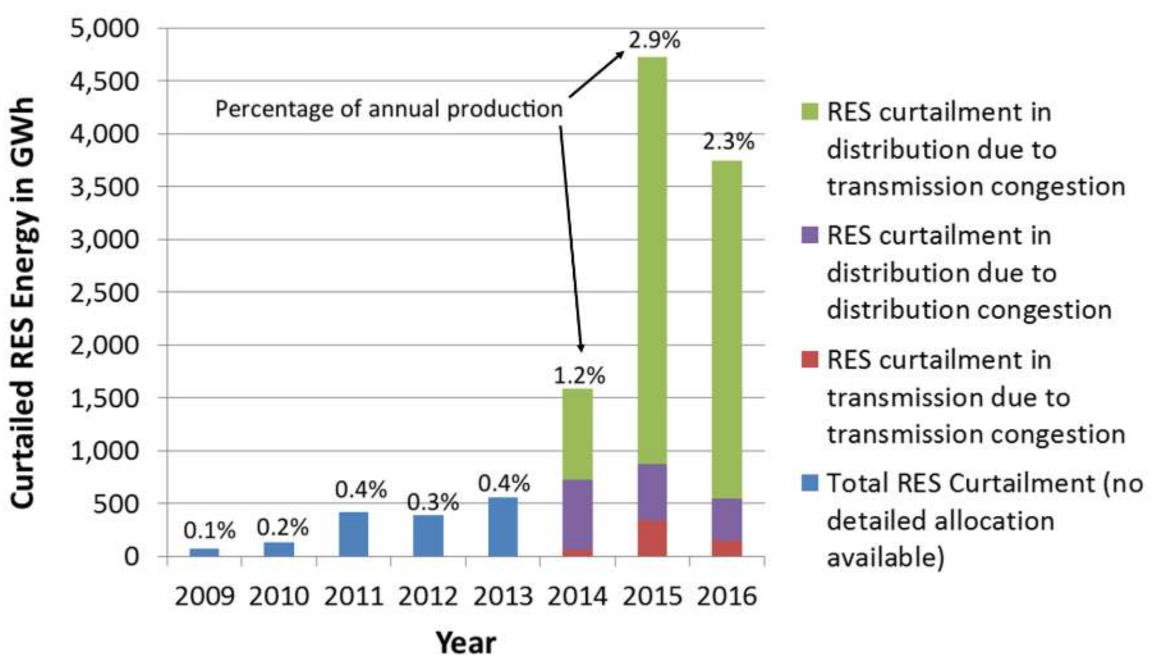

Figure 6: Curtailed RES energy in Germany (according to §14 EEG) (own diagram, data source: Bundesnetzagentur [8])

The characteristics of the electrical power system, the definition of stakeholder roles and responsibilities, the wording of grid and market services, and the state-of-the-art and the objectives of TSO/DSO cooperation can differ by different countries and/or regions. However, sharing the experiences, best-practice examples and lessons learned from different projects and different countries or regions can positively contribute to the further development of the TSO/DSO cooperation and can improve the integration of high shares of distributed generation (especially PV) into the electrical supply system.

1.2. TSO/DSO Grid Operation Challenges

An overview of the TSO and DSO cooperation in different countries is given by the IEA ISGAN (Annex 6) discussion paper [10]. In the ISGAN paper [10] the following TSO/DSO grid operation challenges are identified:

- **Congestion of transmission-distribution interface and congestion of transmission lines (Line congestion):** The transformer at the TSO/DSO interface can be operated by the TSO or the DSO. In case the transformer is operated by the TSO, the DSO has to cooperate in order to avoid critical transformer loadings. Furthermore, transmission lines may become critically loaded due to high consumption or generation within the distribution level and/ or by high power transfer within in the transmission level. Congestion management at the distribution level can avoid critical loadings.

- **Balancing challenge:** *"Instantaneous generation and consumption have to be in balance at all times. Increased penetration of fluctuating decentralized generation results in increased errors in the production forecast and therefore makes it more challenging to balance the grid. For this reason, it is expected that necessary balancing power actions will increase significantly in the coming years. The TSO could, via the DSO, use flexibility on the distribution grid to reduce imbalances* [10]". This TSO/DSO grid operation challenge involves for example economic dispatch and frequency control and response of distributed generators.

- **Voltage support (TSO/DSO):** The objective of voltage regulation is to keep the voltage magnitude in the power supply grid within the specified limits. Further cooperation between TSO and DSO can here improve the voltage regulation in the distribution and transmission levels. Examples for TSO/DSO cooperation in voltage support are given in [10] & [SysDL2.0]:
  - Use of capacitor banks in the distribution level to support the TSOs grid voltage,
  - Reactive power provision from DG to support the TSOs grid voltage,
  - Coordination of the TSO/DSO transformer tap setting, and
  - Coordination of the permissible voltage bandwidth at TSO/DSO interface.

- **(Anti-) Islanding, re-synchronization & black-start:** During an intentional islanding (Micro-Grids), re-synchronization or a black-start process of a grid section, the distributed generators should not disturb or even support the grid operation. Furthermore, unintentional islanding of distribution grid sections should be avoided. Therefore, an advanced cooperation of involved grid operators may be beneficial.

- **Coordinated protection**: Transmission faults can cause unintended alarms or protection tripping at the distribution level and vice versa for distribution faults. Furthermore, fault current calculation can become more and more challenging in a power system with a highly distributed generation. For example, transmission faults may be fed from multiple directions (including downstream distribution grid sections), and also the fault current level can vary for different DG penetration scenarios and different switching states at the distribution level. Advanced TSO/DSO cooperation can, therefore, improve the protection coordination and system reliability.

An overview of the state of the art and future developments for the TSO/DSO cooperation is given in the ISGAN discussion paper [10].

Table 2: Summary of state-of-the-art TSO-DSO operation challenges (source: [10])

Congestion of transmission-distribution interface (TFO congestion)	• Avoided in many countries by considering n-1 criteria in the network planning • Cooperation mostly during the planning phase • Emergency situations: TSO disconnects distribution feeders, possibly through a request to the DSO
Congestion of transmission lines (Line congestion)	• Mostly avoided by considering n-1 criteria in the network planning phase • In some cases the TSO is responsible for the control of demand and generation at both the transmission and distribution level. • Generally, curtailing of loads on the distribution grid is applied in case of critical transmission line loading. Sometimes this is performed manually, sometimes automated.
Balancing challenge	• Generally, the DSO is not involved in grid balancing. • Sometimes, distribution customers take part in the balancing process. Possibly, but not necessarily, the DSO is involved, for example in the prequalification.
Voltage support (TSO/DSO)	• Most often, the TSO supports the DSO grid voltage only by means of the tap changer on the TSO-DSO transformer. • The distribution grid capacitor banks are possibly used to support the transmission voltage. • There are examples of distributed generation being used to support the voltage, as they are required to operate at a fixed power factor.
(Anti-) Islanding, re-synchronization & black-start	• Islanding situations are prohibited and avoided by using appropriate protection settings, mainly for safety reasons. • Distributed generation is disconnected from the grid when islanding occurs. • Liability in the case of islanded operation is an issue to be discussed. • Black-start procedures, even today, demand close cooperation of the TSO and DSO. Procedures on grid restoration are set up in close cooperation.
Coordinated protection	• Coordination of protection is limited to interaction on protection settings, assuring selectivity in case of failure.

1.3. Advanced Functionalities for Network Automation and TSO/DSO Coordination

A key enabler for advanced TSO/DSO cooperation is **advanced automation within the distribution level**. The CIGRE/CIRED C6.25/B5 Joint Working Group (JWG) provides here a comprehensive overview of advanced distribution automation functions for emerging TSO/DSO functionalities (source: [11]):

- Situational awareness:
  - DER Forecasting
  - Load Forecasting
  - Advanced Monitoring
  - Distribution System State Estimation
  - Topology Recognition
- System adjustment:
  - Active Power Dispatch/Scheduling
  - Reactive Power Dispatch/Scheduling
  - Volt/Var Optimization
- Protection and Reliability:
  - Automatic Reconfiguration
  - Contingency Analysis
  - Fault Location
  - Fault Isolation and System Restoration

1.4. Organizational Challenges TSO/DSO Cooperation

The previous sections focus on technical challenges in the field of TSO/DSO cooperation. Furthermore, several organizational and regulatory challenges need to be addressed for advanced TSO/DSO coordination. Advanced market designs and TSO/DSO coordination schemes need to be developed, to access the full flexibility and additional ancillary services of DER units for the bulk power system. In detail, several stakeholders are involved in the TSO/DSO/DER coordination and roles and responsibilities need to be specified and regulatory frameworks need to evolve. In this subchapter an overview of possible future DSO Models are presented by Kristov and De Martini.

Possible Future DSO Models

Authors: Lorenzo Kristov & Paul De Martini

The complex challenges of TSO-DSO coordination will ultimately require clear specification of the roles and responsibilities of TSOs and DSOs for a high-DER electric system. At present however, there is no one specification that is recognized as optimal, and indeed, what is optimal may differ in different areas depending on existing industry and regulatory structures, rates of DER growth, overarching policy objectives and other factors. Fortunately the physics of power systems does not vary with such factors, and so it is possible to identify essential functional capabilities that will be required, and then consider different ways to assign those functions to DSOs, TSOs and possibly other entities. De Martini and Kristov apply this strategy and use the lens of grid architecture to define and contrast two conceptually different models they call the Minimal DSO and the Total DSO (see: [12] and [13]).

Clearly there would be numerous design variations and implementation details with each of the two models. But the comparison comes down to one central distinction: Does the DSO limit its role to the traditional function of providing no more than a reliable wires service (Minimal DSO), or does it take on major system and market operations functions for the local distribution area at each T-D interface (Total DSO)? Restating in grid architecture terms: Are all the DERs in the future high-DER electric system centrally controlled and optimized by the TSO and wholesale market operator[5] (Minimal DSO)?

[5] In Europe the TSO is typically a separate entity from the wholesale market operator or power exchange, whereas in the US the independent system operators (ISOs) and regional transmission organizations (RTOs) are both system and market operators. The two DSO models discussed here are applicable to either context. To keep

Or, do the markets and operational controls reflect a layered architecture, with the DSO providing, at distribution level, the dispatch optimization and real-time balancing performed by the TSO at transmission level (Total DSO)?

Figure 7 illustrates the Minimal DSO model:

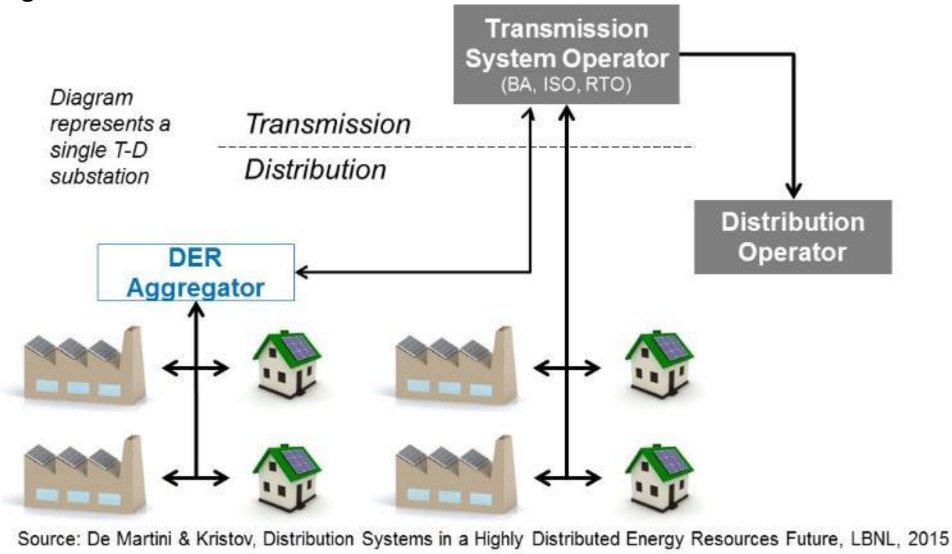

Figure 7: Minimal DSO Model

Figure 8 illustrates the Total DSO model:

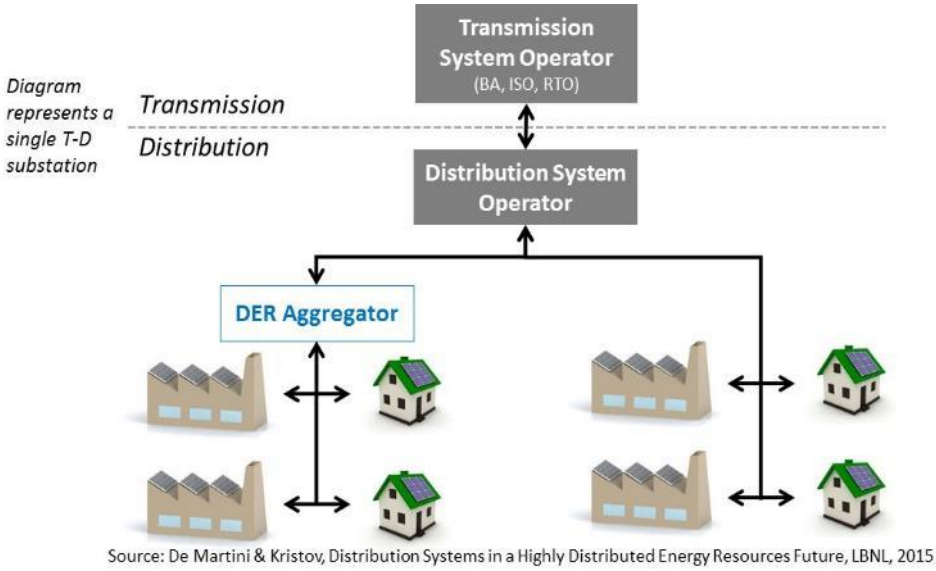

Figure 8: Total DSO Model

Some key observations. First, in its software systems a TSO does not model distribution circuits and the actual physical locations of DERs. Rather, it models all DERs as if they were located at their associated T-D interface substation.[6] With the Minimal DSO, the TSO will issue dispatches directly to DER operators with no visibility to the impacts of the dispatches on the distribution system, adding uncertainty for both DSO and TSO operations that grows in severity with the volume of DERs. In the Total DSO model, in contrast, the TSO will see a single composite or virtual resource at each T-D interface and will issue dispatches to the DSO, who then determines how best to respond to each

notation simple for this section, the term TSO is used broadly to include ISOs and RTOs in the US, and to encompass both the market and the system balancing functions in the European structure.

[6] The T-D substation is also a pricing node in those ISO/RTO markets based on locational marginal pricing (LMP).

dispatch given the DERs available and the current distribution system conditions. The Total DSO performing this function eliminates the operational challenges created by the TSO directly dispatching multiple DERs at each T-D interface.

Second, the Total DSO coordination model just described is easily scalable with the layered architecture. Just as the TSO can simplify its dispatch function and visibility needs by limiting its focus to the interchange at the T-D interface, the DSO can have a comparable relationship with a microgrid located within its distribution system. The microgrid operator can offer grid services to the DSO and respond to operating instructions from the DSO without the DSO having control of or visibility to any of DERs and/or subsystems located within the microgrid.[7] One consequence of this scalability is increased system security and resilience due to the ability to switch to island operation at any level of the hierarchy, i.e., by the DSO at the T-D interface, or by the microgrid at the DSO-microgrid interface. The Minimal DSO model, in contrast, does not afford such scalability, mainly because transactions between DERs and the TSO bypass the physical electric distribution system on which those transactions must flow.

Third, with the proliferation of DERs owned and operated by diverse third parties – including end-use customers with behind-the-meter generating and storage assets, developers of distributed generation and storage on the distribution system, and aggregators of DERs – the DSO and its regulator will need to develop operating procedures, interconnection rules and market mechanisms that enable DERs to maximize their commercial value and their value to the electric system in a non-discriminatory fashion. These modernization elements for high DER will be needed under either of the two DSO models or their variants.

The following table provides additional features for comparing the Minimal DSO and the Total DSO.

Table 3: Comparison of Minimal and Total DSO Model

Design Element	Minimal DSO	Total DSO
Market structure	Central market optimization by TSO with large numbers of participating DER	DSO optimizes local markets at each T-D substation; bulk power market sees a single virtual resource at each T-D interface
Distribution-level energy prices	Locational energy prices based on LMP + distribution component (e.g., LMP+D)	Based on value of local DER services, using wholesale LMP only for imports/exports
Resource/capacity adequacy	As today, based on system coincident peak plus load pocket & flexibility needs; opt-out allowed for micro-grids	Layered RA framework: DSO responsible for each T-D interface area; TSO responsible to meet net interchange at each interface
Grid reliability paradigm	Similar to today	Layered responsibilities; e.g., DSO takes load-based share of primary frequency response
Multiple-use applications of DER (MUA)	DER subject to both TSO and DSO instructions Rules must resolve dispatch priority, multiple payment, telemetry/metering	DER subject only to DSO instructions, as DSO manages DER response to TSO dispatches & ancillary services provision
Regulatory framework (US)	Federal-state jurisdictional roles similar to today	Explore framework to enable states to regulate distribution-level markets
Comparison to existing model	Current distribution utility roles & responsibilities, enhanced for high DER	Total DSO is similar to a neighboring balancing authority or TSO

At first glance the Minimal DSO seems like the natural evolution of today's system structure. As the volume of diverse DERs grows over time, more DERs participate in the wholesale market, the TSO

[7] The scalability attribute means that microgrids can be nested within larger microgrids. A microgrid could involve orchestrating DERs a within single building, or multiple DERs and smart buildings across a campus, or a multi-user microgrid structure linking DERs, smart buildings and hundreds of diverse end-users across a local distribution system area.

develops systems to directly control participating DERs and requires DER providers to install sensors and communication links as part of grid codes. The DSO in this model keeps to its traditional mission of providing reliable distribution services. Under this model the energy market remains a centralized transmission-level construct while distribution is purely a transport medium, albeit modernized for high DER penetration. This model doesn't scale, however, because it violates basic system control principles that will lead to significant operational problems for both TSOs and DSOs.

Kristov and De Martini argue that the Total DSO employing a layered control architecture, in contrast, will be more readily scalable, more secure and ultimately more sustainable as technologies evolve and DERs become more diverse and ubiquitous. It is important to recognize the technological innovation driving the proliferation of distributed resources. The energy "internet of things" is combining with shared economy models to enable real value creation from broad electrification (of transportation, buildings, industry), innovation in scalable technologies, and autonomous adoption by customers and communities seeking flexibility, resilience, local economic benefits and reduced environmental impacts. The Total DSO model can be a major paradigm shift if TSOs are committed to the Minimal DSO (essentially a "Total TSO") approach. Total DSO also significantly expands the DSO functions and responsibilities compared to today. Ultimately policy makers will need to assess alternative DSO models in terms of their value in achieving the society's objectives for the energy sector.

1.5. International Working Groups and Committees

This section gives an overview of selected international working groups and committees in the field of "TSO/DSO cooperation" and related literature.

Table 4: International working groups and committees

Region	Working group/ committee	Scope/ relevant Literature:
Worldwide	IEA ISGAN Annex 6, Task 5 (Power transmission and distribution system)	The group released a discussion paper on current interactions between transmission and distribution system operators and an assessment of their cooperation in Smart Grids for different countries [10].
Europe	ENTSO-E (European Network of Transmission System Operators)	The ENTSO-E published two position papers considering the TSO/DSO cooperation [1] and [15]. The European Network Code on Operational Security [14] of the ENTSO-E describes, for example, the data exchange between TSO and DSO. The ENTSO-E Demand Connection Code and the EU Commission Regulation 2016/1388 define requirements for the TSO/ DSO interconnection [17].
Europe	CEER: Council of European Energy Regulators.	The council published a conclusion paper on the future role of DSOs from the perspective of European regulators [16]. Further steps are planned in the field: responsibilities between TSO/DSO on a European level, clear cost separation between TSO/DSO e.g. for congestion management, the role of the DSO for balancing and ancillary services and the need for an established platform for optimized exchange and cooperation between TSO/DSO.
Worldwide	JWG1-C6.25/B5/CIRED	CONTROL AND AUTOMATION SYSTEMS FOR ELECTRICITY DISTRIBUTION NETWORKS OF THE FUTURE Definition of Control and Automation Systems for Distribution Networks of the future; survey on the current state of the art and expected requirements; interfacing of control and automation systems; requirements for the architecture; communication requirements. Activity report in [11].
United States of America	More than smart, T-D Operations Interface Working Group	*"More Than Smart operates a T-D Operations Interface Working Group, comprised of the California ISO, state utilities, and DER providers that evaluate a potential operations framework for coordination between the transmission and distribution grids.* [21]" Publications and presentations can be found in [21].
Europe	EDSO (European Distribution System Operators for Smart Grids)	In [20] *"EDSO draws a series of recommendations to improve cooperation for system planning, Network user connection, system operation, data management and market facilitation."* [20]
Europe	Smart Grid Task Force – Expert Group 3	The Expert Group 3 provided regulatory recommendations for the deployment of flexibility in the transmission and distribution level [18].

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2. Overview of International R&D Projects

In this chapter R&D activities from different countries with a focus on TSO/DSO cooperation are presented. The overview of international R&D projects will be provided in two different levels of detail:

- **Detailed Report:** A comprehensive overview of the project is presented, covering information about project time frame and members, case study area, project scope, selected highlights of the project and (preliminary) conclusions and recommendations. The detailed report is provided by the project leader and/or project members.
- **Factsheet:** A factsheet of the project is presented, covering the following information (if available):
    - Organizational information: Project name, project partners and project period
    - Short project description and project objectives (related to TSO/DSO cooperation)
    - Addressed Grid operation challenges in TSO/DSO cooperation (see Chapter 1.2)
    - Applied communication infrastructure and protocols
    - Addressed functionalities active distribution network and/or TSO/DSO interface (see Chapter 1.3)
    - Key findings, conclusions and/or recommendations
    - Further information and comments

In Table 5 an overview of identified projects is presented. Table 5 also indicates the source of information: **Project member:** The project factsheet is provided by the project leader and/or project members. **Literature review:** The project factsheet is based on a literature review. The references for the information are provided.

Table 5: Project overview and provided level of detail

Project	Region	Content	Page
SmartNet	EU	Detailed Report – Project member	14
Q Study	GER	Detailed Report– Project member	20
SysDL 2.0	GER	Detailed Report– Project member	29
TDX-ASSIST	EU	Factsheet – Project member	39
PVPT	DK	Factsheet – Project member	36
Real-time optimization and control of next-generation distribution infrastructure	USA	Factsheet – Project member	37
Modeling of DER in Transmission Planning Studies	USA	Factsheet – Project member	38
New 4.0	GER	Factsheet – Project member	40
NETZ:KRAFT	GER	Factsheet – Project member	41
EU-SysFlex	EU	Factsheet – Project member	44
PV-Regel	GER	Factsheet – Project member	45
Next-Generation SCADA	JPN	Detailed Report– Project member	46
TDI 2.0	UK	Factsheet -Literature review	51
evolvDSO	EU	Factsheet -Literature review	53
FutureFlow	EU	Factsheet -Literature review	55
VOLATILE	SWE, DK	Factsheet – Project member	57
IDE4L	EU	Factsheet -Literature review	59
CALLIA	EU	Factsheet -Literature review	62
INTERPLAN	EU	Factsheet – Project member	63

2.1. SmartNet

Gianluigi Migliavacca (RSE)

Project Overview

Table 6: Fact sheet - SmartNet

Project SmartNet - Smart TSO-DSO interaction schemes, market architectures and ICT Solutions for the integration of ancillary services from demand side management and distributed generation
Country: Italy (coordinator), Austria, Belgium, Denmark, Finland, Luxemburg, Norway, Spain, UK
Start: 1st January 2016 **End:** 31st December 2018
Research Partners: Austria (AIT), Denmark (DC, DTU, Energinet.dk, Eurisco, NYFORS, NOVASOL), Belgium (N-SIDE, VITO), Italy (RSE, EUI, SELNET, SELTA, SIEMENS Italia, TERNA), Norway (SINTEF-E and SINTEF-ICT), Spain (TECNALIA, ENDESA), UK (UStrath), Finland (VTT) and Luxemburg (Vodafone)
Project Description: The SmartNet project aims to provide optimised instruments and modalities to improve the coordination between the grid operators at national and local level (respectively the TSOs and DSOs) and the exchange of information for monitoring and for the acquisition of ancillary services (reserve and balancing, voltage control, congestion management) from subjects located in the distribution segment (flexible load and distributed generation).
Project Goals: comparing architectures for optimized interaction between TSOs and DSOs, including exchange of information for monitoring as well as acquisition of ancillary services (reserve and balancing, voltage regulation, congestion management), both for local needs and for the entire power system.
Grid operation challenges: Analyzing how ancillary services (most notably: system balancing and congestion management) could be provided by entities connected to distribution grids, ensuring a seamless operation between TSO and DSO through the real time market.
Key Findings: Three simulation cases referred to the target horizon 2030 are run for three European countries (Denmark, Italy and Spain) and different TSO-DSO coordination schemes are compared in order to understand which one is optimal. In addition, three physical pilots are created to demonstrate monitoring-and-control capability of distributed energy resources (DERs) connected to distribution grids and flexibility services they can offer to the system (thermal inertia of indoor swimming pools, distributed storage of radio-base stations). Regulatory guidelines are elaborated taking into account all project results.
Further information: More detailed information can be found on the following homepage: http://smartnet-project.eu/

Introduction

One of the tricky points in the transition from traditional fossil fuels' generation to greener energy systems concerns the change of roles when it comes to managing the existing electricity network: electricity is generated more and more at local/low voltage level and needs to be injected into the transmission/high-voltage level – while in the past it was exactly the opposite. How to make this reversion possible and smooth?

In Europe, there is a sharp increase in reserve needs for coping with the variability introduced by a steadily increasing RES share in the generation. The big challenge is to extend the possibility of providing Ancillary Services (AS) (frequency and voltage control, congestion management, etc.) to entities connected to the distribution network. The legislative package proposed by the European Commission in November 2016, nicknamed the Clean Energy Package, assigns a role to Distribution System Operators (DSOs) for local congestion management but not for balancing, whose management would remain in the hands of the Transmission System Operators (TSOs)[8]. However, such a sharp decoupling risks to lead to inefficient system operation.

All these issues are addressed by the SmartNet European research project (http://smartnet-project.eu/), under technical and administrative management by RSE[9], which aims at comparing different TSO-DSO interaction schemes and different real-time market architectures with the goal of finding out which would deliver the best compromise between costs and benefits for the system. The objective is to develop an *ad hoc* simulation platform which models all three layers (physical network, market and ICT), analysing three national cases (Italy, Denmark, Spain). Subsequently, this simulation platform will be scaled to a full replica lab, where the performance of real controller devices will be tested.
SmartNet also includes three physical pilots for testing specific technological solutions:

- technical feasibility of key communication processes (monitoring of generators in distribution networks while enabling them to participate to frequency and voltage regulation): Italian Pilot
- capability of flexible demand to provide ancillary services for the system:
  - Thermal inertia of indoor swimming pools: Danish Pilot,
  - Distributed storage of base stations for telecommunication: Spanish Pilot.

The consortium, under technical and administrative management by RSE, consists of 22 partners from 9 European Countries, including TSOs (Energinet.dk, TERNA), DSO (ENDESA, SE, Edyna), manufacturers (SELTA, SIEMENS), and telecommunication companies (VODAFONE).

Case Study Area

SmartNet analyses five different coordination schemes between TSO and DSO and different architectures for the real-time ancillary services markets with reference to three countries: Italy, Denmark and Spain. For each country, the model needed to perform significant simulations encompasses nodal representation of the transmission network and of the distribution networks (some of them represented in detail till medium voltage, some others in a more synthetic way), detailed representation of the different resources providing bids for system flexibility (both connected to transmission and distribution), detailed representation of the aggregation process and of the real-time ancillary services market.

Five TSO-DSO Coordination schemes

The need for increased cooperation between TSOs and DSOs is widely recognized by regulators.
Within SmartNet, five TSO-DSO coordination schemes are proposed and analysed from a conceptual point of view. Processes taken into consideration during the analysis, relate to the prequalification, procurement, activation and settlement of the Ancillary Services (AS).
The coordination schemes present different possibilities to organize the interaction between system operators. Each coordination scheme is characterized by a specific set of roles, taken up by system operators, and a detailed market design. A role is defined as "an intended behaviour of a specific market party which is unique and cannot be shared", implying a unique set of responsibilities.
The following coordination schemes are analysed: 1) the Centralized AS market model, 2) the Local AS market model, 3) the Shared balancing responsibility AS market model, 4) the Common TSO-DSO AS market model and 5) the Integrated flexibility market model.

In the Centralized AS market model, the TSO operates a market for resources connected both at TSO- and DSO-level, without extensive involvement of the DSO. In the Local AS market model, the DSO organizes a local market for resources connected at the DSO-grid and, after solving local grid constraints, aggregates and offers the remaining bids to the TSO. In the Shared balancing responsibility

[8] EC (2016) Proposal for a DIRECTIVE OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on common rules for the internal market in electricity – Art.32.
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model, balancing responsibilities are divided between TSO and DSO according to a predefined interaction schedule. The DSO organizes a local market to respect the schedule agreed with the TSO while the TSO has no access to resources connected at the distribution grid. In the Common TSO-DSO AS market model, the TSO and the DSO have a common objective to decrease costs for system services. This common objective is realized by the joint operation of a common market (centralized variant), or the dynamic integration of a local market, operated by the DSO, and a central market, operated by the TSO (decentralized variant). Finally, in the Integrated flexibility market model, the market is open for both regulated (TSOs, DSOs) and non-regulated market parties (BRPs, CMPs), requiring an independent market operator to guarantee neutrality.

All coordination schemes are analysed on their benefits and attention points and are illustrated by a conceptual visualization. The analysis showed that the feasibility of the implementation of each coordination scheme is very dependent on the regulatory framework and the national organization of TSOs and DSOs. Furthermore, the implementation of certain coordination schemes will have an impact on other markets such as the intraday markets.

Market design

Compared to conventional power generating units, Distributed Energy Resources (DERs) comprise a family of power sources with a wider variety of physical and economic characteristics. Actually, there are DERs whose power intake/production is not even fully predictable or controllable, such as EVs or wind turbines, or DERs whose primary energy service is not necessarily "power", as in the case of combined heat-and-power units. However, the current design of TSO real-time markets is tailored to a very different reality: that of a power system comprising almost exclusively a limited range of controllable and dispatchable power generating units, the vast majority of which are located at the transmission grid. Consequently, these TSO real-time markets may fail to efficiently accommodate the potentially more dynamic and less controllable behaviour of DERs.

Against this background, the SmartNet project has identified which changes to current TSO real-time markets may serve to facilitate the effective utilization of DERs. In this endeavour, the conclusions that are being drawn pertain to three different dimensions, namely:

- **Spatial** dimension: the market must allow for the *joint management* of transmission and distribution-grids.
- **Time** dimension: the market must be able to react to the varying system conditions more quickly, *closer to real time and with some degree of anticipation* on the plausible evolution of the power system state variables.
- **Service** dimension: the market must enable the *coordinated provision* of power balancing, congestion management, and voltage regulation.

In light of these conclusions, the SmartNet Team is currently developing a framework for the nearly real-time management of transmission and distribution-grid congestion and power balancing. This framework also accounts for voltage and reactive power constraints and is designed for a market for ancillary services with a high-frequency clearing pace (the market can be cleared, for example, every five minutes), with a short look-ahead horizon (of one hour, for instance), and a fine time-resolution (of one minute for the first 5-min time slot of the market as an example). Furthermore, the market clearing can be carried out in a rolling-window fashion, so that it can benefit from updated system information as it comes closer to the point in time when the ancillary service is to be provided. In addition, the market allows for a number of different complex bids, ranging from the basic energy-price bidding curves to the more sophisticated deferrable and exclusive bids.

Nevertheless, the framework that is being developed can be easily adapted to alternative market architectures that, albeit not so ambitious, may encounter less resistance on the way to actual implementation in the midterm (2030), among others in those countries where the pilots are being conducted, namely, Spain, Denmark and Italy.

Flexibility and aggregation

One of the main goals of SmartNet is to demonstrate the possibility to leverage the flexibility from DERs, namely from energy storage (static and EVs), distributed generation (RES, CHP and conventional units) and demand side management (shiftable and sheddable loads, as well as TCLs). Mathematical models of DERs are set up such that the flexibility can be accurately determined and used for the provision of AS, while specifying the physical and dynamic behaviour of the resources. Depending on the type of AS to be provided (balancing, congestion or voltage control), the level of details needed in the model can change: e.g. detailed locational information is important for congestion/voltage control but sometimes less needed for balancing; reactive power modelling is optional, depending on whether the voltage constraints are taken account of. Flexibility costs are also needed for attributing a bidding price to individual DERs. Four cost components are considered: *discomfort cost*, *indirect cost*, *revenue change* and *operational cost*.

Since DERs are typically small in terms of the flexibility quantity they can individually provide, the aggregator's role is to gather the flexibility provided by many DERs, and forward it, in the form of complex price-quantity bids, to the AS market. The aggregator plays a key role, by reducing the amount of data passed onto the AS market, which could potentially congest the clearing algorithm. Also, it helps makes it possible for small DERs to participate in AS markets and obtain additional revenue streams.

Out of the three distinct aggregation approaches used in the electricity markets, i.e. *physical*, *hybrid* and *data-driven*, the physical approach was found to be the most suitable one for SmartNet purposes. The eight abovementioned DERs categories are grouped, based on the modelling similarities, into five aggregation models: *atomic loads*, *CHP*, *curtailable generation and sheddable loads*, *storages* and *TCLs*. Cost-optimal scheduling of DERs, i.e. clearing the AS market, should be performed while taking account of the distribution network's physics. However, the optimal power flow (OPF) is nonlinear and non-convex and the overall problem can be classified as Mixed Integer Non Linear Programming (MINLP), very hard to solve. Considering that the AS market clearing has to be carried out in a limited time while considering an accurate network model, a convex approximation is needed. Use of the power flow's convex approximation allows development of an overall model which is mixed-integer convex, and which has superior tractability. The numerical comparison of OPF formulations shows that *second-order cone programming branch flow model* offers the best accuracy and very high computational tractability. However, it requires the tuning of a penalty, which should not be too low/high.

ICT and security

The presented five TSO-DSO coordination schemes revealed new challenges and opportunities for ICT with respect to communication cost, quality, availability, response time, and security. In order to fully exploit potentials offered by ICT, we analysed the TSO-DSO coordination schemes and respective use case descriptions from ICT's viewpoint. We also studied existing and future ICT technologies to assess their abilities to fulfil the recognized communications and security requirements. The study of new technologies included next generation wireless networks (5G) and Internet-of-Things (IoT) to enable a flexible way of collecting information also from edges of the network. Network Function Virtualisation (NFV), Software Defined Networking (SDN) and network slicing were investigated to offer flexible ancillary services to stakeholders without dedicated communications networks. DataHub and Blockchain implementations were investigated in order to provide easy access to data storage, to enable cross-border data exchange, and to improve security and privacy in communications. The use case descriptions of TSO-DSO coordination schemes were translated into networking components, interfaces, and exchanged data objects. Core operations were divided into four functional stages:

prequalification, procurement, activation, and settlement. Each data exchange belonging to a specific stage was described with communications and security requirements.

Capturing of ICT and security requirements was done by using an iterative and incremental procedure involving several refinement and harmonization stages. As a result, a generic ICT architecture containing a core set of system actors, components, and services was created.

The modelling follows SGAM reference architecture model principals describing the structure of the architecture and interactions between entities from the business layer down to the component layer.

In addition to the common architecture design, we also created more detailed SGAM models for pilots and simulation platform. These derived models are called profiles, and they map the ICT architecture and communication requirements of specific coordination schemes to the pilot specifications.

The three pilots

The Italian power system is in a dynamic evolution process, where the large increase of RES penetration in the last 10 years is leading to a number of challenges, including a rise of active power from MV/LV to HV and the difficulty to integrate unpredictable RES with traditional generation units.

In order to address these challenges, an improved monitoring of the grid at MV and LV levels, as well as a smarter operation of the grid and a deeper coordination between the TSO and local DSOs can be envisaged. In this context, the Italian SmartNet pilot is implemented in Ahrntal, an alpine region in Northern Italy characterized by high penetration of hydro generation, to demonstrate:

- Aggregation of information in real-time at the TSO-DSO interconnection point: total power installed per source, total load and gross load compensated by DER and real-time data for P and Q for all sources. Where real-time information is not fully available, updated forecast and reference production will be used to extrapolate and estimate missing data.
- Voltage regulation by generators connected at HV and MV.
- Power-frequency regulation (Frequency Restoration) by generators connected at MV.

The Danish system is characterised by a high penetration of RES (mainly wind, but, increasingly, also PV) and other highly-flexible DER (CHP, waste treatment plants and other technologies such as EVs and heat pumps which are expected to have a significant role in the mid-term).
Aim of the pilot is to demonstrate the opportunities for making use of predictable demand to contribute to transmission and distribution (T&D) grid operation. In particular, it is aimed at demonstrating the use of price signals to control the set-points of thermostats of swimming pools in rental summer houses. Such price-based control is expected to be able to handle many of the issues arising in both T&D grids, as well as to balance wind power generation.

The Iberian Peninsula is still weakly connected to the rest of the European power system. Additionally, in the last years there was an increased contribution of both wind power and PV to the electricity supply in Spain. Under these conditions, the use of flexible demand looks a very promising tool for Spanish grid operators.

The Spanish pilot is demonstrating the prospects for the DSO of using the flexibility of mobile phone base stations to reduce congestion in distribution grids, and to help the TSO maintain system balance by fixing an exchange schedule at the TSO-DSO connection point. With that purpose, the DSO organises a local market, where different aggregators offer their flexibility. Once cleared, the market aggregators perform direct control over the DER they manage and the DSO checks the compliance with local market results

Some preliminary conclusions and lessons learned

Whereas final regulatory recommendations will be possible only towards the end of the SmartNet project, a few preliminary considerations can already be highlighted on the basis of the experience acquired during the first half of the project:

- Cooperation and coordination between TSOs and DSOs are an essential element, if DERs are to play a significant role in the provision of real-time ancillary services (this is particularly relevant if the services are provided to TSOs and can affect the secure operation not only of the local distribution networks to which they are connected but of the entire system as well). **While it could be appropriate that TSOs retain a responsibility for the provision of balancing services, nonetheless they could have to share part of this responsibility with DSOs to the extent that the importance of the contributions to this service from entities connected to distribution will grow.**
- While the EU framework can provide the main guidance for a certain level of synchronisation and harmonised solutions, national and regional regulators will be in a better position to decide which coordinating scheme between TSO and DSO will be the most appropriate locally, and how the regulation should be developed to enable this change. In general, **a balance has to be sought for between local optimality and the implementation of a harmonised pan-European design.**
- The role of the emerging DSOs will depend on the implemented coordinated scheme, and can range from only managing local congestion to managing local market and the provision of ancillary services sold by DERs at both TSO and DSO levels. The latter will involve more integrated TSO-DSO operation. However, it can be expected that the complexity of the implemented scheme will be affected by the size of the DSOs: only big DSOs will be ready to take a role of significant responsibility. Being the DSO landscape very variegated in Europe, **we can expect smaller DSOs to have to integrate their efforts in order to be fit for the new responsibilities.**
- In addition to advancements of TSO-DSO coordination schemes, types, characteristics and regulation regarding the provision of ancillary services will need to evolve so to enable more participants to take part and use these new business opportunities. Therefore, as the potential flexibility providers are mainly small DERs, **regulation will have to take fully into account the characteristics of the potential flexibility providers connected to the DSO side.** In particular, the importance of the market design for ancillary services has not to be overlooked: **only if the architecture of real-time markets will be able to take fully into account the characteristics of the potential flexibility providers connected to distribution grids, it will be possible to obtain a significant participation on their side.**
- The role taken by the aggregator is crucial: **aggregators must be able to provide a simplified interface towards the market, hiding most details and complexities of the characteristics of the single flexibility providers. Aggregators must deliver flexibility providers efficient price signals so as to incentivise their participation.**
- **Viable business models must be available for all market participants**, including DERs, aggregators and other customers. It is expected that this may also include new regulation like the establishment of the right incentive schemes, whenever needed.
- **Network planning will also have to facilitate better utilization of RES**, while minimising infrastructure investments, or postponing investments so to reduce the risk of stranded assets.
- Finally, **technical optimality will have to be supported by a thorough cost-benefit analysis**.

In short, the path towards a full-fledged participation of DERs to for ancillary service markets is still a long way. Nonetheless, studies like the SmartNet project will provide a contribution towards an increase in the efficiency of the electricity system, thus allowing to reduce prices for the consumers and, at the same time, enabling them to play the central role envisioned in the general philosophy of the Winter Package.

2.2. Q-Study

Markus Kraiczy & Haonan Wang (Fraunhofer IEE), Sebastian Schmidt & Frank Wirtz (Bayernwerk Netz GmbH)

Project Overview

Table 7: Fact sheet Reactive Power Management in the Distribution Grid of Bayernwerk Netz GmbH

Q-Study - Reactive Power Management in the Distribution Grid of Bayernwerk Netz GmbH
Country: Germany
Start: 2015 **End:** 2018
DSO: Bayernwerk Netz GmbH (German DSO) **Research Partners:** Fraunhofer IEE
Project Description: This project covers several research questions in the field of reactive power management at the TSO/DSO interface with the support of distributed generators. In the project, a new operational concept of DER for reactive power management is developed and tested in hardware-in-the-loop and field test applications. Furthermore, new grid planning procedures for DER reactive power support at the TSO/DSO interface are developed and discussed.
Project Goals: • Availability assessment of DER controllable reactive power support • Identification of additional reactive compensation demand in a distribution grid section • Cost-Benefit Analysis of different reactive power management approaches • Controller-in-the-loop test and field test of the central reactive power controller of MV-PV systems
Grid operation challenges in cooperation TSO/DSO: • Voltage support (DSO/TSO)
Communication infrastructure: Planned field test application: • DSO control center / DG remote control: IEC 60870-5-104 • DSO control center / HV/MV substation IEC 60870-5-104
Functionalities TSO/DSO interface: • Volt/Var Optimization • Reactive Power Dispatch / Scheduling
Conclusion / Key Findings / lessons learned: • Overall, the dynamics and the extent of reactive power exchange at the TSO/DSO interface in the investigated grid section rise with an increased degree of cabling in the distribution level and increased distributed generation, if no additional measures are applied. • In the investigated grid section, a very high availability (95% to 98% percentile) of DER reactive power support for all analyzed grid use cases is especially determined for hydro power plants and bioenergy plants. Furthermore, PV systems could provide a significant controllable reactive power support with high (80% to 90% percentile) and partly very high availability (95% to 98% percentile) in the peak generation case to avoid undesired operation points. Also for the undesired operation points according to the Demand Connection Code (DCC) a high availability for PV reactive power support is determined. • A methodology was introduced to determine the additional reactive power compensation demand in a distribution grid section with or without DER reactive power support. In the investigated case study, DER reactive power support could significantly reduce but not avoid the demand for additional reactive power compensators at the distribution level. • The proposed PV reactive power management approach combines central and local control concepts for reactive power support at the HV/MV interface and for local voltage control at the PV side. The presented concept requires only a few online measurement

data from the grid and is therefore especially interesting for grid sections without an extensive monitoring system.
Further comments: • Field test demonstration not yet finished
Further information / publications: Publications: • [Q-Study.1] M. Kraiczy, H. Wang, S. Schmidt, F. Wirtz, M. Braun: Reactive Power Management at the Transmission-Distribution Interface with the Support of Distributed Generators – A Grid Planning Approach, IET Generation, Transmission & Distribution (submitted), January 2018. • [Q-Study.2] H. Wang, M. Kraiczy, S. Schmidt, F. Wirtz, C. Töbermann, B. Ernst, E. Kämpf, M. Braun: Reactive Power Management at the Network Interface of EHV- and HV Level: Assessment of Technical and Economic Potential Based on a Case Study for Bayernwerk Netz GmbH, ETG Congress - Die Energiewende, Bonn, 2017. • [Q-Study.3] E. Kaempf, M. Braun, H. Wang, B. Ernst: Remuneration of controllable reactive power inside so far free of charge ranges: Cost-Benefit Analysis, 7th Solar Integration Workshop, Berlin, 2017. • [Q-Study.4] H. Wang, M. Kraiczy, S. Wende- von Berg, B. Ernst, E. Kämpf, M. Braun, S. Schmidt, F. Wirtz: Reactive Power Coordination Strategies with Distributed Generators in Distribution Networks, 1. International Conference on Large-Sacle Grid Integration of Renewable Energy in India, New Delhi, 2017. • [Q-Study.5] H. Wang, M. Kraiczy, S. Schmidt, B. Requardt, C. Töbermann, M. Braun: Blindleistungsmanagement im Verteilnetz durch zentrale Regelung großer PV-Anlagen: Pilottest in einem Mittelspannungsnetz der Bayernwerk AG, 4. Konferenz Zukünftige Stromnetze für Erneuerbare Energien, Berlin, 2017. • [Q-Study.6] M. Kraiczy, H. Wang, S. Schmidt, F. Wirtz, C. Töbermann, M. Braun: Gesicherte und dargebotsabhängige Blindleistungsbereitstellung durch Erzeugungsanlagen im Verteilungsnetz, 4. Konferenz Zukünftige Stromnetze für Erneuerbare Energien, Berlin, 2017. • [Q-Study.7] H. Wang, T. Stetz, M. Kraiczy, K. Diwold, S. Schmidt, M. Braun: Zentrales Blindleistungsmanagement für die Netzverknüpfungspunkte Hochspannung/Mittelspannung der Bayernwerk AG, ETG-Fachtagung, Kassel, 2015. • [Q-Study.8] H. Wang, T. Stetz, F. Marten, M. Kraiczy, S. Schmidt, C. Bock, M. Braun: Controlled Reactive Power Provision at the Interface of Medium- and High Voltage Level: First Laboratory Experiences for a Bayernwerk Distribution Grid using Real-Time-Hardware-in-the-Loop-Simulation, ETG-Congress, Bonn, 2015. • [Q-Study.9] M. Kraiczy, T. Stetz, H. Wang, S. Schmidt, M. Braun: Entwicklung des Blindleistungsbedarfs eines Verteilnetzes bei lokaler Blindleistungsregelung der Photovoltaikanlagen im Niederspannungsnetz, ETG-Fachtagung, Kassel, 2015.

Introduction

Parts of this chapter are published in [Q-Study.1] and [Q-Study.2].

One possible objective of reactive power management is to keep the reactive power flow at defined grid nodes (e.g. the TSO/DSO-Interface) within specified reactive power limits. Furthermore, also controllable reactive power flexibility by distributed generators (DGs) can be provided at the TSO/DSO-interfaces, which can support the voltage regulation in the upstream voltage levels. In this report, an availability assessment of DG reactive power support is shown for a real German distribution grid section with very high PV penetration. The reactive power requirements at the TSO/DSO-interface in this report are set according to the new ENTSO-E Demand Connection Code[10] (DCC). **It should be highlighted, that these requirements are not the current requirements at the TSO/DSO-Interfaces in the investigated grid section and that the detailed national implementation of the DCC is still under discussion.**

[10] COMMISSION REGULATION (EU) 2016/1388 of 17 August 2016 establishing a Network Code on Demand Connection

Figure 9 shows the annual active (P) and reactive (Q) power exchange at the TSO/DSO network coupling points (NCPs) and the DCC requirements for the investigated grid section. It can be seen that currently not all operation points at the TSO/DSO-NCPs are within the requested operational area. Otherwise, a relevant DG feed-in can be determined for undesired operation points at the TSO/DSO interface (hatched area, Figure 9) and DG reactive power management might significantly improve the reactive power exchange at the TSO/DSO-interface.

Furthermore, an application-oriented reactive power management concept with DG systems is introduced and results of controller-in-the-loop tests are presented in this report.

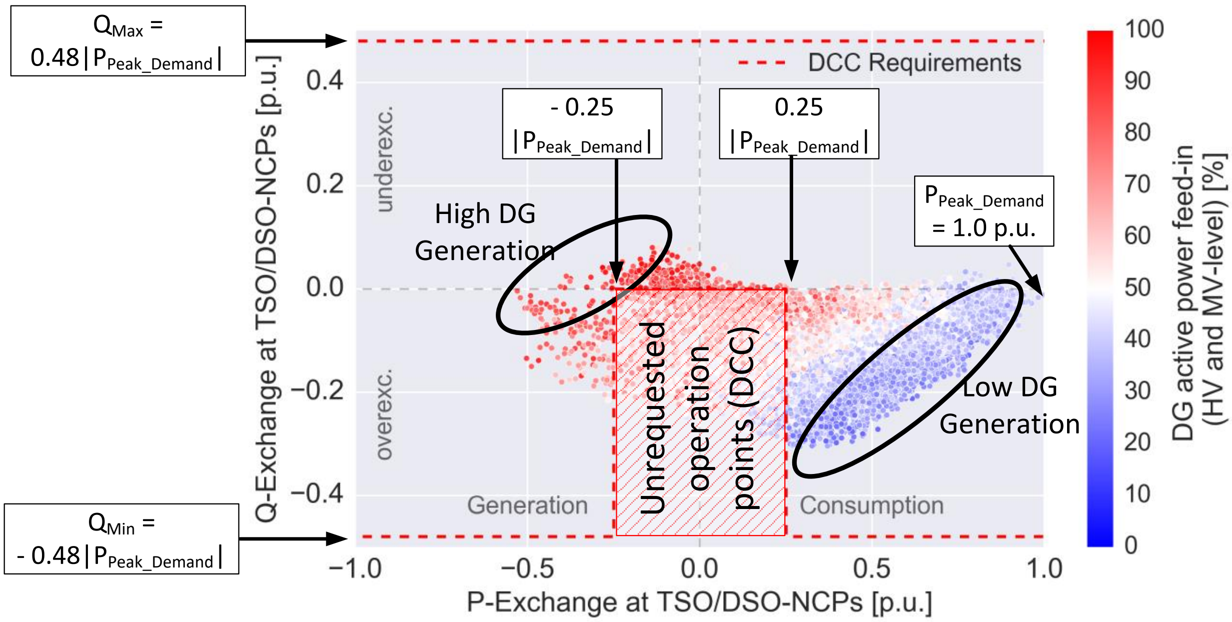


Figure 9: Annual PQ exchange at the TSO/DSO-NCPs (normalized to the annual peak demand of the distribution grid section) and DG active power feed-in at the HV and MV-level (normalized to the maximum DG feed-in) [Q-Study.2]

Case Study Area

In this case study report the focus is set on two different case study areas. The DG reactive power availability assessment is performed for a real German HV grid section. The developed application-oriented reactive power management concept is analyzed and tested in detail for one MV-grid "Smart Grid Seebach" in this particular HV grid section.

The investigated HV distribution grid section of Bayernwerk Netz GmbH covers 9 EHV/HV substations (9 TSO/DSO-NCPs) and 87 HV/MV substations and is situated in an area which achieves within the highest PV penetration rates in Germany. Figure 10 shows the installed generation capacity by generation type and voltage level. The values are normalized to the total generation capacity in the investigated distribution grid section. The total generation capacity exceeds the maximum peak demand of the grid section by a factor of around 1.9 and significant reverse power flows are already measured at the EHV/HV interfaces (compare Figure 9).

Approximately 50% of the total DG capacity is installed in the LV level with majorly PV installations. In the MV level, approximately 30% of the total DG capacity is installed, with PV systems, hydro power, bio power plants and a few wind turbines. In the HV-level, approximately 15% of total DG capacity is installed including hydro power plants, hydro pump storages, thermal power plant, PV and wind parks.

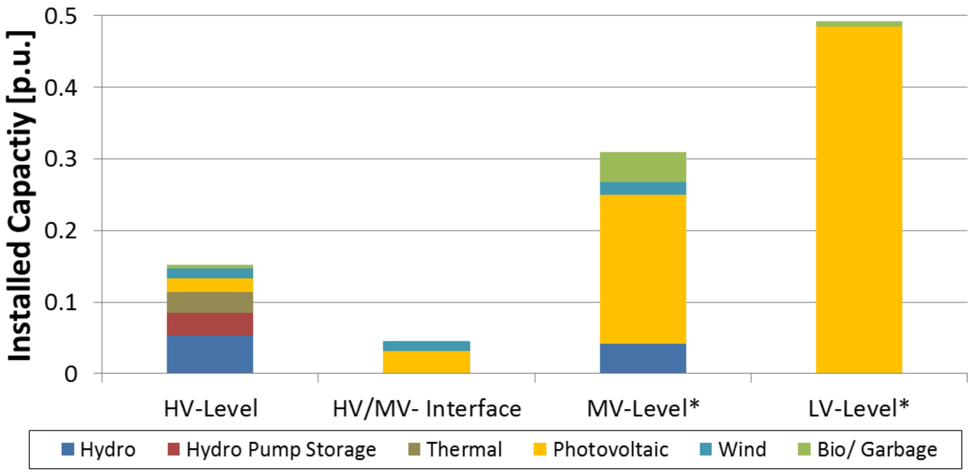


Figure 10: Installed generation capacity in the investigated grid section (normalized to total installed DG capacity in the investigated distribution grid section) * the installed DG capacity at MV and LV-level is calculated by the aggregated MV and LV DG capacity and a typical DG voltage level allocation [Q-Study.2]

Furthermore, the "Smart Grid Seebach" is chosen in this case study and used as an additional research area for detailed investigations regarding the reactive power management at network interface between the HV- and MV level. The selected "Smart Grid Seebach" is a down-streamed MV grid (20 kV) of the mentioned grid section above and has one HV/MV-network connection point (110 kV-NCP) to the up-streamed HV level. Since the total generation capacity of DER (45 MVA) in "Seebach" is substantially higher than its maximum peak demand (12 MVA), significant reverse power flows can be also often observed at the 110 kV-NCP.

Reactive Power Assessment by Distributed Generators

In this chapter, an availability assessment for DG reactive power support for relevant grid use cases is performed. A simplified methodology is shown in Figure 11. Generally, two different types of analysis can be applied:

- **Theoretical analysis:** A comprehensive time series analyses of DG generation data is performed. The DG Q provision is only limited the by the Q(P)-capability of the generators, hence no grid simulations are required and no grid constraints (e.g. voltage violations) are considered.
- **Technical analysis:** Detailed load flow simulations of the investigated grid section are performed. The DG Q provision is limited by the Q(P)-capability of the generators and local voltage constraints. Furthermore, the impact of DG Q-management on the grid operation can be analyzed in detail, for example, the impact on voltage magnitude, line loading, and grid losses.

In this case study report, a theoretical analysis of the DG Q potential in the HV to MV-level is performed. A technical analysis of the DG Q potential is performed in [Q-Study.1] and [Q-Study.6]. The considered Q(P)-capability of the DG systems is shown in Figure 11 (2nd block). The aggregation of the DG Q potential (4th block) is performed in the time domain, therefore simultaneity effects between the DG systems are considered. The statistical assessment (5th block) can be performed for different time intervals (e.g. time of the day, time of the year) or for relevant use cases (e.g. high load condition, maximum reverse power flow). In this case study report the statistical assessment is performed for solely points in time with an undesired Q exchange at the TSO/DSO-interfaces according to the DCC requirements (use case DCC, compare Figure 9, hatched area).

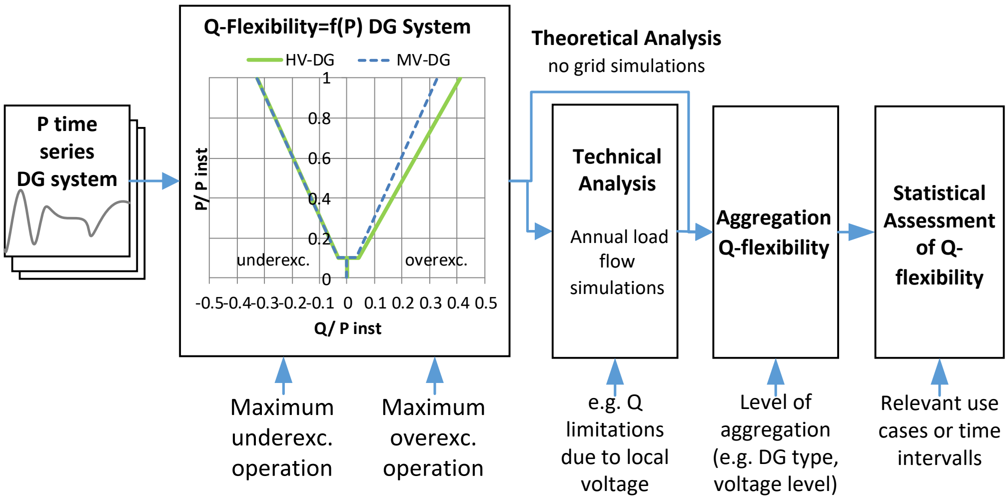


Figure 11: Applied methodology for the reactive power flexibility assessment by distributed generators [Q-Study.2]

Figure 12 (top) gives an overview on the DG Q potential at different voltage levels. Some of the case study results are confidential; therefore the results are normalized by the maximum DG Q potential in the investigated grid section (Figure 12, black dashed line). The color bars indicate different availability values for the DG Q potential (availability assessment according to [Q-Study.2]):

- **Very high availability (e.g. 95% and 98% percentile):** this DG Q potential is at least available for 98% or 95% of the analyzed operation points.
- **High availability (e.g. 80% and 90% percentile):** this DG Q potential is at least available for 80% or 90% of the analyzed operation points.
- **Median availability (50% percentile):** this DG Q potential is at least available for 50% of the analyzed operation points.
- **Minimum availability (0% percentile):** the maximum determined DG Q potential for the analyzed operation points (very low availability).

Overall, only 33% of the maximum DG Q potential shows a very high availability (Figure 12 (top), dark blue bars, 98% percentile, total Q potential) for the analyzed grid section and is hence largely independent from weather conditions and other external impact factors. A comparison of the voltage levels shows a high controllable DG Q potential especially at the MV-level (0.42 p.u. in median) and at the HV-level (0.21 p.u. in median). In Figure 12 (bottom) the DG Q potential is shown in detail for the MV level. A DG Q potential with very high availability (Figure 12 (bottom), dark blue bars, 98% percentile) is only determined for hydro power plants and bio power plants in the MV level. However, PV systems can provide a significant Q potential with a high availability (Figure 12, white bars, 80% percentile) and with median availability PV system can provide the highest controllable DG Q potential. An explanation for the high availability of Q potential by PV systems can be derived from Figure 9. Undesired operation points at the TSO/DSO-NCPs (DCC) only occur for operation points with a relevant DG feed-in and for the analyzed grid section PV is the dominant generation type (compare Figure 10). Therefore, undesired operation points at TSO/DSO-NCPs (DCC) usually occur with a relevant PV active power feed-in and hence with a relevant PV Q potential. Overall, the analysis identifies also an interesting Q potential for PV systems at the MV level.

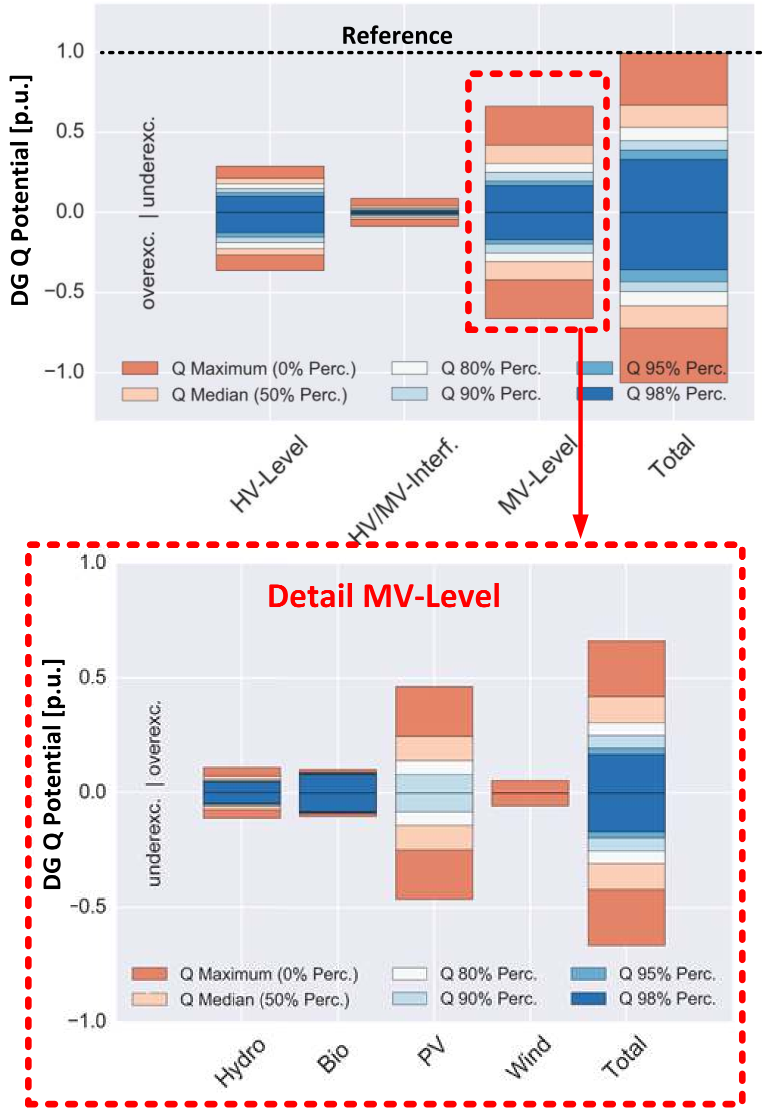


Figure 12: Overview of DG Q potential at different voltage levels (top) and detailed results of DG Q potential for the MV level (bottom) for the applied use case. The values are normalized to the total maximum underexcited DG Q potential in the investigated grid section (black dashed line). (based on: [Q-Study.2])

The Developed Reactive Power Management Concept

The proposed Q-Management concept aims at controlling the reactive power exchange at a 110 kV-NCP by using the reactive power capability of DG in the MV-level. Figure 13 gives a general overview of the introduced Q management approach. The proposed concept can be mainly divided into a central and a local control application. The central controller measures the Q exchange at the 110 kV-NCP and determines optimal Q set points for all associated DG at the MV-level, depending on the current Q requirements at the upstream HV-level. In the local DG controller an extended Q(V) control is implemented (see Figure 13, bottom right), which checks the conformity of the remote Q set point with the local voltage requirements. In case the local DG voltage is within a normal operation range, the remote Q setpoint is applied by the local controller. In case the local DG voltage is too high or too low for the remote Q setpoint; the setpoint is limited by the extended Q(V) characteristic. Therefore, the voltage regulation is performed locally by the DG and the central controller do not require detailed information of the system state in the MV-level (e.g. local voltage magnitudes). Overall, the concept can be implemented in a real distribution grid environment without requiring detailed measurements in the grid and is therefore especially interesting for grid sections without an extensive monitoring and communication infrastructure. Otherwise, the central Q controller cannot fully guarantee the compliance of Q setpoints with voltage limitations and capacity limitations of grid assets. These compliances should be covered by complementary grid planning procedures.

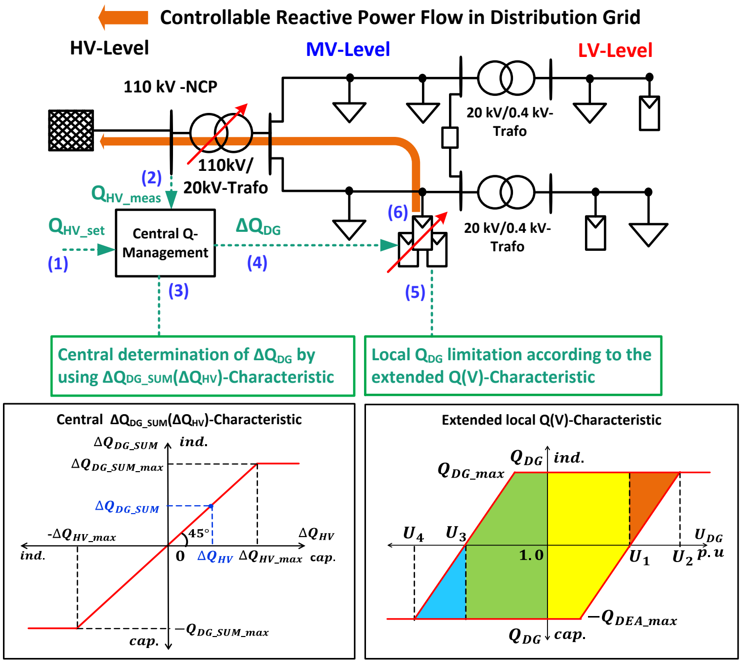


Figure 13: Reactive Power Management Concept (based on [Q-Study.8]).

Simulation and Controller in the Loop Test

In a first step, the technical feasibility and the potential of the Q Management approach are investigated in different MV grids of Bayernwerk Netz GmbH by performing time series and worst-case analyses [Q-Study.7]. As a result, the proposed Q-management approach could enable a controlled Q-exchange at the 110 kV-NCP with satisfactory control accuracy. A relevant Q potential at the 110 kV-NCP can be observed in most of the investigated MV grids of Bayernwerk AG, which however strongly dependents on the number, size and type of the available DG in the MV level.

In a next step, the Q Management approach is investigated in a laboratory environment under more realistic conditions using a real-time Controller-in-the-Loop simulation platform [Q-Study.8]. The goal of this investigation is to test the functionality and stability of the proposed Q Management concept. Figure 14 shows the test infrastructure, which can be mainly divided into two parts: the distribution network “Seebach” and an external PC. The “distribution network Seebach” consists of the detailed MV network model “Seebach” including the MV DG and the local DG controllers and is realized on the real-time-simulator platform “ePHASORsim” from Opal-RT. The central Q controller, on the other hand, is implemented on an external PC, which determines the optimal Q set points for all controllable DG. Measurement- and control signals between external PC and real-time simulator are exchanged via the proxies, clients and message bus provided by the “OpSim” platform. The real-time Controller-in-the-Loop tests are performed for two characteristic days (clear sky day and highly variable day). The control target of the central Q controller is to minimize the Q exchange at the 110 kV-NCP. Different control configurations, like measurement and control intervals, are tested. In addition, time delays were added in the simulations to emulate the delay of data communication in a real grid environment.

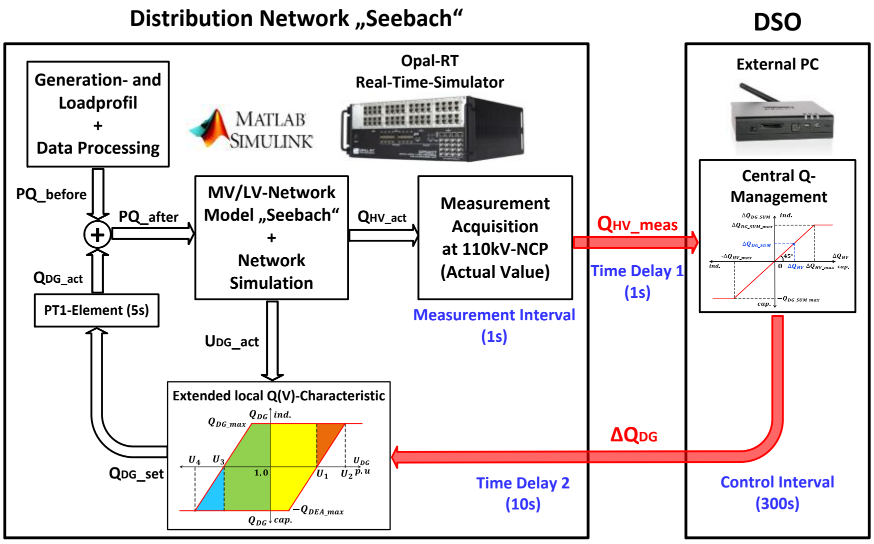


Figure 14: Test infrastructure for real-time Controller in the Loop Test (based on [Q-Study.8]).

Figure 15 shows an exemplary result of the real-time Controller-in-the-Loop simulation for the time period 9 am to 5 pm and for the clear sky day. The red line represents the original Q exchange at the 110 kV-NCP without using an active Q-Management, which can be considered as reference scenario in this investigation. The blue line shows the controlled reactive power exchange by applying the introduced Q-management approach. Overall, the Q management approach could minimize the Q exchange at the 110 kV-NCP relevantly with a satisfactory accuracy. Furthermore, critical controller configurations for the stability of the Q management concept were identified in the tests. In a next step, the proposed Q management concept should be tested and studied in a field test in the MV grid "Seebach".

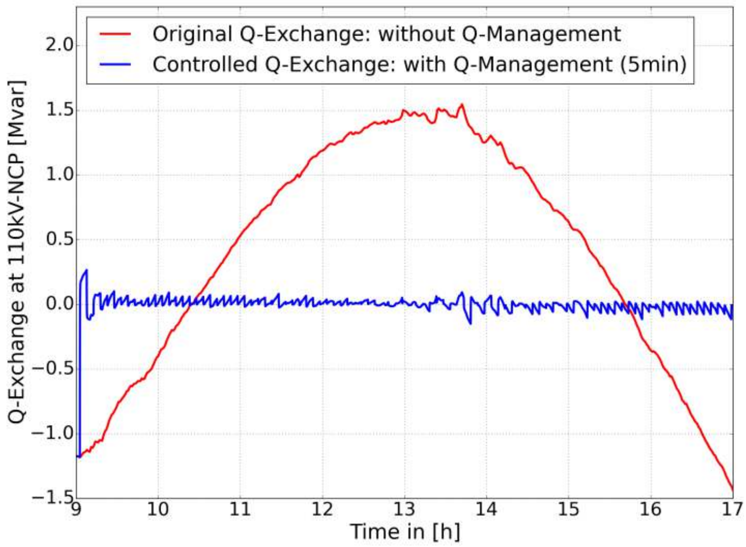


Figure 15: Exemplary results for the real-time Controller-in-the-Loop test (9 am to 5 pm) (based on [Q-Study.8]).

Conclusion

The following list presents selected key findings from the project:

- The increased degree of cabling in the investigated distribution grid section can lead to a relevant rise of reactive power export (overexcited distribution grid) at the transmission-distribution interfaces, especially at times with low load and low generation (night time). Furthermore, also the maximum reactive power import (underexcited distribution grid) at the transmission-distribution interfaces can relevantly rise with increased reverse power flows and the application of DER local reactive power control (e.g. fixed power factor), this effect especially appears at times with high generation in the distribution level. **Overall, the dynamics and the extent of reactive power exchange at the transmission-distribution interface in the investigated grid section increases with an increased degree of cabling in the distribution level and increased distributed generation, if no additional measures are applied (detailed information: [Q-Study.8]).**

- A comprehensive availability assessment of controllable DER reactive power support at the TSO/DSO interface was performed for different grid use cases, like peak generation case, peak load case, low load / low generation case and for undesired operation points at transmission-distribution interface according to the Demand Connection Code (DCC) (DCC use case shown in this report). **In the investigated grid section, a very high availability (95% to 98% percentile) of DER reactive power support for all analyzed grid use cases is especially determined for hydro power plants and bioenergy plants. Furthermore, PV systems could provide a significant controllable reactive power support with high (80% to 90% percentile) and partly very high availability (95% to 98% percentile) in the peak generation case to avoid undesired operation points. Also for the undesired operation points according to the Demand Connection Code (DCC) a high availability for PV reactive power support is determined.** Otherwise, for the peak load case and the low load / low generation case, PV could not provide relevant controllable reactive power support. A Q@Night functionality of PV systems was not considered in the analysis, which could additionally increase the availability of PV reactive power support (detailed information: [Q-Study.1], [Q-Study.2] and [Q-Study.6]).
- **In the project, a methodology was introduced to determine the additional reactive compensation demand in a distribution grid section with or without DER reactive power support. In the investigated case study, DER reactive power support could significantly reduce but not avoid the demand for additional reactive power compensators at the distribution level.** The effectivity of DER reactive power support and the demand for additional reactive power compensators strongly depends on the reactive requirements at the TSO/DSO interface and the required strictness of compliance (e.g. full compliance for 100% of annual values required or undesired values are tolerated but penalized by a compensation fee) (detailed information: [Q-Study.1]).
- An application-oriented PV reactive power management concept was developed and analyzed in detailed controller-in-the-loop tests. **The proposed control approach combines central and local control concepts for reactive power support at the HV/MV interface and for local voltage control at the PV side. The presented concept requires only a few online measurement data from the grid and is therefore especially interesting for grid sections without an extensive monitoring system** (detailed information: [Q-Study.4], [Q-Study.7] and [Q-Study.8]).

2.3. SysDL 2.0

Sebastian Wende v. Berg (Fraunhofer IEE)

Project Overview

Table 8: Fact sheet – SysDL2.0

SysDL 2.0: Ancillary Services provided by Distribution Networks
Country: Germany
Start: 10/2014 **End:** 03/2018
Research Partners: Fraunhofer IEE, University of Kassel, Technical University of Dresden **DSOs**: MITNETZ Strom mbH, ENSO, Drewag, Thüringer Energienetze **TSO:** 50Hertz Transmission GmbH **Industry Partners:** Siemens, F&S Automation
Project Description: The SysDL 2.0 research project (ancillary services from area distribution grids) is focusing on developing and validating the system-based principles for the coordinated provision of ancillary-service upstream products. To this end, the project participants are incorporating the third-party operated generation systems available in the distribution grid. In addition, a field test is also being conducted in different distribution grids taking into regard the respective grid topology.
Project Goals (TSO/DSO cooperation): Coordinated provision of ancillary services from DSOs to the TSO (reactive power dispatch, voltage control) by means of controllable distributed generators and other controllable equipment (STATCOMs, OLTCs etc.). Development of control algorithms, development of fault-tolerant communication infrastructure, laboratory and field tests.
Grid operation challenges in cooperation TSO/DSO: • Voltage support (DSO/TSO) • Congestion of transmission-distribution interface • Congestion of transmission lines
Communication infrastructure TSO/DSO : • Involved parties: DSO, TSO, DG, forecast provider • TSO control center / DSO control center: TASE.2 • DSO control center / DG remote control: IEC 60870-5 • DSO control center / SysDL-Demonstrator: CIM
Functionalities TSO/DSO interface : • Forecast active power generation • Forecast of active and reactive power consumption • Forecast of reactive power flexibility at TSO/DSO interface • Optimization of voltage control TSO/DSO • Optimization of DG active power curtailment
Key Findings / lessons learned: • Definition of use cases • System Architecture • Standardized Data Model CGMES • Implementation in operation center
Further Information: More detailed information can be found on the following homepage: http://www.sysdl20.de/

Introduction

In the German national project "SysDL 2.0", new concepts for the provision of ancillary services from DSO for TSO under the usage of distributed renewable generation are investigated. In order to achieve this goal, controller for the coordination of reactive power from DG, are developed and were tested in a special co-simulation real-time environment [OpSim]. The defined use cases focus on harnessing reactive power for voltage control in transmission and distribution grids. The final aim of this project is to develop a field test demonstrator, which runs in parallel to the DSO operating system and provides the operator with solutions to coordinate the DGs. In order to reach this goal, a demonstrator was developed, which consists of three main components; an Enterprise Service Bus (ESB) which coordinates the in- and outgoing data flows, a CIM CGMES database which consists of all needed static and dynamic data, and an optimization toolbox which consists of a state estimation, network optimization algorithms, and forecast processing routines.

The demonstrator will provide forecasts of reactive power flexibility ranges and provide them via a graphical user interface to the DSO and TSO. Both operators can have real-time information and coordinate each other via the interface how to operate at interconnection points. In detail, the DSO can provide reactive power as ancillary service and due to the flexibility range for now and the next 4 hours, the TSO can plan with it (e.g. to stabilize voltage) and request realistic amounts from the DSO. The interaction between DSO and TSO will then be performed via TASE.2 or other means of communications. An overview of the communication and participants is given in Figure 16.

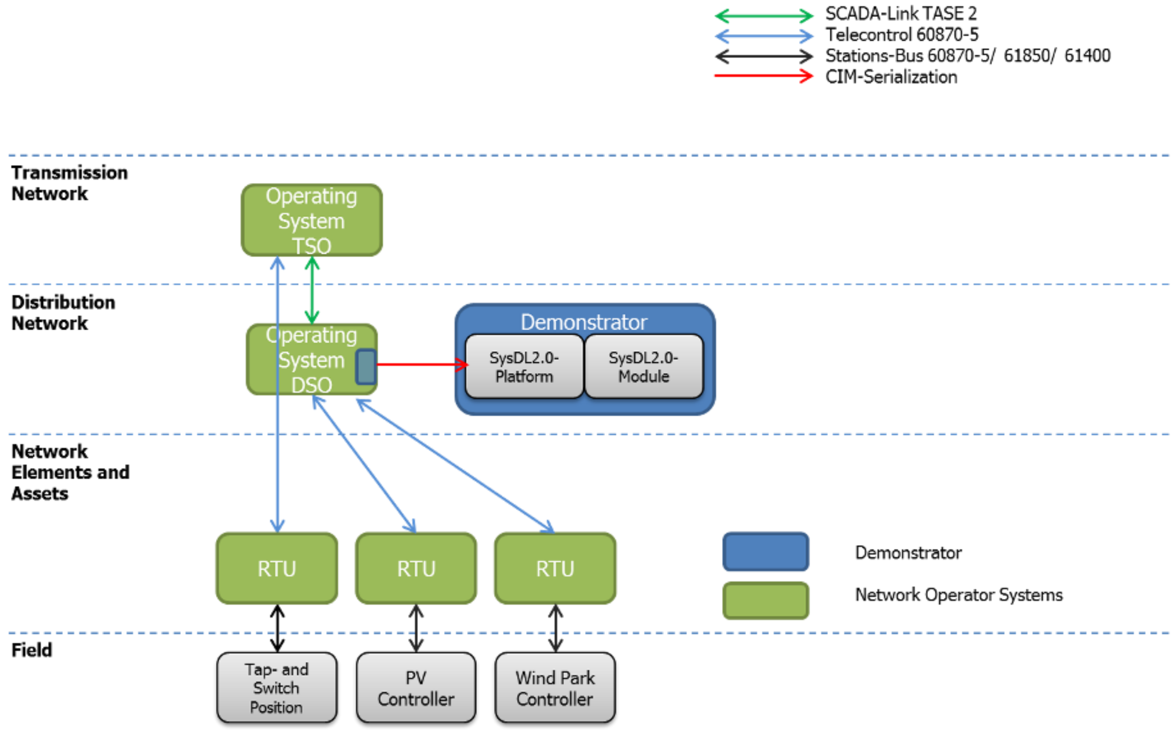


Figure 16: Overview of communication means and participants in the field test.

Case Study Area

In the project, the 110 kV distribution grids of three DSOs are under investigation. All three networks are connected to the 50hertz 380 kV transmission grid. Only in two of these networks are field tests intended. Those are the ones from Enso Netz and MITNETZ. In the Enso network, five wind parks and one PV plant are located. Each one has a nominal power of about 30 MW. Nevertheless, only one Wind Park is able to participate in the field test due to a lack of communication infrastructure for the other ones. This wind park consists of four sub-wind parks, which are all connected at the same connection point within the 110 kV grid. In the MITNETZ area, there are about 40 DGs of which are about 50 % Wind parks and 50% PV plants. Here, about 10 DGs will be controllable for the field test.

In both networks, the generation from renewables is on average already higher than the consumed energy. Especially in the MITNETZ network, the penetration level is already extremely high.

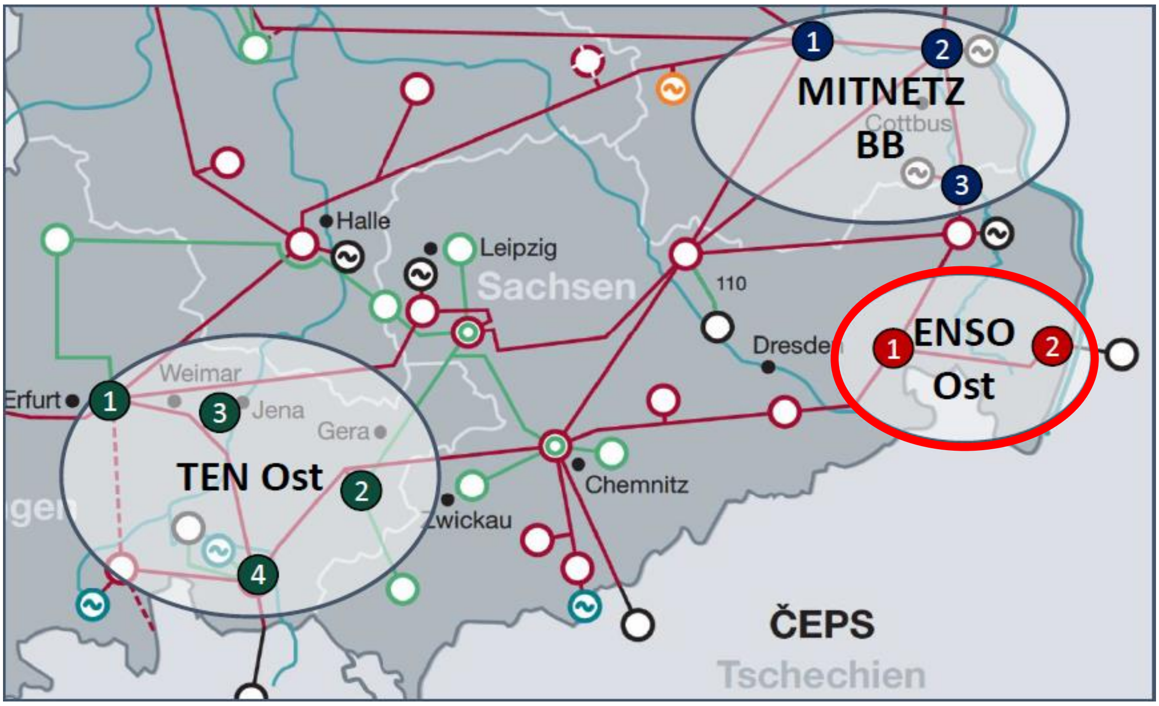


Figure 17: Schematic overview of the investigated distribution networks in the 50hertz area.

In the MITNETZ network, a significant amount of PV is installed but the main source of generation is in both networks Wind energy.

Ancillary services with reactive power from DG in distribution grids

Use Cases:

In the project, 6 Use Cases were, in cooperation with TSO and DSO, developed. These Use Cases base on the assumptions, that no changing of transformer step positions is possible and active power must not be reduced. Also, only reactive power from DG's can be harnessed for the generation of ancillary services. With these constraints, three Use Cases with direct implications for TSO and three with direct implications for DSO were formulated (see Table 9).

Table 9: Overview of the SysDL2.0 Use Cases.

		Primary Use Case	Description	Variables
TSO	A	Voltage Demand ModU	▪ Risk of deviation from voltage boundaries (EHV grid) ▪ Modification of local voltage boundaries for EHV/HV – PCC's in the distribution network	Voltage boundaries at EHV/HV PCC (=)
TSO	B	Reactive Power Demand ModQ	▪ Risk of deviation from voltage boundaries (EHV grid) ▪ TSO demands reactive power at EHV/HV- PCC's in in the distribution network	Reactive power supply at EHV/HV PCC (=)
TSO	C	Redispatch Validation	▪ TSO demands clearance for preventive / curative redispatch with power plants in the HV-grid	Clearance
DSO	D	Local Voltage Stability 110kV ModU	▪ Voltage in the distribution network is approaching its boundary ▪ Regulation of voltage in the distribution grid	Voltage in the distribution grid (=)
DSO	E	Minimize Power Losses 110kV ModU	▪ Normal operation ▪ Regulation of reactive power in order to minimize power losses	Power losses in the distribution grid (min)
DSO	F	Local Shortage Management. 110kV	▪ Shortage in the distribution grid ▪ Regulation of reactive power, in order to minimize the depression of DG	Depression of DG (min)

PPC.. Point of Common Coupling (EHV/HV or HV/MV) DG
(min).. minimize cost function (max).. maximize cost function (=).. minimize deviations from specifications

Short description of each Use Case:

A. The voltage in the transmission grid is going to violate the agreed voltage boundaries at the PCC EHV/HV. The SysDL2.0 controller is going to check, if there is a solution using DG reactive power to keep the voltage profile in the distribution grid within the operational limits. The DSO can then inform the TSO how far the voltage boundary can be exceeded on high voltage side.
B. The TSO has a voltage problem in the transmission grid and requests reactive power from the distribution grid. The SysDL2.0 controller determines the maximal capacitive and inductive reactive power, which can be provided from DGs and be supplied at PCC. The DSO informs the TSO about the flexibility range and the TSO can then request a certain amount.
C. The TSO wants to use a power plant in the distribution grid for dispatching its energy. The SysDL2.0 controller checks if this dispatch effects some network boundaries and in case there is a violation, it will compute a solution using reactive power if this is possible. The results will then be fed back to the TSO and the DSO will give its agreement to the requested dispatch.
D. The voltage boundaries within the 110 kV distribution network will be held with the usage of DGs reactive power. In all Use cases, the SysDL2.0 controller will consider this constraint.
E. In case everything is at normal state in the networks and no requests are existent, the SysDL2.0 controller will minimize the active power network losses using reactive power. In detail, the voltage profile will be smoothed and lifted towards a higher average voltage. Even if there are requests existent, minimizing network losses is tried to achieve but with a minor priority.
F. Prevent local overloading of equipment is also a permanent constraint for all Use Cases. If an overloading is detected, the SysDL2.0 controller tries to find a solution, which can clear the congestion with the help of reactive power.

SysDL2.0 Controller

The controller consists of several parts, which are:

- Topology Processing
- Measurement allocation
- State Estimation
- Forecast preparation
- Optimal (reactive-) Power Flow

- Result preparation

Topology processing and measurement allocation

Equipment and topological data are stored in CIM format in a database from as well as the measurements from the network. This information is collected from the database and then transformed into the data model of the load flow solver. Within this step, the measurements are assigned to the related assets and then the network is transformed from a detailed topological model into a condensed load flow model. Within this step, the individual switch configurations are considered and the effective topology is obtained.

State Estimation

Since these measurements consist of an error (noise, missing values, wrong topology, …), a state estimation is applied in order to correct for those errors and improve the data quality. The state estimation is also able to detect possible topology errors by performing a χ2-Test.

Forecast preparation

In order to compute short-term forecasts (4 hrs), latest measurements are sent to the forecast server and are used to improve the predictions, which in general base on the weather forecast for the DG locations and trained neuronal networks. The forecast is then used to generate predicted network states on which the same operations will be performed as on the current network state. This way, not only the flexibility for the current state are obtained, also for the next 4 hours. This helps TSO and DSO to plan the network activities.

Optimal (reactive-) Power Flow

The optimal power flow is done in a linearize approach using sensitivity matrices. It is an iterative method with respect to network constraints and congestion analysis (n-1 cases). The controller has to perform in real time, which puts hard constraints on the optimization time needed. In general, following description of the problem is applied:

For all Use Cases, loss minimization is the basic cost function

$$\mathrm{F(Q)} = \min \sum_{i=1}^{N} P_{\mathrm{loss}}^{i}(\boldsymbol{q}) \quad ,$$

General constraints for all Use Cases:

1. Reactive Power Boundaries of DG:
$$q_{\mathrm{min}}^{i} \leq q^{i} \leq q_{\mathrm{max}}^{i} \; \forall \; i \in \{\mathrm{DG}\}$$
2. Voltage Limits:
$$u_{\mathrm{min}} \leq u \leq u_{\mathrm{max}}$$
3. Operational Limits for the Equipment:
$$I^{i} \; \leq I_{\mathrm{max}}^{i} \quad \forall \; i \in \{\mathrm{Equipment}\}$$

If there is a request from TSO to DSO to supply reactive power at PCC, then an additional constraint enters the OPF:

Q- (V-) Setpoint within a given range:

$$\left|Q_{\mathrm{PCC}} - Q_{\mathrm{PCC}}^{\mathrm{set}}\right| \leq Q_{\mathrm{range}}$$

In order to determine flexibility ranges, a different cost function has to be used. This function is again subject to constraints 1 - 3

$$\mathrm{G(Q)} = \max \sum_{i=1}^{n} g_{Q}^{i}(\boldsymbol{q}) \quad \text{with } g_{Q}^{i}(\boldsymbol{q}) = \pm Q_{\mathrm{PCC}}^{i},$$

Q_{PCC}^{i} describes the reactive power exchange at i-th PCC. These will be maximized or minimized. The flexibility is then either the range per transformer or PCC or the sum over all PCCs

Result preparation

The computed setpoints for DGs are then converted into CIM objects and stored in a database. If needed, the reactive power setpoints are also expressed as cos(phi) of the individual DG. There are also setpoint objects for transformers, PCCs and the whole network, which consists of reactive power setpoints as well as upper and lower boundary for the possible reactive power flow over those network elements. A characteristic visualization of the results is given in Figure 18.

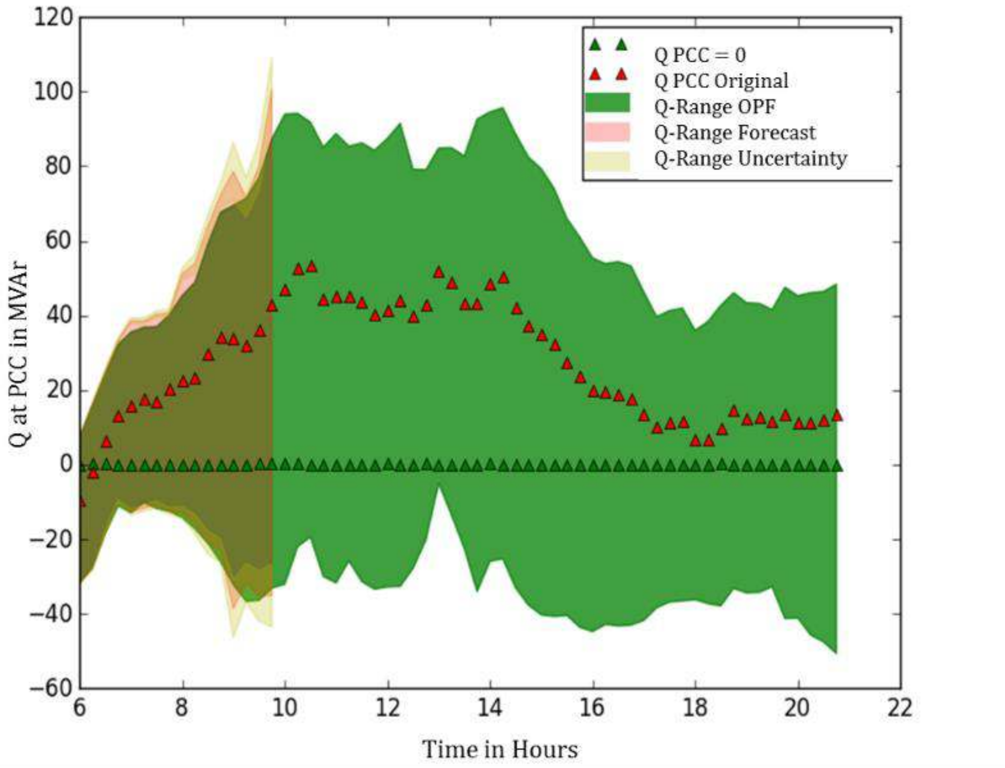


Figure 18: Characteristic visualization of the SysDL2.0 results.

SysDL2.0 Field Test Demonstrator

The field test demonstrator is a system platform, which consists of the following elements:

- CIM CGMES database
- Talend ESB (message bus)
- SysDL2.0 Controller (described above)
- Standardized interfaces

CIM CGMES DB

CIM CGMES stands for Common Grid Model Exchange Standard and was chosen as the basic data model in the project. Both DSO provides their network information and measurements in this format and will be read in via a CIM interface. The data is then stored in the database. The database can be accessed via SQL queries. These queries can also be used via a REST service, which allows the reading and writing in the database.

Talend ESB

In order to coordinate the communication and data flow within the demonstrator, an Enterprise Service Bus (ESB) from Talend is used. This ESB sets up the messaging system (ActiveMQ) and REST service. It also controls the incoming data via the CIM interface. See the overview of the components in Figure 19

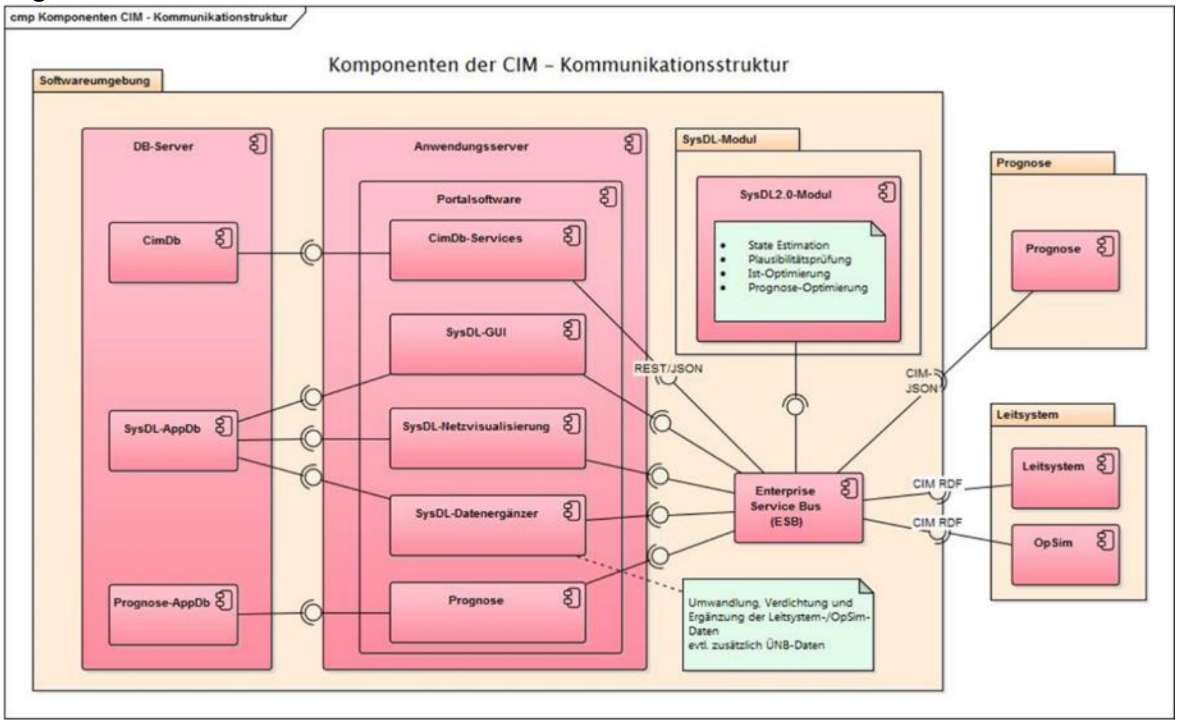


Figure 19: System architecture of the SysDL2.0 Field Test Demonstrator.

Standardized Interfaces

Using standardized interfaces like CIM or IEC61850 enables the system platform to be applied at different DSO operating centers in a similar way. This reduces the development effort and minimizes conversion errors when receiving and translating incoming data. The CIM data model provides the most sophisticated standard describing the electrical network. With the use of CIM, the interoperability and sustainability were enhanced.

Conclusion

Within the duration of the project, it became very clear, that the most difficult part was setting up the scene for the aimed field test. Finding a suitable and standardized data model was necessary and resulted in an enhanced effort. Nevertheless, this effort paid back when it came to the implementation and connection with the DSO control center. Using the CIM CGMES help to describe and interpret the grid data in a common way. The project ended with a successful field test, in which the functionalities of the modules could be proven. It turned out, that the one-way direction of data flow resulted in a very difficult handling of the determined setpoints for DER. The system operator had to adjust about 10 DER within 2 minutes, which was not doable. We see therefore a strong need for following projects to implement a closed loop automated process.

2.4.A Live PV Testing for Larger Adoption (PVTP)

Kenn H.B. Frederiksen (Kenergy)

Table 10: Fact sheet PVTP

Project: A Live PV Testing Platform for Larger Adoption (PVTP)
Reported by: Kenn H. B. Frederiksen (Kenergy)
Country: Denmark
Start: 01.08.2016 **End:** 01.08.2018
Research Partners: DTU Electrical Engineering (University), Bornholms Forsyning (DSO), Kenergy, Eniig, SolarConnectivity
Project Goals/ Research Tasks: • Analysing the capabilities in the utility infrastructure and implementation of the testing equipment at Bornholms Forsyning so the utility are able to run the photovoltaic inverters as Statcom systems. • Setting up the ITC infrastructure from the control room of Bornholms Forsyning to the solar inverters. • Investigate possible control strategies and evaluate control measurements point to be used for the control. • Evaluate the economical gain of running the photovoltaic inverters as a Statcom and compare it with alternative reactive power solutions.
TSO/DSO Grid operation challenges: 1. Voltage support 2. Balancing challenges
Communication infrastructure and functionalities TSO/DSO interfaces : BE is a Danish DSO who also acts as a TSO on the Danish island of Bornholm. From the control room of Bornholms Forsyning the operators have the opportunity to control energy flow to/from Sweden, local central power plant and the installed wind turbines on the island.
Key Findings/ Recommendations: Ongoing project
Further comments: The project is a continuation of a prior project PV-net where the theory and potential of using solar inverters in the low voltage network was explored. The project has received funding from Energinet.dk ForskEL journal no. 12421.
Further Information: The PVTP project is taking place on the Danish island of Bornholm, which is also hosting the Ecogrid 2.0 project. More information about the Ecogrid 2.0 project can be found at the homepage: http://www.ecogrid.dk/en/home_uk#hvad3

2.5. Real-time optimization and control of next-generation distribution infrastructure

Barry Mather (NREL)

Table 11: Fact sheet - Real-time optimization and control of next-generation distribution infrastructure

Real-time optimization and control of next-generation distribution infrastructure
Country: USA
Start: 07/2016 **End:** 06/2019
Research Partners: National Renewable Energy Laboratory, California Institute of Technology, University of Minnesota, Harvard University, Southern California Edison **Industry Advisory Board:** California Independent System Operator, PJM Interconnection LLC, E.On, Centrica
Project Goals: Development of a comprehensive distribution network management framework that unifies real-time voltage and frequency control at the home/distributed energy resource level with network-wide energy management at the utility/DSO level. Design of system-theoretic distributed control framework that enables distribution feeders to emulate virtual power plants effectively implementing frequency response mechanisms and following dispatch signals precipitated from the TSO, while concurrently ensuring that voltages and power flows within the feeder are within safety limits.
Grid operation challenges in cooperation TSO/DSO: • Frequency response (TSO/DSO) • Tracking of dispatch signals
Communication infrastructure TSO/DSO : • Involved parties: DSO, TSO, Distributed energy resources (DERs) • Communication frequency: every seconds/subseconds • TSO control center / DSO control center: TCP or UDP • DSO control center / DER control module: TCP or UDP • DER control module / DER: standardized communication protocol (e.g., modbus)
Functionalities TSO/DSO interface : • Frequency response • Tracking of automatic generation control signals • Optimization of active and reactive power flexibility at TSO/DSO interface • Minimization of DER active power curtailment • Voltage regulation within the feeder
Key Findings/ lessons learned: • DERs located in distribution feeders can provide primary frequency response capabilities to improve frequency nadir and steady-state frequency deviation. • Ongoing project.
Further Information: Benjamin Kroposki: benjamin.kroposki@nrel.gov Emiliano Dall'Anese: emiliano.dallanese@nrel.gov Andrey Bernstein: Andrey.bernstein@nrel.gov More detailed information can be found on the following homepage: https://www.nrel.gov/grid/real-time-optimization-control.html

2.6. Modelling of DER in Transmission Planning Studies

Jens Boemer (EPRI)

Table 12: Fact sheet – Modelling of DER in Transmission Planning Studies

Project: Modeling of DER in Transmission Planning Studies
Country: California, United States
Start: 2015 **End:** 2016
Research Partners: EPRI, NREL, SANDIA
Project Goals: Modeling of transmission system performance with DER
Grid planning challenge: Maintain grid stability with large amounts of DER
Communication infrastructure TSO/DSO : DER deployment data exchange, e.g., capacity, type, legacy vs. modern grid code compliance
Functionalities TSO/DSO interface : n/a
Key Findings: technical justification for ride-through requirements for DER
Further comments: ongoing research is addressing higher DER penetration levels
Further Information: Jens Boemer, EPRI, jboemer@epri.com Anish Gaikwad, EPRI, agaikwad@epri.com Eknath Vittal, EPRI, evittal@epri.com **Publications:** • [MDTPS.1] Electric Power Research Institute (EPRI) (2016): Analysis to Inform CA Grid Integration Rules for PV. Final Report on Inverter Settings for Transmission and Distribution System Performance. 3002008300. Available online at: http://www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=000000003002008300 • [MDTPS.2] van Ruitenbeek, Emmanuel; Boemer, Jens C.; Rueda, José L.; Gibescu, Madeleine; van der Meijden, Mart A.M.M. (2014): A Proposal for New Requirements for the Fault Behaviour of Distributed Generation Connected to Low Voltage Networks. In Uta Betancourt, Thomas Ackermann (Eds.). 4th International Workshop on Integration of Solar Power into Power Systems. Berlin, Germany, November 10-11. Energynautics GmbH. Langen: Energynautics GmbH. Available online at: http://integratedgrid.com/wp-content/uploads/2016/07/van-Ruitenbeek-Boemer-et-al.-2014-A-Proposal-for-New-Requirements.pdf

2.7. TDX-ASSIST

Frank Marten (Fraunhofer IEE)

Table 13: Fact Sheet – TDX-ASSIST

Project Name: TDX-ASSIST
Country: England, France, Slovenia, Portugal, Germany
Start: 10/2017 **End:** 09/2020
Research Partners: Brunel University London, EDF, Fraunhofer IEE, Offis, ENTSO-e, ELES, EG, EIMV, EDP, R&D Nester, REN, INESC TEC
Project Description: This project aims to design and develop novel Information and Communication Technology (ICT) tools and techniques that facilitate scalable and secure information systems and data exchange between Transmission System Operators (TSO) and Distribution System Operators (DSO).
Project Goals (TSO/DSO cooperation): The three novel aspects of the TSO/DSO ICT tools and techniques to be developed in the project are: scalability – ability to deal with new users and increasingly larger volumes of information and data; security – protection against external threats and attacks; and interoperability –information exchange and communications based on existing and emerging international smart grid ICT standards.
Grid operation challenges in cooperation TSO/DSO: • Congestion Management • Voltage Support (reactive power) • Balancing Challenge • Exchange of planning data • Real-time fault location
(Planned) Communication infrastructure TSO/DSO: • The project aims to upgrade standards such as CIM Common Grid model Exchange Specifications CGMES, for TSOs and DSOs to exchange operative data as well as reduced network models of neighboring grid areas.
(Planned) Functionalities TSO/DSO interface: • Advanced Monitoring • Exchange of planning data • Active Power Dispatch/ Scheduling • Reactive Power Dispatch / Scheduling • Volt/ Var Optimization
Further Information: More detailed information can be found on the following homepage: http://tdx-assist.eu/

2.8. NEW 4.0

Friederike Meier (Fraunhofer IEE)

Table 14: Fact sheet – NEW 4.0

Project Name: NEW4.0 (here focus work package 1: Grids)
Country: Germany
Start: 12/2016 **End:** 12/2020
Research Partners: ARGE Netz GmbH & Co. KG, Fraunhofer IEE, HAW Hamburg/ CC4E, HanseWerk Natur GmbH, Schleswig-Holstein Netz AG, Stadtwerke Norderstedt, Stromnetz Hamburg GmbH, TenneT TSO GmbH.
Project Description: The goal of this work package 1 „Grids“ is to facilitate the system integration of renewable energy as well as the coordination of various participants in all grid levels for a secure grid and system control. Therefore, the transparency of the grids should be increased and the congestion should be reduced by intelligent control methods.
Project Goals (TSO/DSO cooperation): 1) Enhanced online transparency of the actual grid state in the DSO grid 2) Enhanced prognosis and extrapolation of wind power feed in 3) Concept, Simulation, and realization of a power grid traffic light concept 4) Enhanced Determination of the hosting capacity of specific PCCs 5) Techno-economic optimization of grid planning principles 6) New system control concepts 7) Interruptible loads like household appliances as a storage in the power grid 8) Transferability to other grid areas 9) Potential assessment of a sector coupling
Grid operation challenges in cooperation TSO/DSO: • Congestion Management • Voltage Support (TSO/DSO)
(Planned) Communication infrastructure TSO/DSO: • Not available
(Planned) Functionalities TSO/DSO interface: • DER Forecasting and Load Forecasting → Congestion Forecasting • Active Power Dispatch/ Scheduling in the Day Ahead planning process using a newly designed market platform • Perspective: Plants and interruptible loads in the DSO grid participate in the clearing of congestion in the TSO grid
(Preliminary) Key Findings/ lessons learned: • Market demonstrator available
Further Information: More detailed information can be found on the following homepage: http://www.new4-0.de/

2.9. NETZ:KRAFT

Maria Valov, Wolfram Heckmann (Fraunhofer IEE), Christian Hachmann (University of Kassel), Manuela Wunderlich (DERlab)

Table 15: Fact sheet – NETZ:KRAFT

Project Name: NETZ:KRAFT - Grid restoration in consideration of future power plant structures
Country: Germany
Start: 01/2015 **End:** 06/2018
Research Partners: Fraunhofer IEE, 50Hertz Transmission GmbH, TransnetBW GmbH, TenneT TSO GmbH, Amprion GmbH, E.ON Hanse AG, EAM GmbH & Co. KG, MITNETZ Strom GmbH, DREWAG NETZ GmbH, Avacon AG, ENERCON GmbH, Energiequelle GmbH, SMA Solar Technology AG, ÖKOBIT GmbH, PSI AG, Dutrain GmbH, GridLab GmbH, Friedrich-Alexander-Universität Erlangen-Nürnberg, Universität Kassel, DERlab e.V.
Project Description: The project NETZ:KRAFT analyzes the possibilities offered by distributed and renewable energy resources to contribute to the restoration of the power system after blackouts. Therefore, the project combines two different approaches: the top-down approach (re-energizing the system from transmission grid to distribution grid) and the bottom-up approach (creation of re-energized or still operating islands in the distribution grid, which are then synchronized to re-energize the transmission grid).
Project Goals (TSO/DSO cooperation): Two main goals of NETZ:KRAFT are: 1. Further development of the existing grid restoration processes at the transmission grid level, considering the increasing amount of distributed energy resources. 2. Active usage of distributed energy resources in supply islands of distributions system operators to shorten the outage of the grid. Additionally, to the technological aspects, the project also deals with the coordination between system operators. NETZ:KRAFT brings relevant stakeholders – DSOs, TSOs, manufacturers, researchers – together to deal with the challenge of power system restoration in future scenarios for the electric power system. Several case studies and demonstrations are being developed within the project. These include, among others: - Start of a thermal generation unit, supported by wind park - Connection of long overhead lines with wind park available for supply with reactive power - Connection of load in networks with different generator types (conventional, DER, mixed etc.) - Synchronization of subnetworks - Grid restoration with HVDC - Supply islands in distribution networks (case studies: city, rural area, agricultural site and more) - Analysis of power system protection
Grid operation challenges in cooperation TSO/DSO: • Balancing Challenge • (Anti-) Islanding, re-synchronization & black-start
(Planned) Functionalities TSO/DSO interface: • Active Power Dispatch/ Scheduling • Reactive Power Dispatch / Scheduling
(Preliminary) Key Findings/ lessons learned:

- An increasing penetration of renewables, especially on the distribution level, offers opportunities for DSOs to support the power system restoration coordinated by the TSO by means of
  - Making use of remote controllable renewable power plants to balance uncontrolled feed-in of small distributed generators and load variation
  - Compensating the power ramps caused by automatic reconnection of small distributed generators,
  - Maintaining predefined levels of power exchange at the connection point to TSOs control area and
  - Providing precise load values on demand.

  In order to do so, there is an increased need for coordination and the availability of information on installed distributed generation as well as forecasts for the availability of weather-dependent generation.

Further Information:

Wolfram Heckmann, Fraunhofer IEE, wolfram.heckmann@iee.fraunhofer.de

More information about the NETZ:KRAFT project can be found at the homepage:

- [Netz:Kraft.1] http://forschung-stromnetze.info/en/projects/grid-restoration-with-future-power-plant-structures/
- [Netz:Kraft.2] http://netz-kraft-projekt.de/

Publications:

- [Netz:Kraft.3] Luis Pabón, Andres Felipe Correa, Maria Valov, Gustav Lammert, Daniel Premm, “Impact of Plant Level Voltage Control of Large-Scale Inverter Based Generators on Long-Term Voltage Stability”, Power Systems Computation Conference 2018, 11.-15.06.2018, Dublin.
- [Netz:Kraft.4] Christian Hachmann, Maria Valov, Gustav Lammert, Wolfram Heckmann, Martin Braun, “Unterstützung des Netzwiederaufbaus durch Ausregelung der dezentralen Erzeugung im Verteilnetz“, Konferenz „Zukünftige Stromnetze für erneuerbare Energien“, 30.-31.01.2018, Berlin.
- [Netz:Kraft.5] Christian Hachmann, Gustav Lammert, Darío Lafferte, Martin Braun, “Power System Restoration and Operation of Island Grids with Frequency Dependent Active Power Control of Distributed Generation”, NEIS Conference 2017, September 21-22, 2017, Hamburg.
- [Netz:Kraft.6] Holger Becker, Akim Naranovich, Tobias Hennig, Alev Akbulut, Denis Mende, Sebastian Stock, Lutz Hofmann, “System Restoration using VSC-HVDC connected Offshore Wind Power Plant as Black-Start Unit”, 19th European Conference on Power Electronics and Applications, 11.-14.09.2017, Warschau.
- [Netz:Kraft.7] Alev Akbulut, Holger Becker, Denis Mende, David Sebastian Stock, Lutz Hofmann, “Neighboring system as black start source and restoration process based on the VSC-HVDC as tie line”, 19th European Conference on Power Electronics and Applications, 11.-14.09.2017, Warschau.
- [Netz:Kraft.8] Darío Lafferte, Alexander Klingmann, Dirk Fetzer, Gustav Lammert, Christian Hachmann, Tina Paschedag, Martin Braun et.al., “Black start and island operation of distribution grids with significant penetration of renewable resources”, 1st International Conference on Large-Scale Integration of Renewable Energy in India, 6.-9. Sept. 2017.
- [Netz:Kraft.9] Dirk Fetzer, Gustav Lammert, Kai Fischbach, Manuel Nuhn, Christian Jaehner, Holger Becker, Martin Braun, “Reconnection of Photovoltaic Systems in Low-Voltage Diesel-Powered Microgrids”, 1st International Conference on Large-Scale Grid Integration of Renewable Energy in India, 6.-8.9.2017.
- [Netz:Kraft.10] Maria Nuschke, “Development of a Microgrid Controller for Black Start Procedure and Islanding Operation”, INDIN‘2017 24./27.7.2017, Emden.

- [Netz:Kraft.11] Martin Shan, Friedrich Welck, Weiwei Shan, Holger Becker, Sebastian Stock, “Operating Wind Turbines as Dynamically Controllable Loads in Grid-Restoration Scenarios”, Wind Integration Workshop 15.-17.11.2016.
- [Netz:Kraft.12] Holger Becker, Denis Mende, Tobias Hennig, Alev Akbulut, Lutz Hofmann et. al., “Power System Restoration - How could wind energy generators be included into today’s restoration plans?”, Wind Integration Workshop 15.-17.11.2016.

2.10. EU-SysFlex

Sebastian Wende – von Berg (Fraunhofer IEE)

Table 16: Fact Sheet – EU SysFlex

Project Name: EU SysFlex
Country: England, France, Slovenia, Portugal, Germany
Start: 11/2017 **End:** 10/2021
Research Partners:
Project Description: The EU-SysFlex project tests a high level of integration of renewable energy sources in the pan-European system. The aim of the EU-SysFlex project is to identify issues and solutions associated with integrating large-scale renewable energy; provide practical assistance to power system operators across Europe; and identify a long-term roadmap to facilitate the large-scale integration of renewable energy across Europe. Project activities cover a large part of the innovation process, to bring new solutions to the market: from the development of new approaches for system operation with high renewables, to market design and regulatory requirements, to the integration of new system services and data management.
Project Goals (TSO/DSO cooperation): The goal of the project is to perform the Scalability and Replicability analysis (SRA) of the results from demonstrations within the project and provide a clear vision and strategy in the form of a roadmap for development and deployment of system services needed by TSOs to support the integration of RES, storage and flexible demand technologies, in order to meet the carbon targets while maintaining the security of supply and minimizing the electricity costs to consumers.
Grid operation challenges in cooperation TSO/DSO: • Congestion Management • Voltage Support (TSO/DSO) • Balancing Challenge • Market design • Communication technologies
(Planned) Communication infrastructure TSO/DSO: • The project aims to upgrade standards such as CIM CGMES, for TSOs and DSOs to exchange operative data. Also a communication platform will be developed which will service a data pool for all participating stakeholders.
(Planned) Functionalities TSO/DSO interface: • Advanced Monitoring • Topology Recognition • Active Power Dispatch/ Scheduling • Reactive Power Dispatch / Scheduling • Volt/ Var Optimization
Further comments: The EU-SysFlex project is funded from the EU framework programme for research and innovation Horizon 2020 under the call H2020-LCE-2016-2017 (http://eu-sysflex.com/about/).
Further Information: More detailed information concerning the project can be found on the following homepage: http://eu-sysflex.com/

2.11. PV-Regel

Mathias Bünemann, Daniel Premm (*SMA)*

Table 17: Fact Sheet – PV-Regel

Project Name: PV Regel
Country: Germany
Start: 08/2014 **End:** 07/2018
Research Partners: SMA Solar Technology AG, Technische Universität Braunschweig, GEWI AG
Project Description: To master the energy transition, renewables have to take over more system responsibility. In this project technical solutions which enable PV systems to provide control reserve with minimal losses and additional system costs are developed. Additionally, the goal is to work out recommendations to adapt the control reserve market conditions to establish PV as a provider of further ancillary services.
Project Goals (TSO/DSO cooperation): DEVELOPMENT OF CONCEPTS AND SOLUTIONS FOR THE PROVISION OF CONTROL RESERVE WITH PV.
Grid operation challenges in cooperation TSO/DSO (highlight relevant challenges): • Congestion Management • Balancing Challenge • TSO/DSO cooperation for providing TSO services (control reserve) with units connected to the distribution systems
(Planned) Communication infrastructure TSO/DSO: • Control reserve in PV plants is usually activated by a direct communication between control reserve provider and plant. Typically, the provider connects to the local network via VPN and uses ModBus in order to communicate set points. In this project, necessary modification of both the communication protocol and infrastructure shall be identified.
(Planned) Functionalities TSO/DSO interface: • DER Forecasting • Active Power Dispatch/ Scheduling • DER Now-casting (determine of current active power potential)
(Pre-liminary) Key Findings/ lessons learned: • PV Systems are technically prepared to provide high quality control reserve • State of the art inverter technology can also provide virtual inertia to fully substituted conventional generators; further investigations necessary with respect to a massive deployment on distribution/transmission grid scale. • Current control reserve market conditions (in Germany) exclude PV as a provider of further ancillary services. Recommendations for adapted market conditions are: use of intraday forecast, shorter tendering periods and shorter product time slices
Further Information: More detailed information can be found on the following homepage: http://forschung-stromnetze.info/en/projects/balancing-power-with-pv-systems-for-stable-grid-operation/

2.12. Next-Generation SCADA

Kazuhiko Ogimoto (University of Tokyo), Koichi Takeuchi, Jun Yoshinaga (TEPCO Power Grid Company)

Foreword

In the deregulation of the electricity sector in Japan, in consideration of the closely-related and complicated operation of transmission and distribution levels, it was decided not to unbundle transmission and distribution. TEPCO Power Grid Co. is developing the next generation SCADA to support the objectives of cost reduction, enhancement of service quality and provision of new functionalities for the future. The next-generation SCADA is being designed based on the strategies to enhance the operational flexibility by location and responsibility of users and objects and the system design flexibility by complying international standards.

Table 18: Fact Sheet – Next-Generation SCADA

Project Name: Next-Generation SCADA
Country: Japan
Start: 2016 **End:** 2018
Research Partners: Toshiba **DSOs**: TEPCO Power Grid Co. **TSO:** TEPCO Power Grid Co. **Industry Partners:** Toshiba
Project Description: TEPCO PG Company is now developing the Next Generation SCADA which cover transmission system (154kV, 66kV) and distribution system (6kV) by accommodating many roles of maintenance and operation staff members of different locations with different responsibilities, sharing operation and maintenance data, and assuring the security of the system. The new system will be expanded to accommodate 275 kV system and 500 kV in the future to be a powerful tool to treat TSO/DSO issues. As a future component of the system, a Centralized Voltage Control System for feeders is under demonstration test to reduce the number of tap changes of devices and to improve the voltage control in the distribution level to avoid the voltage deviation due to massive PV penetration.
Project Goals (TSO/DSO cooperation): The objectives of Next-Generation SCADA are to reduce costs, adopt international standards, and maintain and enhance the quality of work. The objective of the Centralized Voltage Control System is an optimized voltage profile in the distribution feeders, which should be a powerful tool to accommodate higher PV penetrations in the LV and MV level.
Grid operation challenges in cooperation TSO/DSO: • Visibility and manageability through a transmission and distribution system • Accommodation of different roles of staff members of maintenance and operation • Adaptation to international standards • Congestion management under PV penetration
(Planned) Communication infrastructure TSO/DSO: • Involved parties: DSO, TSO: Business units of TEPCO Power Grid Company • TSO control center / DSO control center: 10 Sub-transmission Control Centers, 56 Distribution Automation Centers
(Planned) Functionalities TSO/DSO interface: • Complete data sharing according to role and responsibility • Enhanced authentication by non-contact IC card and palm vein authentication • Optimization of voltage control in feeders (Demonstration test)

- Capability to accommodate future forecast, optimization and control functions including distributed PV management
- **Applied functionalities Next-Generation SCADA:**
  - Advanced Monitoring
  - Distribution System State Estimation
  - Topology Recognition
  - Automatic Reconfiguration
  - Contingency Analysis
  - Fault location
  - Fault Isolation and System Restoration
  - Advanced Authentication
  - Advanced cyber security
  - Compliance to international standards
- **Functionalities under demonstration test for near-future deployment:**
  - DER Forecasting
  - Load Forecasting
  - Reactive Power Dispatch /Scheduling
  - Volt/ Var Optimization
  - Voltage Regulator Coordination

(Pre-liminary) Key Findings/ lessons learned:

- Full support of transformation of organizations, roles, and responsibilities of section and persons
- Full share of data according to roles and responsibilities
- Implementation in operation/maintenance centers of TSO and DSO
- Fundamental SCADA structure enhancement for future innovative functionalities

Further Information:

- [Next-SCADA.1] Ministry of Economy, trade and Industry, Committee report (May 2018) http://www.meti.go.jp/report/whitepaper/data/20180522001.html
- [Next-SCADA.2] M. Watanabe, M. Miyata, N. Itaya and T. Takano, "Field demonstration and evaluation of centralised voltage control system for distribution network," in CIRED - Open Access Proceedings Journal, vol. 2017, no. 1, pp. 1143-1147, 2017

Introduction

Japan has been experiencing rapid deployment of renewable energy resources, especially variable renewable energy (VRE), since the Feed-in Tariff (FIT) Program was launched in July of 2012, one year after the Great East Japan Earthquake and Tsunami. The widespread and rapid penetration of VRE has been affecting power system operations of each of Japan's ten balancing areas (utilities that balance demand supply within certain geographic areas of interconnected power grids). The significance of impact depends largely on the degree of the penetration.

In 2014, under the situation of rapid VRE penetration, the Japanese government established the "Working Group on Grid Connection of Renewable Energy" (the Working group) in 2014 and the "Subcommittee on Massive Integration of Renewable Energy and Next Generation Electric Power Network" (the Subcommittee) in 2017 in order to discuss: the carrying capacity in balancing areas and the subsequent enhancement thereof; and the challenges and potential solutions toward massive integration of renewable energy [Next-SCADA.1].

As typically experienced in the Kyushu area with peak power demand of 15 GW and an about 2.5 GW interconnection to the main island, where the PV penetration is still growing beyond the current level of about 8 GW, the PV penetration have been causing issues such as power system operational difficulties of balancing and network congestion in both of transmission and distribution systems.

In the Working group, many discussions and decisions have been made on the accommodation of PV and wind capacity under FIT program and countermeasures to enhance the accommodation capacity assuming the current laws and rules by academic researchers as a neutral person, also including the opinions from the stakeholders such as utilities in charge of transmission and distribution, generators of renewables including PV and wind, power companies. Since 2014, the Working group has been verified the capacity of renewable energy integration in the ten balancing area in Japan, and established several decisions to R&D project for remote control/management of renewable energy generation.
In the Subcommittee, which is comprised of academic researchers, representatives of utilities, industry, consumers, market and system operation regulators, have been discussing the improvement of FIT program and other issues related to renewable energy integration and power networks.

The Subcommittee, among the issues of renewable, has just discussed about “Connect and Manage”. There is a discrepancy between areas with high demand and those suitable for renewable energy in Japan. Under the current grid operation rule (“Invest & Connect”), grid enhancement must be required if grid capacity is full, requiring time and money. With a view to the maximum and flexible use of the existing grid, Japan will develop the “Connect & Manage” rule, under which new grid connection will be permitted on the premise of constraint during grid congestion (as shown in Figure 20).

	Current operation	Direction of revision
(1) Streamlining of power flow calculation	Full capacity operation of all generators	Nearly actual flow
(2) Overloads in N-1 situation	Always secure free capacity for emergency	Release the capacity by instantaneous tripping in emergency condition
(3) Non-firm access	(Not considered)	Grid access without grid enhancement

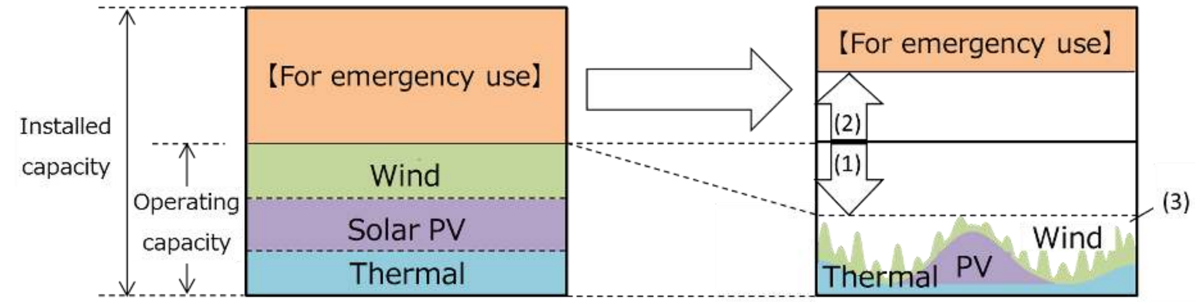


Figure 20: Maximum use of existing grid (Connect & Manage) [Next-SCADA.1]

Under the penetration of PV and other renewables, each of ten TSO-DSO companies in Japan are now expected to manage the transmission and distribution system in operation and planning and to accommodate renewable energy sources economically with reasonable service security and quality.

Next-Generation SCADA System

Under the general situation, power companies in Japan are seeking to deploy next-generation SCADA system to enhance the reliability, efficiency, security, and robustness of operation of both the transmission and the distribution systems. Among the utilities in Japan, TEPCO Power Grid Co. (Transmission/Distribution Company in Tokyo Electric Power Co. group) is now developing the next generation SCADA to support the objectives of cost reduction enhancement of service quality, and provision of new functionalities for the future. The next-generation SCADA (see Figure 21) is being designed based on the strategies to enhance the operational flexibility by location and responsibility of users and the system design flexibility by complying international standards to satisfy the following requirement:

1) Flexibility for organizational changes

2) Development of operational procedures by a collaboration of different sections and automatic generation
3) Centralization of operation and maintenance
4) Centralization of data management
5) Enhanced reaction to incidents by back-up support by other sections

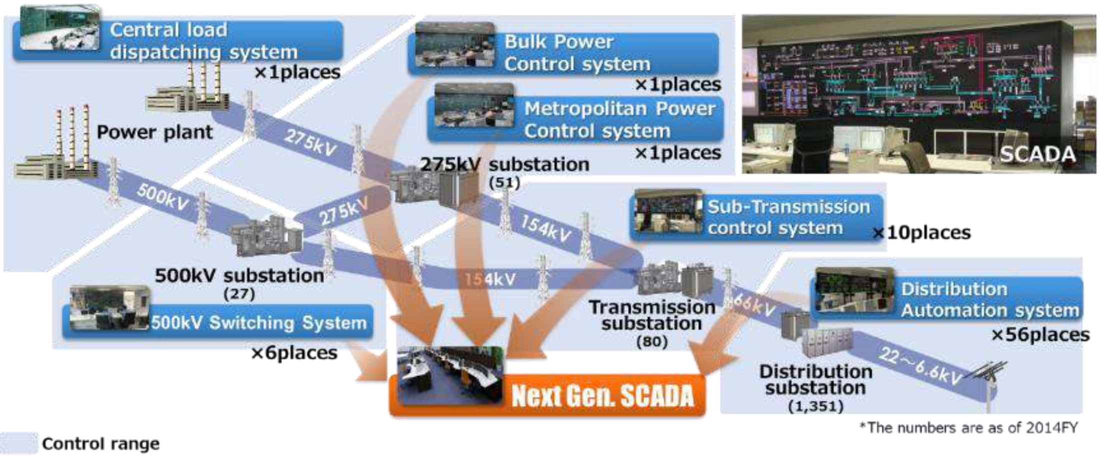


Figure 21: The next generation SCADA planned by Power Grid Company. (Source: TEPCO)

In the next generation SCADA, users are authenticated by a combination of a non-contact IC card and Palm vein authentication. This authentication realizes not only enhancement of system security but also the flexibility of defining uses, because a person can be authorized for different areas and stations (Figure 22).

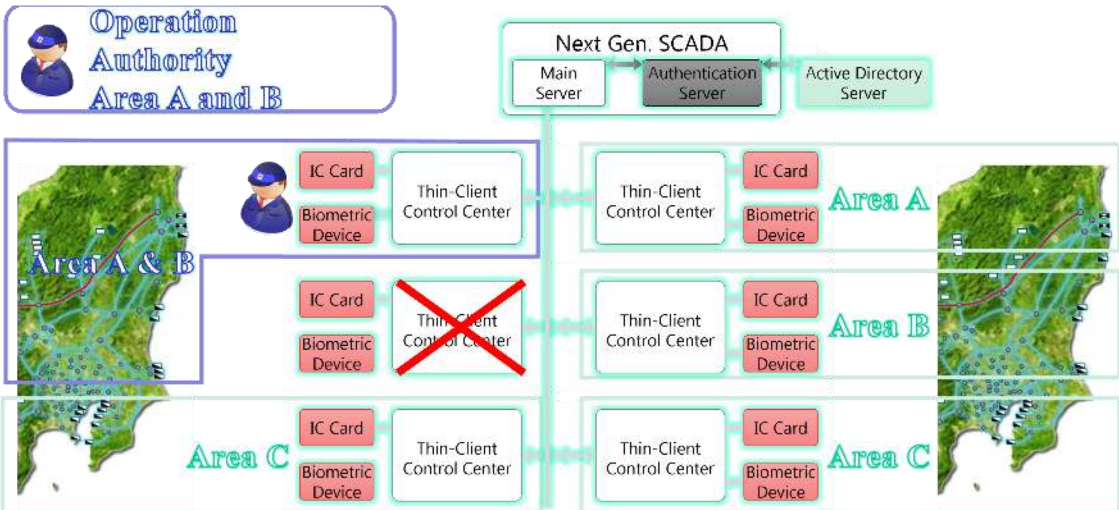


Figure 22: Flexible authentication in the next-generation SCADA (Source: TEPCO)

Optimized voltage control in a distribution system

Currently, in Japan, all the controllable devices in a distribution system are mainly controlled autonomously. Although the autonomous control is simple and cost effective, there are some limitations of functionalities because all the devices are controlled based on the voltage / current information of the installation point of the equipment. In order to improve their performance to optimize the voltage profile of feeders, controllable devices such as load ratio control transformers (LRTs) and step voltage regulators (SVRs) are remote-controlled from a centralized system using the measurements from sensors across a distribution system. Figure 23 shows DAS (Distribution Automation System) centrally control LRT and series devices using current and voltage data from IT switchgears and Smart grid data Transmission Equipment.

A demonstration test is under way in order to evaluate and assess the performance, operational issues, and further performances under heavy penetration of renewable energy generation. Figure 24 (left) depicts the Feeder Configuration of the demonstration test and Figure 24 (right) depicts the improved performance of the proposed Centralized Voltage Control System by the reduced numbers of tap changes and voltage deviations.

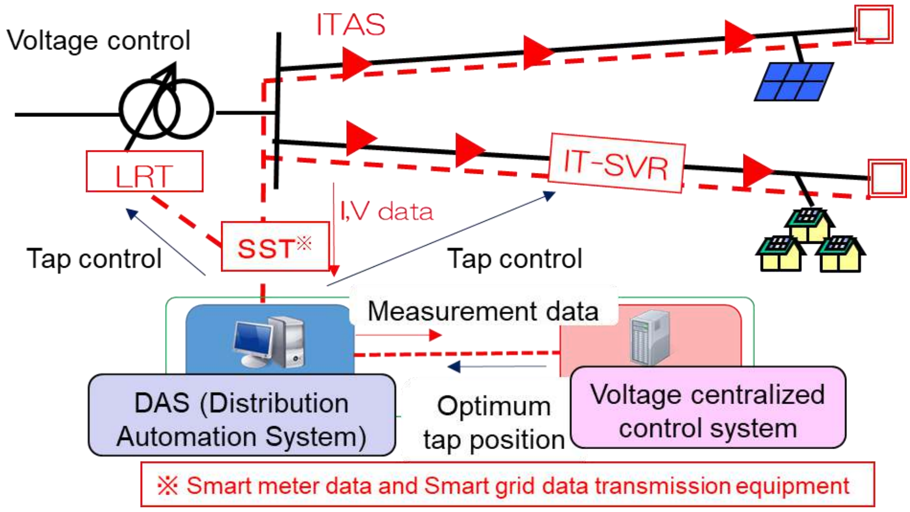
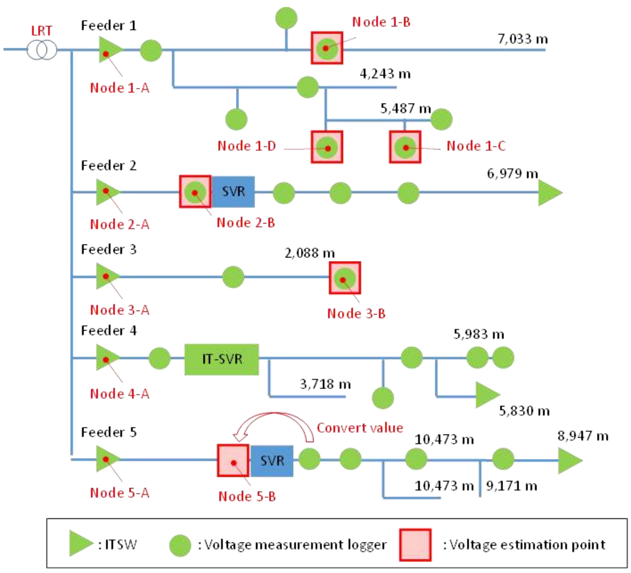


Figure 23: Scheme of the Centralized Voltage Control in a Distribution System (Source: TEPCO)



Control method	Date	Tap change number		Voltage deviation
		LRT	IT-SVR	[V・30min]
Autonomous control (conventional)	2017/01/23	5	12	0.34
	2017/01/24	6	15	0.67
	2017/01/25	6	13	0.84
	2017/01/26	4	7	1.24
	2017/01/27	3	13	1.45
	2017/01/28	5	11	2.28
	2017/01/29	5	6	2.04
	Average	4.9	11	1.27
centralized control system	2017/02/02	4	6	0.04
	2017/02/03	1	4	0.03
	2017/02/04	3	5	0.15
	2017/02/05	2	4	0
	2017/02/06	2	7	0.03
	2017/02/07	5	3	0.03
	2017/02/08	2	5	0.12
	Average	2.7	4.9	0.06

Figure 24: left: Feeder Configuration of the demonstration test. Right: Performance of the proposed Centralized Voltage Control System (Reduction of tap changes, voltage deviations) (Source: TEPCO, [Next-SCADA.2])

Conclusion

The Next Generation SCADA is under development targeting the deployment in one of the four transmission/distribution management areas of TEPCO Power Grid Company in order to give solutions to the existing and emerging issues in the transmission/distribution area. Several R&D and demonstration test are in progress in parallel for the future deployment into the Next Generation SCADA. The fundamental upgrade of the SACADA structure will continue to support the changing responsibilities of a power grid company under the further changing circumstances.

2.13. Transmission & Distribution Interface 2.0

Based on literature review.

Table 19: Fact sheet – TDI 2.0

Project Name: Transmission & Distribution Interface 2.0 (TDI 2.0)
Country: England (UK)
Start: 12/2017 **End:** 12/2019
Research Partners: **Academic Partners:** Imperial College, University of Cambridge **DSO:** UK Power Networks **TSO:** National Grid plc
Project Description: *"The Transmission and Distribution Interface 2.0 (TDI 2.0) project, known as Power Potential, is a world-first trial to maximize network capacity to connect more renewable energy and storage technology in the South-East region of UK. By working jointly together, UK Power Networks (DSO) and National Grid (TSO) aim to open up new markets for distributed energy resources and generate additional capacity by alleviating transmission and distribution constraints. The outcome will be more renewable energy connected to the network and savings for their customers."* [TDI.1]
Project Goals (TSO/DSO cooperation): *"This project seeks to give National Grid access to energy resources connected to UK Power Networks in the South-East region of England to provide it with additional tools to manage certain voltage transmission constraints (High voltage in periods of low demand and low voltage under certain fault conditions)."* [TDI.1] *"The project will focus on the following methods:* • *A technical solution based on information and communication Technologies (ICT), which interacts with all market participants to facilitate the provision of services by the DER to National Grid Electricity Transmission.* • *New commercial arrangements between DER, UK Power Networks and National Grid Electricity Transmission, which ensures that they are sustainable over time.* • *Customer and market engagement which ensures that the solution is open to existing and new participants.* *A coordination framework for secure grid operation which will deliver efficient coordination across System Operator and DNO investment planning, operational planning and real-time horizons."* [TDI.2]

Grid operation challenges in cooperation TSO/DSO:
• Voltage Support (TSO/DSO)
    ○ *"Dynamic voltage stability: requiring reactive power delivery at short notice*
    ○ *High voltage: managing the voltage on the network during low load periods"* [TDI.1]
• Congestion Management
    ○ *"Thermal capacity: potentially leading to generation curtailment during the summer maintenance season"* [TDI.1]

(Planned) Communication infrastructure TSO/DSO: *"Considered Protocol used in communication infrastructure (TSO/DSO): ICCP ("Inter-Control Centre Communications Protocol") is a protocol designed for control system to control system integration. ICCP has been implemented between UK Power Networks (DSO) and National Grid (TSO) and enables*

sharing of real time data between the two parties. It is configured by using a subscriptions table and allows multiple subscribers to the same data points." [TDI.1]
(Planned) Functionalities TSO/DSO interface: • DER Forecasting • Load Forecasting • DER reactive and active power control. • Distribution System State Estimation • Optimal Power Flow function • Contingency Analysis
Further Information: More detailed information can be found in the following documents: • [TDI.1] UK Power, Networks,Nationalgrid ,"Transmission & Distribution Interface 2.0 (TDI 2.0),SDRC 9.1 –Technical High Level Design", July 2017 [Online]. Available: https://www.nationalgrid.com/sites/default/files/documents/SDRC9.1%20Unrestricted%20document.pdf • [TDI.2] UK Power Networks, Nationalgrid, "Transmission and Distribution Interface 2.0 (TDI)" - Bid Document to Ofgem [Online].Available: https://www.ofgem.gov.uk/ofgem-publications/107804

2.14. evolvDSO

Based on literature review.

Table 20: Fact sheet - evolvDSO

Project Name: evolvDSO - Development of methodologies and tools for new and evolving DSO roles for efficient DRES integration in distribution networks
Country: Portugal, Republic of Ireland, France, Belgium, Italy, Austria, Germany, Denmark
Start: 09/2013 **End:** 12/2016
Research Partners: Enel Distribuzione, Cybergrid, EDP Distribucao, European Distribution Operators for Smart Grids, Energy Pool Developpement, Electricitè Reseau Distribution France, ESB Networks, Inesc Porto, Institut Polytechnique de Grenoble, Ricerca sul Sistema Energetico, RTE, RWE Deutschland, RWTH Aachen, University College Dublin, Vlaamse Instelling Voor Technologisch Onderzoek, Energinet.dk
Project Description: *"The objective of the project is to define future roles of DSOs and develop new tools and methods that need to be solved for DSOs to efficiently fulfill their emerging and future roles encompassing planning, operational Scheduling, real-time operations and maintenance. "evolvDSO" will define future and evolving roles of distribution system operators (DSOs) on the basis of various future scenarios which will be driven by different DRES penetration levels and technological degrees of freedom."* [evolvDSO.1]
Project Goals (TSO/DSO cooperation): The project *"aims at defining future roles of distribution system operators (DSOs) on the basis of a set of different future scenarios. Selected tools and methods to enable these future DSO roles will be developed and validated through computer simulations based on real grid data and real-life testbeds, and encompassing Planning, Operational Scheduling, Real-time operations, Market and Maintenance. The new tools and methods will enable DSOs in collaboration with transmission system operators (TSOs) and other market players to support the transition of the distribution networks towards a smart system that supports a successful integration of DRES".* [evolvDSO.2]
Grid operation challenges in cooperation TSO/DSO: • Voltage Support (TSO/DSO) • Congestion Management • Balancing challenge • Other
Functionalities TSO/DSO interface: In the evolvDSO project several innovative functionalities and tools based on the future role of DSO's are developed, for example: TSO-DSO cooperation domain: • *"Sequential Optimal Power Flow (SOPF): derives a set of control actions that keep the active and reactive power flow within pre-agreed limits at the primary substations level (or TSO-DSO interface)"* • *"Interval Constrained Power Flow Tool: estimates the flexibility range in each primary substation node for the next hours and includes the flexibility cost."* [evolvDSO.3] Operational planning domain: • Robust Short-Term Economic Optimization Tool • Network Reliability Tool • Contingency Simulation Tool • State Estimation for LV Networks • Voltage Control for LV Networks Network Planning domain:

- *"FlexPlan: covers the shorter time horizon (i.e. 5 to 10 years in the future) and considers scenarios for the modelling of uncertainties. The applied methodology demonstrates a new approach to find relevant network planning cases. Based on the planning cases an optimal combination of network reinforcements and the usage of flexibilities is determined to solve congestions in the network."* [evolvDSO.3]

Key Findings/ lessons learned:

In the following list selected project conclusions and recommendations with high relevance for TSO/DSO cooperation are presented:

Conclusions on the role of DSO's:

- *"Core responsibilities of DSOs will not change (as defined in Article 25 1--7 of Electricity Directive 2009/72/EC):*

However:

- *DSO needs to implement an active distribution system management approach due to increased complexity*
- *DSO have a central role to play as market facilitator to better support the energy markets*
- *DSO must exploit the end users potential flexibility (not yet implemented) to optimize the management of the distribution network."* (Source: [evolvDSO.1])

Recommendations for tools application in the TSO/DSO cooperation domain:

- **Sequential Optimal Power Flow:** *"Due to the actual control of power flows in the TSO-DSO interface provided by the SOPF, two more recommendations at the regulatory framework level are assigned to this tool:*
  - *For the active power flexibility the DSO should have access to non-firm connection contracts and flexibility market/tenders and be able to active this flexibility (in coordination with the TSO) for grid management purposes;*
  - *Forecasted flexibility usage of DRES connected to its network should be used by the DSO for grid management purposes (in coordination with the TSO)."*
    (Source: [evolvDSO.3])
- **Interval Constrained Power Flow:** *"Future regulatory frameworks should:*
  - *Consider a more active role of the DSO, by offering services to the TSO, such as technical management/validation of flexibility activation in the distribution network;*
  - *Increase the information exchange between TSOs and DSOs concerning the users connected to the distribution networks. This can also include relevant information for operational planning of the transmission network, such as forecasting of the PQ operating point and corresponding flexibility for a specific time horizon. Regarding this, data exchange should be standardized (i.e. protocols, standards and type of data);*
  - *In what concerns the market functioning, data exchange should support its efficiency allowing new market players to emerge;*
  - *Forecasted State of Charge profiles should be shared with the DSO;*
  - *Lastly, storage-flexibility should be a market product available to both TSO and DSO."*
    (Source: [evolvDSO.3])

Further Information:

- [evolvDSO.1] Marco Baron,"evolvDSO project-Development of methods and tools for new and evolving DSO roles for efficient DRES integration", November 2014; [Online] .Available: https://www.engerati.com/sites/default/files/Day2-1200-Marco%20Baron.pdf
- [evolvDSO.2] J. Stromsather, "evolvDSO Project Summary" [Online]. Available: https://www.cordis.europa.eu/result/rcn/163061_en.html
- [evolvDSO.3] Marco Baron," evolvDSO-Final Report", February 2017

2.15. FutureFlow

Based on literature review.

Table 21: Fact sheet - FutureFlow

Project Name: FutureFlow
Country: Austria, Slovenia, Serbia, Romania, Hungary, Germany, Belgium, France
Start: 01/01/ 2016 **End:** 31/12/2019
Research Partners: **TSOs:** ELES, APG, Transelectrica and MAVIR **Research Centers:** EIMV, EKC Ltd. **Retailers:** Elektro Energija d.o.o., GEN-I d.o.o **IT provider:** SAP **As well as:** cyberGrid GmbH, Gemalto SA, 3E
Project Description: *"FutureFlow links interconnected control areas of four TSOs of Central-South Europe which today do face increasing challenges to ensure transmission system security: the growing share of renewable electricity units has reduced drastically the capabilities of conventional, fossil-fuel based means to ensure balancing activities and congestion relief through re-dispatching. Research and innovation activities are proposed to validate so that consumers and distributed generators can be put in a position to provide balancing and re-dispatching services, within an attractive business environment."* [FutureFlow.1]

Project Goals (TSO/DSO cooperation): *"FutureFlow is addressing some hot topics that TSOs are challenged with nowadays:*
 	
• *Integration of renewables into balancing markets*
    o *FutureFlow shall test if Demand Side (DSM) and Distributed Generation (DG) units are capable of providing the most challenging balancing services, such as automatic Frequency Restoration Reserve (aFRR), to the balancing markets and to which extent. It shall answer the question which industrial technologies are most suitable for participation in aFRR markets.*
• *Establishment of regional/EU wide markets for cross-border exchange of balancing and redispatching services*
    o *Four TSOs / four electric power systems, rather different in terms of their size, market maturity, amount of resources capable of providing flexible balancing services etc., are implementing Regional Balancing Platform with Common Activation Function for cross-border exchange of aFRR and redispatch services. […]*
• *Grid Security*
    o *In the environment with significant influence of RES, the concern of grid security has been growing. FutureFlow establishes a very strong link between Grid Security, Consumers and RES. Consumers instead of being passive observers become the guardians of the Power System.*
• *Implementation of regulatory policies*
    o *FutureFlow is creating environment fit for DSM and DG. Among wide selection of existing balancing products, that nowadays are of questionable usefulness for renewables, FutureFlow shall search for and test which product and its characteristics fit most for DSM&DG."* [FutureFlow.1]

Grid operation challenges in cooperation TSO/DSO: • Balancing Challenge • Congestion management
(Planned) Functionalities TSO/DSO interface:

For example the following functionalities are addressed: • Automatic frequency restoration reserve (aFRR) software suite • Active Power Dispatch/ Scheduling • Advanced Monitoring • Topology Recognition/ Topology Estimation
Further Information: More detailed information can be found on the following homepage and documents: • [FutureFlow.1] FutureFlow – Project Homepage. [Online]. Available: http://www.futureflow.eu/ • [FutureFlow.2] Maja Kernak Jager, Tomaz Ostir, Anze Popit, Rok Lacko, Ursula Krisper, Marko Mihorko, David Gerbec, Darko Kramar, Matjaz Dolinar, MAVIR Team, Zoran Vujasinovic, Dusan Vlaisavljevic, Nebosja Jovic, Iva Mihajlovic Vlaisavljevic, Alexandru Olteanu, Lucia Moldovanu, HerveGanem,AndrazAndolsek,RubenBaetens, “Deliverable 1.3, Data needed to implement the common activation function “,2016 [Online]. Available: http://preproduction.futureflow.eu/wp-content/uploads/2017/02/FutureFlow-WP1-D1.3-Data-needed-to-implement-the-common-activation-function.pdf • [FutureFlow.3] Ruben Baetens, “Deliverable 7.2 Project” - Website Report, June 2016 [Online]. Available: http://www.futureflow.eu/wp-content/uploads/2017/02/FutureFlow-WP7-D7.2-Project-Website.pdf

2.16. VOLATILE

Stefan Stankovic, Lennart Söder (KTH Stockholm)

Table 22: Fact sheet - VOLATILE

Project Name: "VOLATILE" - Voltage Control on the transmission grid using wind power at other voltage levels
Country: Sweden, Denmark
Start: 01/02/2016 **End:** 30/06/2018
Research Partners: **Academic Partners:** KTH Royal Institute of Technology, Technical University of Denmark **DSO:** Vattenfall Distribution Nordic
Project Description: *"For Sweden nuclear power will be phased out during the coming decades, which causes a need of new generators such as wind energy. In Denmark and other countries large amounts of wind power is currently in operation and it is expected that the amount will increase significantly. In a power system there is a need to keep a good voltage. The possibility to be studied in the project is to use wind power stations on other voltage levels to keep the voltage on the transmission level. Methods concerning controller design, communication and parameter setting will be combined with impact studies on real networks in order to estimate the possibility to implement this option."* [VOLATILE.1]
Project Goals (TSO/DSO cooperation): *"The aim of the project is to investigate possibilities for reactive power support from DSO to TSO in order to assist in voltage control on a transmission grid. DSOs should be responsible for handling reactive power resources in their own grid as well as remuneration of these services to the participants. TSOs should organize higher level reactive power markets where involved players could be DSOs, power plants, transmission connected wind farms, SVC stations, etc. "* [VOLATILE.1]
Grid operation challenges in cooperation TSO/DSO: • Voltage Support (TSO/DSO)
(Planned) Functionalities TSO/DSO interface: • DER Forecasting • Load Forecasting • Distribution System State Estimation • Reactive Power Dispatch / Scheduling • Volt/ Var Optimization
(Preliminary) Key Findings/ lessons learned: • Distribution grids with DG can notably support transmission grid with reactive power services.
Further comments: *"We believe that the best way to establish communication between TSO/DSO is through developing models of reactive power markets. These models should include exchange of information on availability of reactive power sources form distribution grids as well as needs of a transmission system for reactive power support in certain points in the grid. This raises the question about updates of grid codes for greater flexibilities on the distribution/transmission interfaces. "* [VOLATILE.1]
Further Information: Publications: • [VOLATILE.1] Lennart Söder (KTH), Stefan Stankovic (KTH), Qiuwei Wu (DTU), Shaojun Huang (DTU), "ERA-NET SMART GRIDS PLUS – Project VOLATILE Voltage Control on the transmission grid using wind power at other voltage levels" - Status Report, February 2018

- [VOLATILE.2] Stefan Stanković and Lennart Söder, ”Identification of Reactive Power Provision Boundaries of a Distribution Grid with DFIGs to a Transmission Grid”, in Proceedings of IEEE ISGT Europe 2017, Torino, Italy
- [VOLATILE.3] Debasish Dhuaa, Shaojun Huang and Qiuwei Wu, “Load Flow Analysis of Hybrid AC-DC Power System with Offshore Wind Power”, in Proceedings of IEEE ISGT Asia 2017, Aukland, New Zealand

2.17. IDE4L

Based on literature review, with additions by José Luis Domínguez (Institut de Recerca en Energía de Catalunya) and Ricardo Guerrero Lemus (Universidad de La Laguna)

Table 23: Fact sheet – The IDE4L Project

Project Name: The Ideal Grid for All project – IDE4L
Country: Finland, Italy, Spain, Denmark, Sweden, Germany
Start: 09/2013 **End:** 10/2016
Research Partners: **Coordinator:** Tampere University of Technology (TUT) **Academic Partners:** Catalonia Institute for Renewable Energy, Kungliga Tekniska Högskolan, RWTH Aachen University, Technical University of Denmark (TUD), University Carlos III de Madrid **DSOs:** Unareti Spa (UNR), Union fenosa Distribution Sa (UfD), Østkraft a/S (OST) **As well as:** Danish Energy and Schneider Electric SA, Spain (SCH)
Project Description: *"The purpose of the IDE4L project was to define, design and demonstrate the ideal grid for all with an active distribution network that integrates renewable energy sources (RESs) and new loads and guarantees the reliability of classical distribution networks. The active distribution network consists of the infrastructure of power delivery, active resources, and active network management (ANM) and combines passive infrastructure with active resources, ANM functionalities, distribution automation information and communication technology infrastructure. Active distributed energy resources (DERs) include distributed generation (DG), demand, response and storage."* [IDE4L.3]
Project Goals (TSO/DSO cooperation): *"The overall aim of development and demonstration is to develop advanced distribution network automation systems including utilization of flexibility services of DER and to develop advanced applications that enable the monitoring and control of whole network and embedded DERs. Therefore, a common architecture for distributed network automation and management needs to be developed based on standards and formal methodologies to design the architecture and to guarantee its replicability at a European level. Coordination of control actions of commercial aggregators and DSO/TSO for management of complete power system."* [IDE4L.2]
Grid operation challenges in cooperation TSO/DSO: • Congestion Management • Protection Coordination and System restoration (Fault Location, Isolation and Supply Restoration) • Balancing Challenge • Dynamic information exchange (TSO/DSO)
Communication infrastructure TSO/DSO: • *"All data exchange and modeling are based on international standards IEC 61850 (measure and control schema of database), DLMS/COSEM, and CIM (network model schema) to enable interoperability, modularity, the reuse of existing automation components, and the faster integration and configuration of new automation components."* [IDE4L.2] • *"The project has also proposed an implementation of the latest IEC 61850-90-5 protocol for synchrophasor data transfer, which will be released as open source software and can be used to support interoperability and facilitate market access to new integrators or hardware providers."* [IDE4L.2]
Functionalities TSO/DSO interface: The addressed functionalities for an Active Network Management (ANM) are for example: • Advanced Monitoring [IDE4L.3] • Load Forecasting

- Generation Forecasting
- Distribution System State Estimation [IDE4L.2]
- Decentralized Fault Location, Isolation and Supply Restoration (FLISR) [IDE4L.2]
- Active Power Dispatch/ Scheduling [IDE4L.2]
- Advanced Distribution network dynamics monitoring facilitating DSO/TSO interaction [IDE4L.2]

Key Findings/ lessons learned:
Selected key findings and results from the project (not exhaustive):

- Decentralised fault location isolation and supply restoration (FLISR)
  - *"FLISR is part of the distribution automation infrastructure designed and developed within IDE4L. The basic elements are decentralised intelligent electronic devices (IEDs) that provide protection, logic selectivity and backup chronometric selectivity functionalities. IEDs control circuit breakers and switches"* [IDE4L.5]
  - *"The FLISR (Fault Location Isolation and Supply Restoration) where IEDs are communicating based on a peer-to-peer paradigm to clear faults on the network"* [IDE4L.3]
- *"Final Remarks*
  - *The IDE4L project has successfully designed, implemented and demonstrated the concepts of ANM, hierarchical and decentralized automation architecture, and a commercial aggregator to provide flexibility services for grid management. The concept implementations have been validated by successful demonstrations both in integration laboratories and in the field.*
  - *The same IDE4L automation system was implemented in all field demonstration sites. Results proved it effective in the tested configurations (functionalities chosen by the DSO) and hardware implementations.*
  - *Monitoring, control, and protection functions can be deployed locally in the substations and operate in a coordinated manner.*
  - *The IDE4L project has used international information model and interface standards [IEC 61850, DLMS/COSEM (I EC 62056) and CIM (IEC 61970/61968)] for the design of the automation architecture and the implementation of devices and interfaces (FLISR IEDs, SAUs, and PMUs) and all demonstrations. Concepts and implementations have been proved to be interoperable and scalable."* [IDE4L.3]

Further detailed results from the project:

1.- AGGREGATOR:

IDE4L demonstrated that buildings' flexibility could participate in softening grid congestions due to renewable energy generation or to demand overloads. To do so, an aggregator coordinated the action of several buildings to counteract, for example, grid congestion by modifying the consumption of buildings (either increasing or decreasing it). The direction of flexibility (upwards or downwards) and the total amount of energy to manage was given by the DSO or TSO depending on the electricity grid needs.

2.- FLICKER CORRECTION:

Given the variability of renewable power generation power oscillations in the flicker frequency range may appear and lead to voltage fluctuations in weak grids. In IDE4L project an improvement in the power smoothing strategy based on supercapacitors for its application in weak networks or microgrids is provided. In the project it is proposed a solution based on the substitution of the power measurement for the renewable source by local voltage measurement. In other words, a controller is implemented and to generate a power profile capable of smoothing the varying power of renewable sources, but now only with the grid voltage measurement. The approach presents an easy solution of flicker mitigation turning the power smoother into an autonomous device. The power smoother can be placed in every place where is needed to improve the grid quality by mitigating flicker.

3.- INTERCONNECTION SWITCH:

PV plants may be integrated in a microgrid which may involve different protection devices. Unlike traditional protection devices, which are triggered based on current level, protection devices for microgrids based on power electronic interfaces needs to be redesigned. The lack of large current inrush in the event of a fault prevents traditional protections devices to trigger. In IDE4L project an interconnection switch (IS) that isolates the microgrid in the event of disturbances in the distribution grid was implemented and its functionality verified. An interconnection switch is an intelligent electrical device aimed for protection purposes. An IS belongs to a microgrid and its operation is managed by the microgrid central controller but it must be coordinated with the distribution grid protection system. Some functionalities of the IS are:

- Synchrocheck: In this scenario the IS must maintain isolated the microgrid when no synchronization is detected between the grid and the microgrid. When the synchronization condition is accomplished and both grids can be reconnected in a safe way, the IS will reconnect automatically the microgrid to the power network. No external commands are required in this situation.

- Fault detection: The main grid and the microgrid loose phase synchronization. The system must detect the phase difference between the power network and the microgrid and automatically isolate the microgrid by triggering the contactor.

- Protection using communication commands: The interconnection switch must obey external commands overriding the internal logic of the device. In this test, depending on the IEC 61850 commands sent from FLISR, the IS must open the contactor (BlockOpen) and isolate the microgrid even when connected to a healthy grid. The condition of synchronization may be true but the IS will remain open and both grids separated.

Further Information:
More detailed information can be found on the following homepage:

- [IDE4L.1] Project Homepage, [Online]. Available: http://ide4l.eu/results/
- [IDE4L.2] Sami Repo Tampere University of Technology, Final Report "Ideal Grid For ALL" Finland(TUT), 2016 [Online]. Available: https://www.cordis.europa.eu/docs/results/608/608860/final1-ide4l-publisable-summary-30-11-2016.pdf
- [IDE4L.3] Sami Repo,Ferdinanda Ponci, David Della Giustina, Amelia Alvarez, Cristina Corchero Garcia, Zaid Al-Jassim,Hortensia Amaris, Anna Kulmala, "The IDE4L Project: Defining, Designing, and Demonstrating the Ideal Grid for All", IEEE Power&Energy Society, April 2017 [Online].Available:http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=7900473
- [IDE4L.4] Sami Repo Tampere University of Technology (TUT) Department of Electrical engineering, "The role of automation in future distributed electricity generation", October 2015, Online]. Available:http://elec.aalto.fi/fi/midcom-serveattachmentguid-1e57d7fe67803fa7d7f11e599b53f6f481b68a568a5/s2_repo.pdf
- [IDE4L.5] IDE4L — Result in Brief, [Online]. Available: https://cordis.europa.eu/result/rcn/196576_en.html

2.18. CALLIA

Based on literature review.

Table 24: Fact sheet - CALLIA

Project Name: CALLIA - Open Inter-DSO electricity markets for RES integration
Country: Austria, Germany, Turkey, Belgium
Start: 01/07/2016 **End:** 31/03/2019
Research Partners: **Academic Partners:** University of Stuttgart – IEH & IFK , Vienna University of Technology **TSO:** TransnetBW **As well as:** BlueSky Energy (AUT), BEDAŞ (TUR), devolo AG (GER), ISC Konstanz (GER), Pavotek (TUR), REstore (BEL), Salzburg Research (AUT), VITO (BEL), Stadtwerke Heidelberg Netze GmbH (GER)
Project Description: *"CALLIA deepens inter-and intra DSO cooperation through local market clearing algorithms for deploying voltage levels. This mechanism considers TSO system-level markets, thereby guaranteeing stability of the European power system with increasing penetration of RES storage systems. By streamlining interfaces between DSOs and TSOs, market access for flexibility providers is enhanced. New standards and technologies are developed and applied, bringing the existing national demonstration projects to the next level."* [CALLIA.1]
Project Goals (TSO/DSO cooperation): • *"CALLIA aims to develop a full scheme for fostering inter-DSO interactions in an automated fashion."* • *"Coordination between DSOs and TSOs as well as between DSOs established based on social welfare optimizing market principles"* • *"Innovative IP-based communication technologies based on power line communication (PLC)"* • *"Ensure successful network operation not only in a smart metering scenario but also in connecting (local) markets to specific flexibility assets located primarily in distribution grids to achieve a resilient and optimum use of those assets."* • *"Hardware to monitor and control assets according to the CALLIA architecture"* (Source: [CALLIA.1])
Grid operation challenges in cooperation TSO/DSO (highlight relevant challenges): • Congestion Management • Balancing Challenge

(Planned) Communication infrastructure TSO/DSO:
• "G3- PLC a robust communication stack for the expected smart grid functionality
  ○ *Requirement for future-oriented applications such as smart metering, grid monitoring and RES/Loads/Storage agents integration in the future Smart Grid*
  ○ *The transport protocols will be TCP/IP or UDP/IP or Web based method and will for example be orientated to the new IEC 61850-8-1 (MMS over http) for the RES control agents and IETF RFC 6120 XMPP for the energy flexibility management."* [CALLIA.2]

Further Information: More detailed information can be found on the following homepage: • [CALLIA.1] Callia project overview, [Online]. Available: https://callia.info/wp-content/uploads/2017/10/Callia.pdf • [CALLIA.2] Project homepage, [Online]. Available: https://callia.info/en/general/

2.19. INTERPLAN

Ataollah M. Khavari, Mihai Calin (DERlab)

Table 25: Fact sheet - INTERPLAN

Project Name: INTEgrated opeRation PLANning tool towards the pan-European network - INTERPLAN
Country: Germany, Italy, Austria, Poland, Cyprus
Start: 01/11/2017 **End:** 31/10/2020
Research Partners: **Coordinator:** ENEA (Italian National Agency for New Technologies, Energy and Sustainable Economic Development) **Academic Partners:** University of Cyprus (UCY) **Institutes:** AIT (Austrian Institute of Technology GmbH), DERlab (European Distributed Energy Resources Laboratories e.V.), Fraunhofer IEE, Instytut Energetyki (IEn)
Project Description: *"INTERPLAN is a project that aims to provide an INTEgrated opeRation PLANning tool towards the pan-European network, to support the EU in reaching the expected low-carbon targets, while maintaining network security. INTERPLAN will develop a methodology for a proper representation of a "clustered" model of the pan-European network and generate grid equivalents as a growing library able to cover all relevant system connectivity possibilities occurring in the real grid, by addressing operational issues at all network levels (transmission, distribution and TSOs-DSOs interfaces)."* [INTERPLAN]

Project Goals (TSO/DSO cooperation):
• *"Approach*:
    ○ *A methodology for proper representation of a "clustered" model of the pan-European network is provided, with the aim to generate grid equivalents as a growing library able to cover all relevant system connectivity possibilities occurring in the real grid, by addressing operation planning issues at all network levels (transmission, distribution and TSO-DSO interfaces)."*
• *"Sub-objectives:*
    ○ *Definition of a set of detailed use cases to be addressed by future network planning and operation at all network levels, including TSO-DSO interfaces, and establishment of requirements for network models and grid equivalents (WP3).*
    ○ *Development of network models, and identification and characterization of a clustering method (WP4).*
    ○ *Development of an operation planning tool for grid equivalents with the aim to control the operating conditions at all network levels, and apply adequate possible Intervention measures through cluster and interface controllers (WP5)."*

Grid operation challenges in cooperation TSO/DSO: • Congestion Management • Voltage Support (TSO/DSO) • Balancing Challenge
(Planned) Functionalities TSO/DSO interface: • DER Forecasting • Load Forecasting • Distribution System State Estimation • Active Power Dispatch/ Scheduling

• Reactive Power Dispatch / Scheduling • Volt/ Var Optimization • Contingency Analysis • Grid Clustering • Approach for generating grid equivalents • Frequency Control • Optimal power flow tool for active and reactive power management in both TSO and DSO level
(Preliminary) Key Findings/ lessons learned: The outcome of the technical and regulatory assessment of the European electricity grid will be published in the first 10 months of the project runtime.
Further comments: *"As further developments in the future projects, grid operation and planning tools can be provided as fully open source software packages, which feature innovative solutions developed by projects like INTERPLAN. These tools will be widely used by researchers from academia and industry and they will have the possibility to further develop them considering the future needs of the grid.*
Further Information: More detailed information can be found on the following homepage: http://interplan-project.eu/about/

3. Summary

The report provides an overview of objectives, best-practice examples and key findings of international R&D projects in the field of TSO/DSO cooperation. Nevertheless, it should be highlighted that the provided project overview does not intend to be exhaustive or complete. In detail, the status and development of TSO/DSO cooperation depends on a lot of impact factors, for example on the addressed grid operation challenges, the applied communication technologies and standards, the addressed voltage levels and DER types (e.g. residential, commercial, utility-scale PV), and especially the national/regional regulatory framework and requirements. Overall, a major part of the identified R&D projects is ongoing and still a significant research and development demand is identified.

Figure 25 gives an overview of the scope of the identified R&D projects. The TSO/DSO grid operation challenges, congestion management, balancing challenge and voltage support by distributed renewables are widely addressed in the identified R&D projects. Otherwise, TSO/DSO grid operation challenges on protection coordination, grid restoration, and black start are only addressed by a few identified R&D projects. Further important challenges for advanced TSO/DSO cooperation are the development of an appropriate market design and regulatory framework for the provision of bulk system services by DER, the further development of the ICT infrastructure and communication protocols for data and information exchange between TSO, DSO, DER and other relevant stakeholders (e.g. DER aggregator) and also enhanced cooperation on operational and long-term planning between TSOs and DSOs (i.e. integrated modelling of transmission and distribution level).

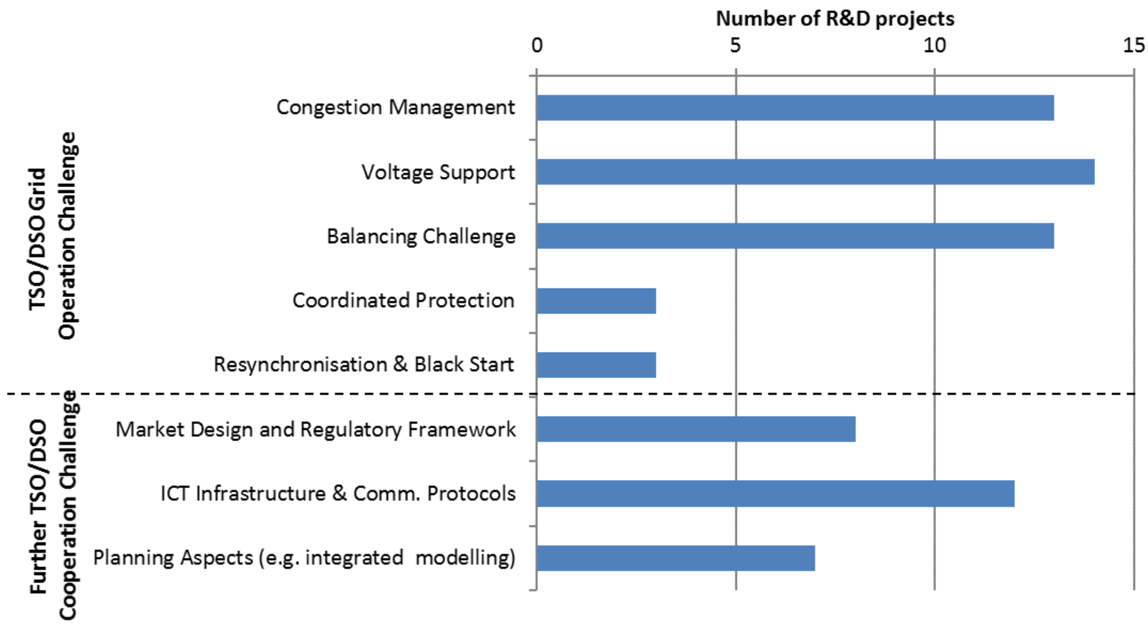


Figure 25: Scope of identified R&D projects on TSO/DSO cooperation challenges (multiple scopes per R&D projects possible)

An overall comprehensive description of **coordination schemes between TSO and DSO** and the **future roles of DSOs** are provided by the *SmartNet* project, by *Kristov & De Martini* and the *evolvDSO* project. Furthermore, the development of regional active power markets (e.g. projects *SmartNet*, *CALLIA* and *NEW 4.0*) and reactive power markets (e.g. project *VOLATILE*) are addressed and discussed within the identified projects.

Another challenge of TSO/DSO cooperation is the further **development of the ICT infrastructure and communication protocols** between TSO, DSO and further relevant stakeholders. Several projects such as *SysDL2.0*, *Interface 2.0*, *IDE4L*, *CALLIA*, *EU-SysFlex* address this challenge. A widely applied standard model for the data exchange is the Common Information Model (CIM) (e.g. *IDE4L*, *SysDL2.0*, *TDX-ASSIST, EU-SysFlex*). An interesting R&D activity is here, for example, the development and application of the Common Grid Model Exchange Specification (CGMES) for CIM, e.g. *SysDL2.0*, *TDX-ASSIST, EU-SysFlex* project.

Congestion Management at the TSO/DSO interface with the support of distributed generation is partly already applied. Main objectives of R&D projects are the further optimization and standardization of congestion procedures including TSO, DSO, DER and market players. R&D activities are for example the integration of load and generation forecast and the preemptive congestion management (e.g. *New 4.0*, *evolvDSO* and *SysDL2.0*). Further R&D activities are for example the improvement of grid observability (esp. advanced metering, state estimation) and the optimization and/or minimization of DER curtailment in congestion procedures (e.g. *evolvDSO*, *SysDL2.0, Real-time optimization and control of next-generation distribution infrastructure*).

The coordination of **power balancing** is another major challenge for power systems with a relevant share of variable renewables and distributed resources. This challenge is for example addressed in the projects *FutureFlow*, *Real-time optimization and control of next-generation distribution infrastructure*, *PVPT, PV-Regel,* and *CALLIA*. A research objective is here the analysis and further development of DER capabilities (e.g. timing, accuracy, and reliability) to provide balancing services for the bulk power system (e.g. frequency control reserve in the project *PV-Regel, FutureFlow*). Furthermore, also the impact of DER dispatch (e.g. by TSO request) on the voltage and loading constraints in the distribution level is analyzed in projects such as *Real-time optimization and control of next-generation distribution infrastructure.*

In **voltage support (TSO/DSO)** overall a relevant potential of DER reactive power support at the TSO/DSO interface is identified in the projects *SysDL2.0*, *Q-Study* and *VOLATILE*. In the project *SysDL2.0,* a demonstrator is developed and tested in a field test application, which includes functionalities such as distribution system state estimation, reactive power flexibility forecast and an optimal power flow solver for an optimized voltage support with DER at the TSO/DSO interface. In the project *Q-Study,* detailed availability and potential analysis of DER reactive power support at the TSO/DSO interface are performed and new grid planning strategies are developed and discussed for a case study area with very high PV penetration.

In the TSO/DSO cooperation challenge **grid restoration** and **coordinated protection,** only a few research projects are identified. In the project *NETZ:KRAFT* different possibilities and concepts for DER units to contribute to grid restoration of the power system after a blackout are analyzed and discussed. In the project *IDE4L,* several active network management applications were implemented and tested, such as for example a decentralized fault location isolation and supply restoration (FLISR) system.

Another identified TSO/DSO cooperation challenge is the **modeling** of the transmission and distribution level for integrated system studies and a stronger collaboration in operational planning and long-term planning procedures. One main challenge is here the development of appropriate grid equivalents of the distribution and/or transmission level. This challenge is addressed in the project *INTERPLAN* for the pan-European power system and in the project *Modeling of DER in Transmission Planning Studies* for different case studies from the US power system.

An overview of the addressed TSO/DSO cooperation challenges in the identified projects is given in Table 26.

Table 26: Overview – Main TSO/DSO cooperation challenges of R&D projects

Project	Region	Project status	TSO/DSO Grid Operation Challenge					Further TSO/DSO Cooperation Challenge		
			Congestion Management	Voltage Support	Balancing Challenge	Coordinated Protection	Resynchronisation & Black Start	Market Design and Regulatory Framew.	ICT Infrastructure & Comm. Protocols	Planning Aspects (e.g. integrated modelling)
Modelling of DER in Transmission Planning Studies	USA	●		■	■					■
IDE4L*	EU	●	▒		▒	▒	▒		▒	
evolvDSO*	EU	●	▒	▒	▒			▒		▒
SysDL 2.0	GER	●	■	■					■	
Q Study	GER	●		■						■
NETZ:KRAFT	GER	◕			■		■			
VOLATILE	SWE, DK	◕		■				■		
PV Regel	GER	◕			■		■	■	■	
PVTP - A live PV testing platform	DK	◕		■	■				■	
SmartNet	EU	◕	■	■	■			■	■	
Next-Generation SCADA	JPN	◕	■	■	Future Appl.	■			■	■
CALLIA*	EU	◑	▒		▒			▒	▒	
Real-time optimization and control of next-generation distribution	USA	◑	■	■	■				■	■
TDI 2.0*	UK	◑	▒	▒					▒	
FutureFlow*	EU	◑	▒		▒			▒	▒	
TDX-ASSIST	EU	◔	■	■	■	■			■	■
INTERPLAN	EU	◔	■	■	■					■
New 4.0 (Work package 1)	GER	◔	■	■				■		
EU-SysFlex	EU	◔	■	■	■			■	■	

Legend poject status 05/2018:

Initial phase ◔

Middle phase ◑

Final phase ◕

Completed ●

Legend main project scope:

▒ *based on literature review

■ based on fact sheets project members

4. Selected Project Findings and Recommendations

This final chapter provides an overview of selected project key findings and recommendations. Recommendations and key findings with high relevance for PV are marked in bold.

Market Design and the Future Role of DSOs

Project evolveDSO:

- *"DSO needs to implement an active distribution system management approach due to increased complexity*
- *DSO have a central role to play as market facilitator to better support the energy markets*
- *DSO must exploit the end users potential flexibility (not yet implemented) to optimize the management of the distribution network."* (Source: [evolvDSO.1])

Project SmartNet (preliminary):

- While it could be appropriate that TSOs retain responsibility for the provision of balancing services, nonetheless they could have to share part of this responsibility with DSOs to the extent that the importance of the contributions to this service from entities connected to distribution will grow.
- In general, a balance has to be sought between local optimality and the implementation of a harmonised pan-European design.
- Being that the DSO landscape is very variegated in Europe, we can expect smaller DSOs to have to integrate their efforts in order to be fit for the new responsibilities.
- In particular, the importance of the market design for ancillary services has not to be overlooked: only if the architecture of real-time markets will be able to fully take into account the characteristics of the potential flexibility providers connected to distribution grids, will it be possible to obtain significant participation on their side.
- The role taken by the aggregator is crucial: aggregators must be able to provide a simplified interface towards the market, hiding most details and complexities of the characteristics of the single flexibility providers. Aggregators must deliver flexibility providers efficient price signals so as to incentivise their participation.
- Viable business models must be available for all market participants, including DERs, aggregators and other customers. It is expected that this may also include new regulations such as the establishment of appropriate incentive schemes, whenever needed.

Field Test Experience and Communication Standards

Project SysDL2.0 (preliminary):

- Finding a suitable and standardized data model was necessary and resulted in an enhanced effort. Nevertheless, this effort paid back when it came to the implementation and connection with the DSO control center. Using the CIM CGMES helped to describe and interpret the grid data in a common way. The project ended with a successful field test, in which the functionalities of the modules could be proven.

Project IDE4L:

- *The IDE4L project has used international information model and interface standards [IEC 61850, DLMS/COSEM (IEC 62056) and CIM (IEC 61970/61968)] for the design of the automation architecture and the implementation of devices and interfaces (FLISR IEDs, SAUs, and PMUs) and all demonstrations. Concepts and implementations have been proven to be interoperable and scalable."* (Source: [IDE4L.3])

Balancing Challenge and Congestion Management

Project Real-time optimization and control of next-generation distribution infrastructure:

- DERs located in distribution feeders can provide primary frequency response capabilities to improve frequency nadir and steady-state frequency deviation.

Project PV-Regel:

- **PV Systems are technically prepared to provide high-quality control reserve**
- **State of the art inverter technology can also provide virtual inertia to fully substituted conventional generators; further investigation is necessary with respect to a massive deployment on distribution/transmission grid scale.**
- **Current control reserve market conditions (in Germany) exclude PV as a provider of further ancillary services. Recommendations for adapted market conditions are: use of intraday forecast, shorter tendering periods and shorter product time slices.**

Voltage Support (TSO/DSO)

Project VOLATILE (preliminary):

- Distribution grids with DER can notably support transmission grid with reactive power services.

Project Q-Study (preliminary):

- Overall, the dynamics and the extent of reactive power exchange at the TSO/DSO interface in the investigated grid section rises with an increased degree of cabling in the distribution level and increased distributed generation, if no additional measures are applied.
- In the investigated grid section, a very high availability (95% to 98% percentile) of DER reactive power support for all analyzed grid use cases is especially determined for hydro power plants and bioenergy plants. **Furthermore, PV systems could provide significant controllable reactive power support with high (80% to 90% percentile) and partly very high availability (95% to 98% percentile) in the peak generation use case. Also for the undesired operation points according to the Demand Connection Code (DCC) a high availability for PV reactive power support is determined.**
- A methodology was introduced to determine the additional reactive compensation demand in a distribution grid section with or without DER reactive power support. In the investigated case study, DER reactive power support could significantly reduce but not avoid the demand for additional reactive power compensators at the distribution level.
- The proposed PV reactive power management approach combines central and local control concepts for reactive power support at the HV/MV interface and for local voltage control at the PV side. The presented concept requires only a few online measurement data from the grid and is therefore especially interesting for grid sections without an extensive monitoring system.

Grid Restoration:

Project NETZ:KRAFT (preliminary):

An increasing penetration of renewables, especially at the distribution level, offers opportunities for DSOs to support the power system restoration coordinated by the TSO by means of:

- **making use of remotely controllable renewable power plants to balance uncontrolled feed-in of small distributed generators and load variation,**
- **compensating the power ramps caused by automatic reconnection of small distributed generators,**
- maintaining predefined levels of power exchange at the connection point to TSO`s control area and providing precise load values on demand.

For further information about the IEA – Photovoltaic Power Systems Programme and Task 14 publications, please visit www.iea-pvps.org.

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