Schweizerische Eidgenossenschaft
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Department of the Environment,
Transport, Energy and Communication DETEC

Swiss Federal Office of Energy SFOE
Energy Research

Annual report from 25. November 2021

IEA ISGAN TCP

Schweizer Beteiligung

Date: 25. November 2021

Place: Bern

Publisher:
Swiss Federal Office of Energy SFOE
Research Programme Grids
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SFOE contract number: SI/502199-01

The author of this report bears the entire responsibility for the content and for the conclusions drawn therefrom.

Contents

1 Introduction

The ISGAN Academy offers the ISGAN community of high-level engineers and decision makers a means of rational and efficient continuous technical skills complement and update in the field of Smart Grids. Through an e-learning platform, experts in the field of Smart Grids presents different webinars on topics of power system fundamentals to more specialised courses on breakthrough smart grids solutions. The information presented includes recent developments, best practices, interesting methodologies, smart grids theory, applications, deployment, events, etc.

2 Goal of Project

According to the Energy Act of January 2018 and the Federal Council decision of August 2019, the general goals for the Swiss energy system is to exit nuclear power and reach zero net greenhouse gas (GHG) emissions by 2050. According to the energy perspectives of the Swiss Federal Office of Energy (SFOE), this will be achieved by increasing the share of renewable energy sources while increasing the energy efficiency.

The implementation of this strategy drives the following (but not limited to) trends: (i) increasing proliferation of variable renewable energy sources (VRES), mainly in a distributed fashion, (ii) increasing electrification of energy demand, i.e. heating and transportation, which leads to a significant increase in both peak and total electricity demand, and (iii) as a result of (i) and (ii), increasing need in techno-economically feasible ways to utilize the available sources of flexibility so that the costs of the energy supply as well as infrastructure investments are minimized.

All these developments put tremendous stress on the energy suppliers and system operators that are responsible for balancing the supply and the demand. As such, they require massive and costly adaptations to the energy infrastructure. The transition also brings along the need for complex new planning, operation, market and ownership models, as well as the need for new regulations to facilitate these models.

FEN, acting as a bridge between academia and the industry, conducts and has been conducting several research activities in this direction. Some of these activities have been performed as an integral part of Swiss participation in the ISGAN activities in the period of 2011-2020. These activities include following:

- In Annex-6, FEN has partly contributed to the TSO-DSO interaction where current interaction between TSOs and DSOs has been investigated for six specified grid operation challenges, and possible future ways of cooperation have been identified.
- Annex-8 activities were more dedicated to offer high-level engineers, decision makers, students and public in general a means of rational and efficient continuous technical skills complement and updates in the field of smart grids.

By exploiting international experiences and insights, the results of this project will continue to provide useful insight to Swiss policymakers and energy stakeholders also for (i) devising future grid investment and operational strategies leveraging the value of flexibility, (ii) decreasing the cost of DER ownership as a result of new potentials of revenue streams by providing flexibility services, and (iii) devising appropriate targets and regulations towards achieving the targets of the Energy Strategy 2050 in the most economic and environmentally friendly manner.

The following research questions will be tackled in this project:

1) How much flexibility can the various end-users provide to the system?
2) Can the distribution utilities avoid infrastructure investments by utilizing locally available flexibility?
3) How should the distribution networks be operated such that the utilization of the distributed flexibility resources is coordinated at the local level?
4) What is the value of local available flexibility for distribution utilities?

3 Summary of Work Performed in 2021 and Achieved Results

3.1 Annex-VI: Power Transmission and Distribution Systems

The following activities have been performed within Annex-VI

- Participation in **monthly Annex-VI meetings** (lead by NTNU Norway and RISE Sweden):
  We were engaged in technical discussions, providing a Swiss perspective. Furthermore, the informal interactions gave rise to continued collaborations, e.g. for ERANet proposals.

- Contribution to a **joint ISGAN annex 6 & ETIP SNET activity on „Flexibility for Resilience“**:
  After participation in an initial technical ISGAN-questionnaire and a dedicated workshop (June 2020), we contributed to the report by providing insights on selected relevant activities in Switzerland. Our contribution is twofold: (i) to the **chapter** on „resilience from dynamic converter flexibility“, and (ii) to the **chapter** listing all the relevant projects.

  The contribution to (i) specifically focuses on the support from converter units as it was identified as critical for dynamic system stability when recovering from severe disturbances. Two main topics were addressed: (a) transmission grid resilience during system splits, and (b) distribution grid resilience during temporary islanding operation. In both cases, we took account the Swiss and European perspectives, how to stabilize the disruption and how to recover from a severe disturbance while relyin on the converter-based generation. The content is based on the recent research results on dynamic converter support in Switzerland (SFOE-funded projects **ACSICON** and the dynamics subtask of **SCCER FURIES**).

  The contribution to (ii) includes three selected activities in Switzerland:

  - **Industrial pilot**: Equigy project
  - **SFOE-funded research project**: TDFlex - TSO-DSO Flexibility: towards integrated grid control and coordination in Switzerland
  - **ERA-Net-funded project with demonstration**: DiGriFlex: Real-time distribution grid control and flexibility provision under uncertainties

  The details of our input are provided in the Appendix. The full report is currently under review and will be published in Q1/2022.

- Started **joint collaboration on the „Flexibility and TSO-DSO interaction“** (lead by AIT in Austria):
  The main goal is a continuation of the international dissemination of related work on TSO-DSO interactions, following the joint ISGAN-activity on this topic in 2020. In the current phase (2021-2022), the focus will be on te usage of flexibility at the TSO-DSO interface. In 2021 two initial discussions have taken place, a dedicated kick-off meeting is scheduled for December 16, 2021. The main content will derived from our work in the SFOE-funded project TDFlex.

- Participation in **discussion/review of IEA project results on „District Heating and Cooling Networks“**:
  The main objective for our side is sharing of knowledge / expertise on the modeling of heat grids within the SWEET-project SURE. An initial exchange has taken place in 2021, the detailed review (including potential contribution of the Swiss perspective) is scheduled for January 2022.

3.2 Annex-VIII: ISGAN Academy

As part of our activities in Annex-VIII, three presentations are reviewed and the feedback is provided to the Academy. Following is the list of the webinars and the associated links to the video recording as well as to the dedicated ISGAN website. The detailed feedback for each webinar is attached in the Appendix.

- **9 December 2021** Optimizing the value of storage in power systems and electricity markets - the Smart4RES project [Webinar recording] [ISGAN Website]
- **18 November 2021** Dynamic Virtual Power Plant to combine flexibilities of dispatchable and non-dispatchable RES – the POSYTYF project [Webinar recording] [ISGAN Website]
- **09 June 2021** Optimising participation of renewables generation in multiple electricity markets: Smart4RES vision, opportunities and role of forecasting [Webinar recording] [ISGAN Website]

4 Collaboration

4.1 National Collaboration

- Collaboration on **local markets**:
  For an **ISGAN survey on local markets** inputs from multiple Swiss researchers (including PSI, ETHZ, ZHAW) were solicited and provided by filling in an ISGAN online survey. In the discussions around the survey two research proposal were created (not yet becoming successful projects, but still planned for the future)
- Collaboration on **district heating**:
  The planned review and possible contribution to the **IEA project report on „District Heating and Cooling Networks“** (see above) will be directly used for the ongoing SWEET-project SURE, in the local Zurich case study for the planning and developed of district heating. We will synchronise our learnings, methods and tools for modeling and planning of district heating grids with the IEA report. The results will be used by several of the national researchers of the SURE consortium.

5 Publications

The webinars can be accessed on
https://www.leonardo-energy.org/

6 Appendix

6.1 Inputs for ISGAN ETIP SNET report on „Flexibility for resilience“

The technical inputs are attached in this section. The full report is currently under review.

A. Equigy pilot project

Project basic information

Main goal: In this pilot project we develop a concept for systematic coordination between the TSO and DSOs with respect to the use of distributed flexibility resources controlled by a third-party aggregator. Note that even though ewz is both a DSO and aggregator in the Swiss ancillary services market, the two roles are considered distinctly in the pilot. The concept covers both the planning and operation phases: (i) Flexibility sharing between a TSO and DSOs in the operational planning stage creating a transparent nodal view on available flexibility per grid node (ii) Coordinated activation of flexibility resources among the TSO and DSOs in operation.

Furthermore, the pilot project aims at implementing the coordination concept on the Crowd Balancing Platform of Equigy, a Joint Venture of European TSOs that develops a technology to facilitate access of distributed energy resources to balancing and redispatch markets. Equigy is envisioned as the communication and data storage layer among the TSO, DSOs, aggregators, and flexible resources. Depending on the complexity, the TSO-DSO coordination module can be either an external software component or integrated within the Equigy platform (partially or completely). The long-term vision is to establish the TSO-DSO coordination on a market-based allocation of the available flexibility.

List of partners: Swissgrid and ewz (in collaboration with Equigy and Venios)

Source of funding: internal

Duration: 2021 – 2024

Webpage:

https://www.swissgrid.ch/en/home/newsroom/newsfeed/20210603-01.html

https://www.swissgrid.ch/en/home/newsroom/dossiers/crowd-balancing-platform.html

Project learnings

An increasing number of small-scale flexible resources are connected to the distribution grid, such as residential batteries, charging stations for electric vehicles, and heat pumps. In principle, the flexibility of these resources can be used to provide services either to the TSO or to the local DSO. In Switzerland, there already exist aggregations of such resources that provide ancillary services to Swissgrid or local services to DSOs.

Today, no systematic mechanism is used to share the available flexibility between the system operators. On the one hand, the DSOs typically have bilateral agreements with the owners of flexibility resources and activate them according to their needs, but without procuring the flexibility as a service in a market setting. On the other hand, the TSO typically procures ancillary services in a market and activates them through aggregators, but without considering the status and constraints of the distribution grid where they are connected.

Typically, an aggregator providing ancillary services to the TSO aligns with the local DSO only at the prequalification stage. Specifically, the aggregator informs the DSO that it intends to control resources in the DSO grid for TSO purposes, and the DSO approves or rejects this request. However, this is a one-time, static alignment process which can lead to inefficient utilization of the available flexibility resources in operation.

In this pilot project we develop a concept for systematic coordination between the TSO and DSOs with respect to the use of distributed flexibility resources controlled by a third-party aggregator. Note that even though ewz is both a DSO and aggregator in the Swiss ancillary services market, the two roles are considered distinctly in the pilot. The concept covers both the planning and operation phases:

- Flexibility sharing between a TSO and DSOs in the operational planning stage creating a transparent nodal view on available flexibility per grid node.

- Coordinated activation of flexibility resources among the TSO and DSOs in operation.

Furthermore, the pilot project aims at implementing the coordination concept on the Crowd Balancing Platform of Equigy[1], a Joint Venture of European TSOs that develops a technology to facilitate access of distributed energy resources to balancing and redispatch markets. Equigy is envisioned as the communication and data storage layer among the TSO, DSOs, aggregators, and flexible resources, as shown in Figure 1. Depending on the complexity, the TSO-DSO coordination module can be either an external software component or integrated within the Equigy platform (partially or completely).

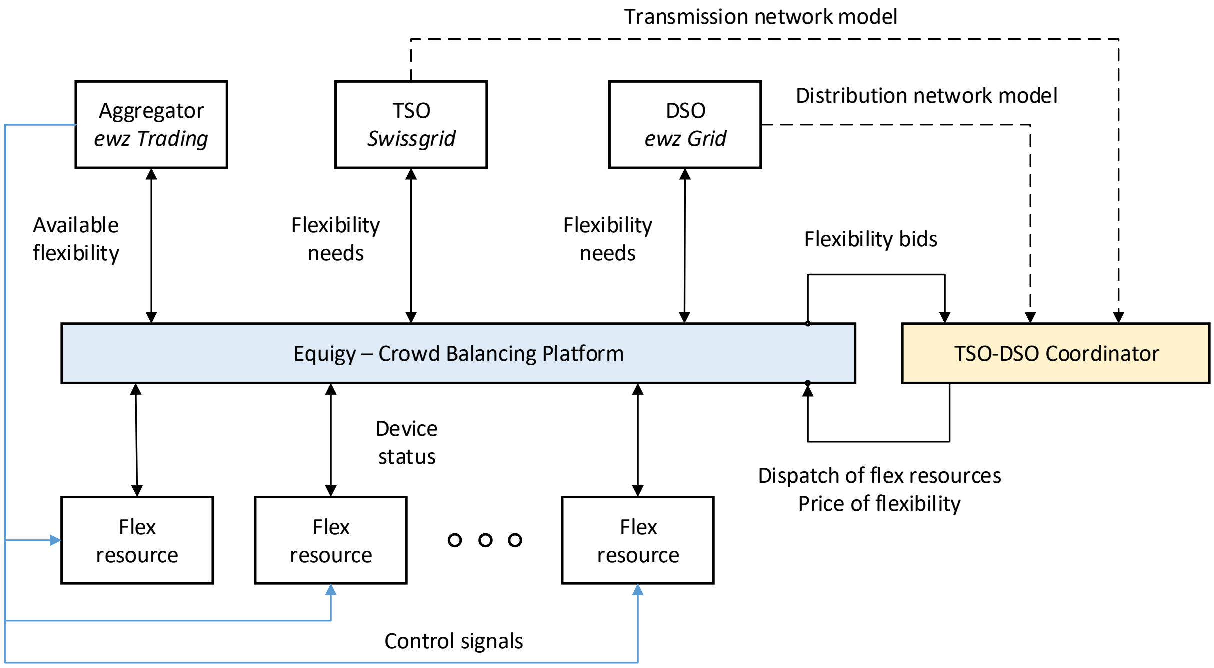

Figure 1: Visualization of roles and data flow through the Equigy platform and the various players.

The long-term vision is to establish the TSO-DSO coordination on a market-based allocation of the available flexibility. The idea is that aggregators offer aggregated flexibility to a market platform and a mathematical optimization algorithm allocates the flexibility resources to the TSO or DSO services with the highest economic value at any point in time, while ensuring that transmission and distribution network constraints are satisfied. Such a common TSO-DSO flexibility market can be implemented with either a centralized, i.e. common optimization between TSO and DSOs, or a decentralized architecture for flexibility sharing, where only the relevant information at the interface nodes between DSOs and the TSO is exchanged.

[1] https://equigy.com/

The project is structured into various phases. In the first phase, we develop a simpler rule-based approach for the TSO-DSO coordination which consists of two elements:

- Local flexibility model: the DSO has priority in deciding which part of the available flexibility should be kept for its own needs and which can be made available to the TSO.

- Traffic light model: the DSO can block activations of flexible resources for TSO purposes, if these would lead to violations in the distribution grid (and vice versa).

From the TSO point of view, the first phase of the project will focus on the products of the Swiss Integrated Market, namely tertiary control energy and international zonal redispatch. ewz will focus on using flexibility for congestion management in the distribution grid. The concept includes various business processes related to registration of flexible resources, bidding of flexibility, evaluation of the traffic light model, and activation of resources for TSO or DSO services, as shown in Figure 2. The feasibility of the concept will be demonstrated by testing it using one or more physical flexibility resources connected to the distribution grid.

The first phase of the project officially started in April 2021 and will run until August 2022, whereas the subsequent phases are expected to run from the end of 2022 to 2024. Upon its successful completion, this pilot project will be a key milestone with high importance for Switzerland due to the large number of DSOs and increasing amounts of distributed energy resources. Built on Equigy, the TSO-DSO coordination concept can become the role model for similar approaches in other European countries.

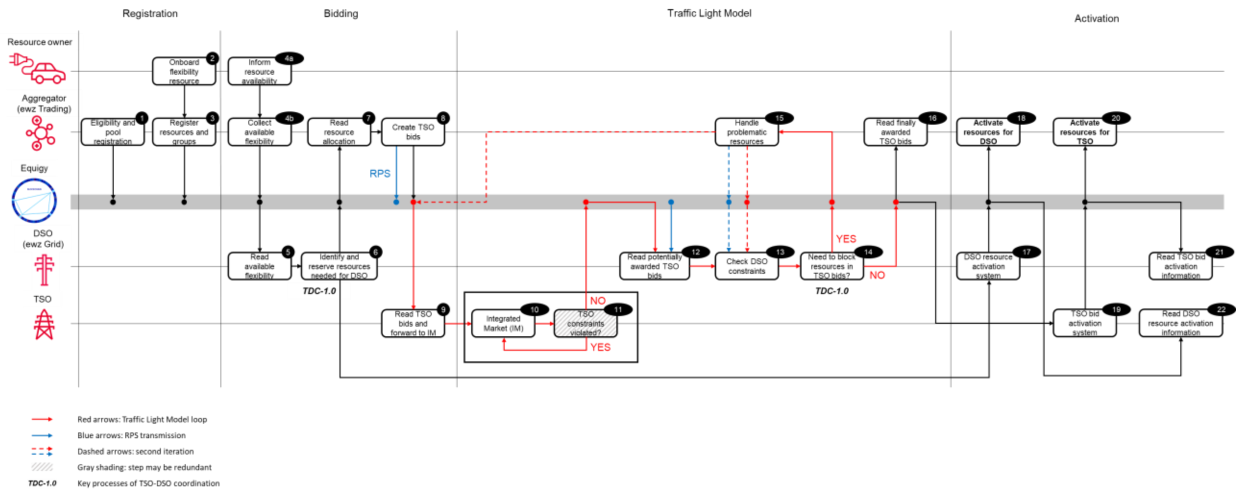

Figure 2: Business processes of the TSO-DSO coordination concept.

B. TDFlex project

Project basic information

Main goal: The project investigates whether it is techno-economically feasible and beneficial to exploit the aggregated flexibility at the TSO-DSO substation provided by the distributed energy resources (DERs) connected to the distribution network for transmission-level network and system benefits: (i) voltage support [*If there is a voltage violation in the TSO grid, is it technically and economically feasible to solve it with PQ-flexibility at the TSO-DSO substation? Compared to (1) use of conventional generators by TSO and (2) technology that can be deployed at the TSO-DSO substation (BESS, synchronous condenser etc.)*], (ii) congestion management [*If there is a congestion in the TSO grid, is it technically and economically feasible to solve it with PQ-flexibility at the DSO substation? Compared to traditional re-dispatch by TSO.*], and (iii) balancing services [*Can the aggregated flexibility be competitively offered in ancillary markets day-ahead or intraday? Even if they are not competitive, for example, in providing reserve, can the aggregated flexibility relieve some generators so that these generators can produce cheap energy instead of providing reserves?*].

List of partners: Research Centre for Energy Networks at ETH Zürich (observing partners include ewz, Repower, Swissgrid)

Source of funding: Swiss Federal Office of Energy (SFOE) and Swiss Association for Energy and Network Research (SGEN)

Duration: 2019 – 2021

Webpage: https://www.fen.ethz.ch/activities/system-operation/tdflex.html

Project learnings

The project investigates the following network and system benefits to determine whether it is techno-economically feasible and beneficial to exploit the aggregated flexibility at the TSO-DSO substation provided by the distributed energy resources (DERs) connected to the distribution network: (i) for congestion management within the TSO grid as well as at the TSO-DSO substation, (ii) for voltage support to the transmission system provided at the TSO-DSO substation and (iii) for balancing services in transmission system. By partnering with local utilities in Switzerland, this project examines the achievable benefits of a stronger TSO-DSO interaction in Switzerland.

General approach consists in using reduced representation of the DSO's grid capability by means of estimating "flexibility boundaries/areas" at the TSO-DSO interfaces and computing the associated cost of providing flexibility. Once the flexibility areas and associated costs are estimated, this capability is modelled as a "pseudo generator" (or flexibility generator) at each TSO-DSO substation for each transmission service. It is assumed that the identification of the flexibility area is performed by the utility or an aggregator either day-ahead or intraday look-ahead (e.g., 15-min-/60-min ahead). The technical and economic potentials of the flexibility at the TSO-DSO interface substation are compared to conventional methods in the following transmission services:

- voltage support [*If there is a voltage violation in the TSO grid, is it technically and economically feasible to solve it with PQ-flexibility at the TSO-DSO substation? Compared to (1) use of conventional generators by TSO and (2) technology that can be deployed at the TSO-DSO substation (BESS, synchronous condenser etc.)*],
- congestion management [*If there is a congestion in the TSO grid, is it technically and economically feasible to solve it with PQ-flexibility at the DSO substation? Compared to traditional re-dispatch by TSO.*], and
- balancing services [*Can the aggregated flexibility be competitively offered in ancillary markets day-ahead or intraday? Even if they are not competitive, for example, in*

providing reserve, can the aggregated flexibility relieve some generators so that these generators can produce cheap energy instead of providing reserves?].

The candidate flexibility providers in the distribution network are selected as follows: distributed renewable energy resources, particularly solar PV, battery energy storage systems, electric heat pumps, EV charging, and conventional electric demand. Figure 3 demonstrates the "flexibility area" concept for a given distribution grid. It is noted that at every time instant

- the operating point of the system, observed at the TSO-DSO interface substation,
- the available maximum solar PV generation,
- the status of the electric heat pumps,
- the status of the EV charging and the available number of EVs,
- the state of charge (SoC) of the BESS, and
- the amount of the electric demand

change. Thus, the "flexibility area" at the TSO-DSO interface substation is **time-dependent** and the shape will vary (size and type) at each time instant as shown in Figure 3. Note that the operating points at different time instants are shifted to the origin to be able to conveniently compare the size of the flexibility area.

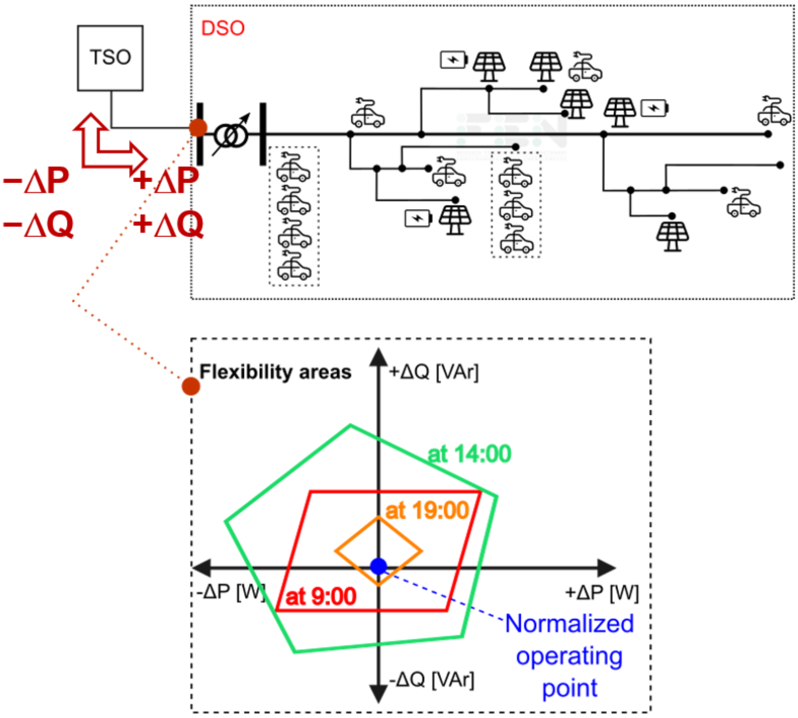

Figure 3: The concept of time-dependent flexibility area at the TSO-DSO substation

Assumptions in the analysis are as follows:

- The grid information (i.e., connectivity, line/transformer parameters, ratings) is known to be able to perform AC optimal power flow analysis.
- Expected amount of electricity generated by each solar PV as well as the electric demand are known by the utility/aggregator either day-ahead, or intraday in high resolution (e.g., every 15 or 60 minutes).
- The utility has the necessary DMS infrastructure to determine the operating point of the system day-ahead as well as intraday by using (i) the grid information, (ii) the information communicated from the customer-side, i.e., net demand (including excess generation due

to not locally consumed electricity generated by the solar PVs), state of charge of BESS, availability of the EVs, status of EV charging, and status of HPs (iii) the forecasts of demand and local generation.

- The utility has necessary telemetry infrastructure to retrieve voltage and current measurement in high time-resolution from each node in the network including the TSO-DSO interface substation.
- The distributed generation resources (i.e., solar PV) are treated as zero-cost generators for optimal power flow (OPF) analysis.
- The conventional electric demand provides a fixed percentage of active and reactive power flexibility (e.g., 10% of the demand). That is, 10% of the demand at a given time instant can be ramped down or ramped up as shown in Figure 4. The flexibility participation can be time-dependent and provided as a signal. How the consumer provides this flexibility (whether curtailing/increasing the consumption of a device such as boiler or heat pump etc.) is not within the scope of this project. The electric demand is assumed to provide active and reactive flexibility.
- Electric demand is modelled as constant active and reactive power. Constant-impedance and constant-current models can be adopted if needed.

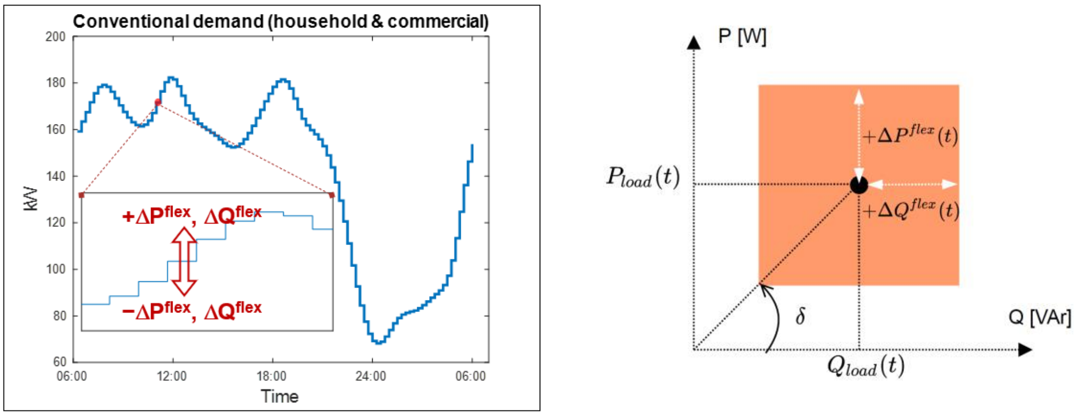

Figure 4: The flexibility provided by conventional electric demand (left), and the PQ flexibility capability curve (right).

- Each solar PV owner provides a fixed percentage of flexibility out of available PV production (e.g., 10%). That is, 10% of the available solar PV generation at a given time instant can be curtailed. The flexibility participation can be time-dependent and provided as a signal.
- The solar PV converters can provide reactive power capability (i.e., reactive power flexibility) with respect to a given PQ capability curve as shown in Figure 5. For illustration a V-curve is used, however, any other curve can be adopted.

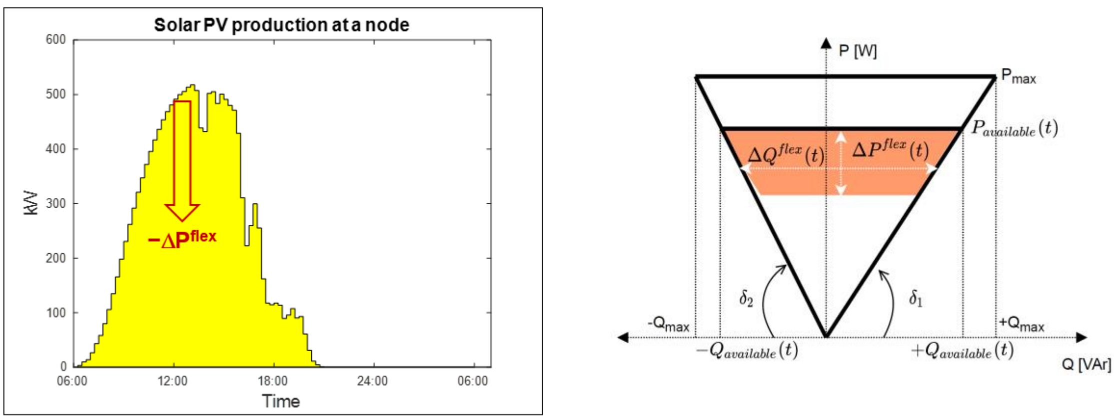

Figure 5: The flexibility provided by solar PVs (left), and the PQ flexibility capability curve (right).

- The EV charging (active power) flexibility is by means of reducing/increasing the charging as shown in Figure 6. EV charging infrastructure at each site allows slow charging as well as continuous ramping down. The availability (the projection of the EV arrival and departure times) of each EV is known via a signal provided by the owner. Vehicle to grid is not allowed.

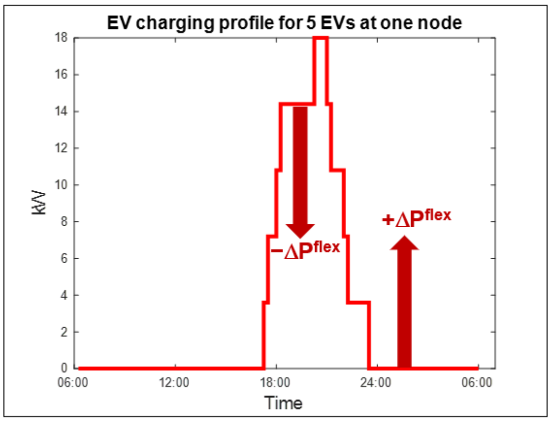

Figure 6: The flexibility provided by EV charging.

- The electric heat pumps can provide (active power) flexibility by means of turning on/off as shown in Figure 7. Continuous ramping up/down is not allowed. The availability of HPs is known via a signal provided by the owner.

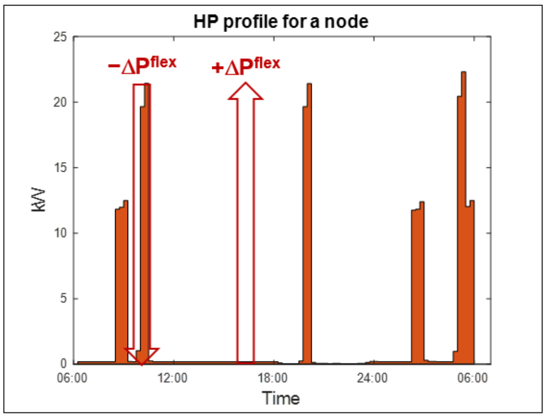

Figure 7: The flexibility provided by electric heat pumps.

- It is assumed that all BESS owners own PV but not all PVs are equipped with BESS. The BESS charging is driven by the excess energy produced by the solar PV. BESS charging schedule is assumed to start either at the time when there is excess solar, or at around the time when the projected maximum solar generation occurs. BESS can provide active and reactive power flexibility as shown in Figure 8.

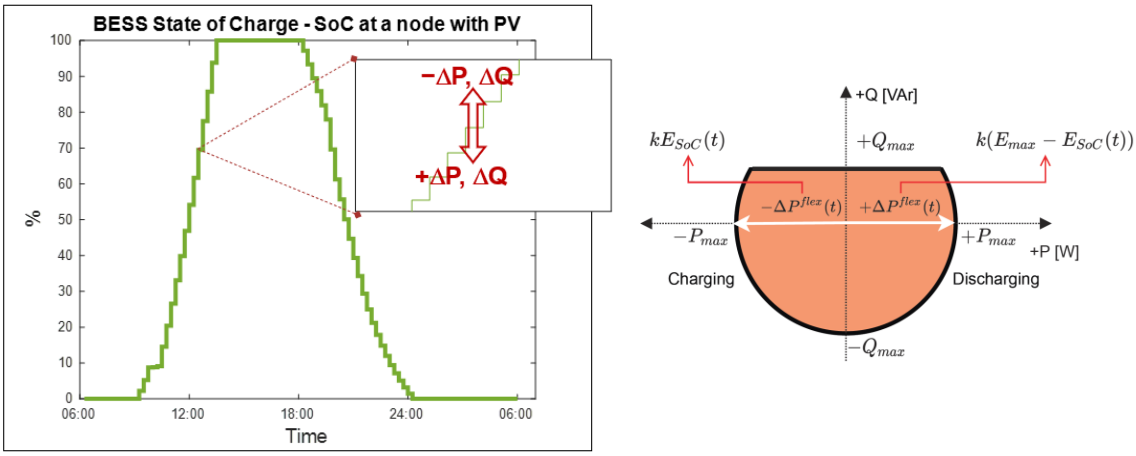

Figure 8: The flexibility provided by BESS (left), and the PQ flexibility capability curve (right). Note that +ΔQ flexibility (discharging) is limited due to its dependence on the nodal voltage and the internal capacitor voltage.

- The network is assumed to be structurally balanced (i.e., there are no 1-/2-phase feeders connected to a 3-phase feeder).
- The electric demand is balanced at each phase, and, thus, positive-sequence modelling is used.

The flexibility area for a given time step is calculated via an AC optimization formulation[2], using an angular sweeping approach[3] to determine the boundaries, utilizing all the available DERs and their flexibility capabilities to maximize the active power flexibility (positive/negative depending on the quadrant) at the TSO-DSO substation, while considering the AC formulation of the distribution grid constraints. One illustrative example is shown for one time instant in Figure 9. The quadrants I & IV represent a positive active power flexibility, corresponding to an increase in power flow from TSO to DSO while the quadrants II & III represent a negative active power flexibility implying that the power flow from TSO to DSO decreases.

[2] N. Savvopoulos, C. Y. Evrenosoglu, T. Konstantinou, T. Demiray and N. Hatziargyriou, "Contribution of Residential PV and BESS to the Operational Flexibility at the TSO-DSO Interface," in proc. of the International Conference on Smart Energy Systems and Technologies (SEST), September 2021.

[3] M. Kalantar-Neyestanaki, F. Sossan, M. Bozorg, and R. Cherkaoui, "Characterizing the reserve provision capability area of active distribution networks: A linear robust optimization method," IEEE Transactions on Smart Grid, vol. 11, no. 3, pp. 2464–2475, 2020.

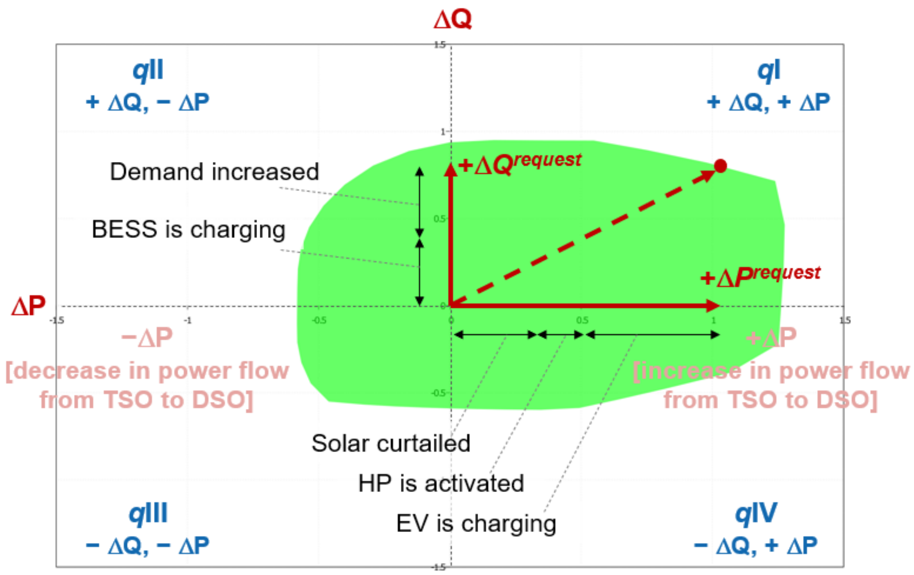

Figure 9: Flexibility area calculated for one time step. Illustrative example of how a flexibility request in the 1st quadrant can be provided.

When the flexibility area at a given time instant is determined as in Figure 9, the associated cost for each flexibility point along the boundary is computed. The minimum cost of providing flexibility for conventional electric demand, electric heat pumps, solar PVs, BESSs and electric vehicles is calculated separately and based on the loss of opportunity for the end-user driven by the retail tariff differences during the day as well as the feed-in tariffs (in the case of flexibility provided by the solar PV). The cost of depreciation resulting from projected activation of flexibility is ignored but can be taken into account.

Once the flexibility areas and associated costs are estimated in order to model the "pseudo generators" (or flexibility generators) for each TSO-DSO substation at each time instant, the benefits are quantified for selected transmission services in Switzerland.

We model each “flexibility generator” at each TSO-DSO substation with its associated costs for congestion management and voltage support in Switzerland to demonstrate the potential benefits. We use AC optimal power flow and model the Swiss transmission system as well as the generation capacities in detail, while the neighbouring countries are modelled as one node each. ***Our initial findings*** show that there is a potential to reduce the winter reserve requirements for hydro plants in Switzerland, thanks to the fact that the aggregated DER flexibility spread across the country relieves congestion resulting in cheaper electricity imported from the neighbouring countries.

We model the energy and reserve market of Switzerland, along with the energy market of its neighbours, such that energy and reserves are simultaneously dispatched. We model the active power flexibility of each “flexibility generator” at the TSO-DSO substation with its associated costs varying at every time instant. ***Our initial findings*** show that less upwards flexibility is provided by the hydro plants in Switzerland thanks to the flexibility provided by the DERs resulting in increased energy production by the cheap hydro plants, which finally reduces the overall dispatch costs.

The ways of procuring (*e.g., by means of bidding in a flexibility market*) and scheduling (*e.g., by means of performing a multi-period scheduling over a time horizon*) such flexibility is not within the scope of this project.

C. DiGriFlex project

Project basic information

Main goal: The first objective of this research project is to develop effective forecasting and optimal control methods to ensure efficient and secure operation of distribution grids, as well as flexibility and ancillary service provision from local low voltage distribution grids to the upstream medium/high voltage grids, under uncertainties. The source of uncertainties varies from stochastic distributed power generation (e.g., solar and wind power generation) and demand uncertainties to system model uncertainties (e.g., uncertain parameters of overhead lines and cables). Secure operation deals with satisfaction of technical constraints of distribution grids such as nodal voltage limits, power flow limits of lines/cables, and technical constraints of grid connected resources such as distributed generation and battery storage capacity limits. Efficient and optimal operation deals with both technical and economic objectives of local distribution operators such as minimization of voltage deviations and line's losses, maximization of ancillary service provision to upstream medium and high voltage grids, and minimization of real-time imbalances with respect to predefined schedules. The second objective of the project is to implement the above forecasting and optimal control methods in a test case low voltage distribution grid and demonstrate the effectiveness of the developed methods for different grid operation scenarios.

List of partners: HEIG-VD/IESE (Institut d'Énergie et Systèmes Électriques), HEIA-FR, EPFL PWRS, University of Naples Federico II, University of Naples Parthenope, DEPsys SA

Source of funding: Swiss Federal Office of Energy (SFOE) through ERA-Net Smart Energy Systems Joint Call 2018

Duration: 2019 – 2021

Webpage: http://iese.heig-vd.ch/projets/digriflex

Project learnings

Context and key questions

In the context of energy transition, emerging local power distribution grids are characterized by; (a) high penetration of intermittent and variable distributed generation from Renewable Energy Sources (RES), (b) active consumers and flexible consumption, and (c) interconnection to the local communication and transportation systems. These impose the following challenges to the optimal operation and control of distribution grids:

- High stress on the low voltage distribution grids regarding bi-directional power flow that must be addressed, from both static and dynamic aspects.
- High level of uncertainties concerning the difficulties in the forecast and control of the power generation (caused by the stochastic nature of RES) as well as uncertainties in power consumption (e.g., caused by the stochastic profile of electric vehicle charging).

To address these challenges, it is necessary to improve the observability (by employing measurement devices and local data acquisition systems), and the controllability (by employing controllable resources, such as battery energy storage systems), of distribution grids.

Moreover, efficient forecasting and optimal control methods are required to ensure that controllable resources are used in the most efficient way with respect to the state of the system. Note that the involved models/algorithms must be capable of; (a) analysing the huge amount of data coming from measurement devices and data acquisition systems, and (b) creating the control signals (for controllable resources) in very short time-steps, near real-time operation of the system.

This potential capability of low voltage distribution grids for controlling distributed flexible resources, makes them a suitable choice for provision of flexibility and ancillary services to the upstream medium and high voltage grids.

In this respect, the main questions that this project addresses are:

1. How the flexible resources within distribution grids should be controlled to ensure secure operation of the grid in real time? What is the impact of uncertainties associated with the local generations and demands?
2. What are the potential flexibilities and ancillary services that distribution grids could provide to the upstream transmission grids? What are the technical constraints?
3. What is the optimal strategy/schedule for controlling flexible resources within a low voltage distribution grid? What is the efficient way to handle uncertainties in the development of the optimization problem?

Objectives

The first objective of this research project is to develop effective forecasting and optimal control methods to ensure efficient and secure operation of distribution grids, as well as flexibility and ancillary service provision from local low voltage distribution grids to the upstream medium/high voltage grids, under uncertainties. The source of uncertainties varies from stochastic distributed power generation (e.g., solar and wind power generation) and demand uncertainties to system model uncertainties (e.g., uncertain parameters of overhead lines and cables). Secure operation deals with satisfaction of technical constraints of distribution grids such as nodal voltage limits, power flow limits of lines/cables, and technical constraints of grid connected resources such as distributed generation and battery storage capacity limits. Efficient and optimal operation deals with both technical and economic objectives of local distribution operators such as minimization of voltage deviations and line's losses, maximization of ancillary service provision to upstream medium and high voltage grids, and minimization of real-time imbalances with respect to predefined schedules.

The second objective of the project is to implement the above forecasting and optimal control methods in a test case low voltage distribution grid and demonstrate the effectiveness of the developed methods for different grid operation scenarios.

Methodology and Outcomes

Techno-economic studies

The different groups of ancillary services (balancing, congestion management, voltage management and service continuity) have been evaluated. Depending on which service is considered and whether export or local use is considered, the relative value of the service is given by (i) the cost of the equivalent network reinforcement, (ii) the cost of a tap changer distribution transformer or (iii) the historical value of the corresponding service in the transmission grid. Items (ii) and (iii) are relatively straightforward: figures have been collected by considering the relevant historical costs. The novelty of the approach is however concentrated in item (i), the relative value of the network reinforcement avoided. An ex-ante average value of this relative value for flexibility has been determined by considering a large number of possible network reinforcements within two grid areas (rural and urban) and then computing an average cost of the reinforcement for each kWh that could be additionally injected into the system. The relative value of the flexibility is obtained by discounting the cost for the reinforcements in the entire grid area and computing an adequate average.

Forecasting systems

The methodologies developed for day-ahead and near real-time forecasting (i.e., 10 minutes ahead) of load and PV power are based on ensemble approaches, i.e., combination of individual forecasts coming from different underlying models. Methodologies are developed within a probabilistic framework in which predictive quantiles of the target variable for the target forecast horizon are generated by the forecasting system. Forecasts can be rescaled in order to extract just a single, spot value (deterministic framework), on occurrence (e.g., to be used as inputs of the real-time optimization models).

Several methodologies have been developed[4,5]:

- A Multivariate Quantile Regression (MQR) model based on underlying Quantile Regression Forest (QRFs)
- A Bayesian Bootstrap (BB) model based on underlying Linear Quantile Regression (LQR), Gradient Boosting Regression Tree (GBRT), and Quantile Regression Neural Network (QRNN) models
- A hierarchical GBRT/QRNN model, based on ranking and combination of NWPs
- A Derivative-Persistence (DP) model

The BB with LQR underlying model has been selected for the actual implementation

Two-level optimization system

The optimization system is developed based on a rolling horizon two-level optimization model. The first level deals with prescheduling of controllable resources in a day-ahead basis (DA), whereas the second level deals with near real-time scheduling (RT) of all the controllable resources. For DA optimization, two alternative methods, namely, “stochastic programming”, and “Distributionally Robust Chance Constrained (DRCC) Programming” are developed, implemented and compared in terms of optimality, robustness, and scalability. The near-real-time optimization is developed based on a deterministic linear programming model.

Validation and demonstration

Both DA and RT optimization models are fed by the DA and RT forecasting system, then tested and validated in the ReIne[6] laboratory (a reconfigurable low voltage distribution grid testbed). Figure **10** shows the schematic of validation test in the ReIne environment. The data acquisition is developed based on the monitoring system of the ReIne distribution grid equipped with GridEye devices by DepSys.

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[4] Bozorg, M., Bracale, A., Carpita, M., De Falco, P., Mottola, F. and Proto, D., 2021. “Bayesian bootstrapping in real-time probabilistic photovoltaic power forecasting.” Solar Energy, 225, pp.577-590.

[5] M. Bozorg, A. Bracale, P. Caramia, G. Carpinelli, M. Carpita, P. De Falco, “Bayesian bootstrap quantile regression for probabilistic photovoltaic power forecasting,” Journal of Protection and Control of Modern Power Systems, vol.5, 21, pp. 1-12, 2020.

[6] M. Carpita, J.-F. Affolter, M. Bozorg, D. Houmard, and S. Westerlin, “ReIne, a flexible laboratory for testing the low voltage networks”, In proc. of the 21st European Conference on Power Electronics and Applications (EPE’19 ECCE Europe), September 2019.

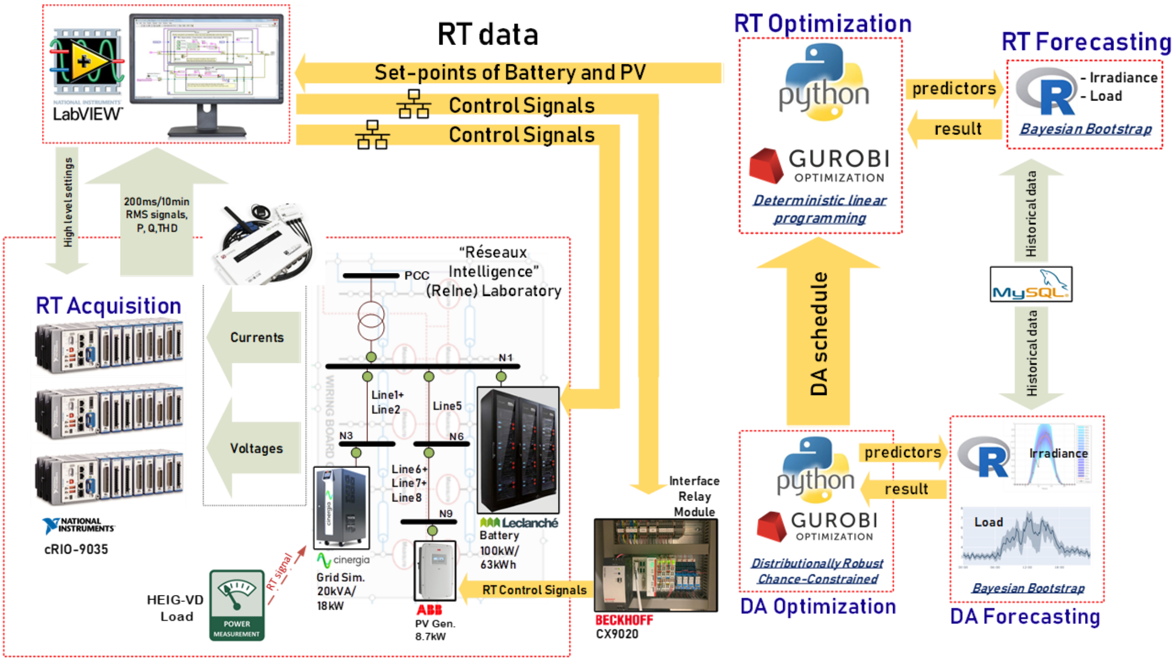

Figure 10 Implementation structure of validation test

D. ACSICON & SCCER-FURIES-Dynamics projects

Project basic information

Main goal: The project investigates dynamic power system stability, which is a growing concern for both large transmission and distribution grids. The main challenges arise from reduced inertia as converter-based generation replaces traditional synchronous machines. Depending on the time of day and the load flow situation, large transmission grids already face several dynamic challenges, ranging from inter-area oscillations, temporary frequency violations, to system splits into multiple synchronous areas.

The two projects have investigated the potential of dynamic grid support from converters as well as the necessary practical considerations regarding controller tuning to allow penetration levels of grid- forming DERs upwards of 100% of the distribution grid load. At the moment, there is no industry consensus on what control structures should be used and how to tune and configure such controllers for maximum benefit to the overall stability of the grid. Furthermore, a large share of the converters will be installed at the distribution level where their effect on overall system stability is not well understood.

To provide a robust solution to these challenges, the projects (i) developed generic dynamic distribution grid models for transmission grid studies, (ii) deployed the models in a large-scale power system simulation of large transmission grid disturbances (including system splits) and (iii) identified the critical share of converters with and without grid-support to maintain power system performance at today's level.

List of partners: Research Centre for Energy Networks (ETH Zürich), Swissgrid, Hitachi-ABB Power Grids Research

Source of funding: Swiss Federal Office of Energy, Innosuisse, Swissgrid

Duration: 2017 - 2020

Webpage:

https://www.fen.ethz.ch/activities/system-operation/acsicon.html
https://www.fen.ethz.ch/activities/system-operation/sccer-furies-dynamics.html

Project learnings

Resilience using dynamic flexibility from converter-based generation

Resilience describes the capability of a system to **recover from serious disruptive events back to normal operation**. An important resilience aspect of the power grid is related to dynamic power system stability, as seen during a black-out in South-Australia (2016) or system separations of the ENTSO-E grid (2006, 2021). In recent projects we have studied the dynamic behavior and stability during large disturbances on all grid levels, with a particular focus on the challenges and potential from converter-connected renewable energy sources.

The energy transition is expected to lead to an increased generation from converter-connected distributed energy resources (DER) like photovoltaic and wind. At the same time, some traditional synchronous machine-based generation is being decommissioned, leading to new dynamic stability challenges at both the transmission and distribution grid level, e.g., stronger frequency transients due to reduced inertia and voltage problems during transients with high local shares of converter-connected sources. Recent developments have resulted in so-called grid-forming converter control architectures that also enable the provision of grid services such as frequency and voltage support through adequate responses in terms of active and reactive power injections, for which grid operation has traditionally relied on synchronous machine-based generation.

Since most converters will be installed at the distribution grid level, the corresponding stability challenge and support functionality is the combined result of thousands individual units. A detailed dynamic modeling of all underlying distribution grids in a transmission grid is not possible both for data and complexity reasons. To derive an aggregated dynamic distribution grid model, the CIGRE medium voltage system (Figure 11) is used as benchmark. The different DER-units are equipped either with a grid-following (current-control) or grid-forming (Virtual Synchronous Machine) architecture, linearized, and aggregated using model reduction techniques. The resulting models can be used with varying DER-penetration levels for simulation-based investigations of dynamic stability and resilience.

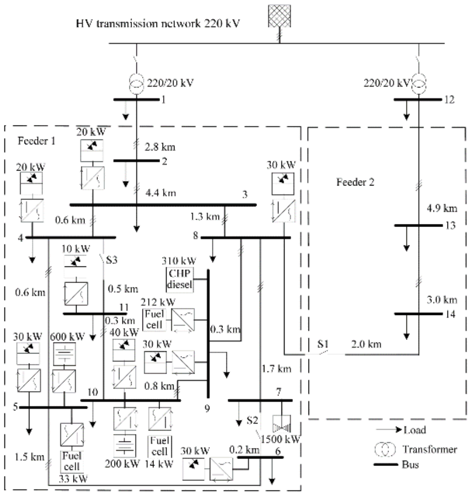

Figure 11: Cigre MV system used for stability studies with different penetration levels of grid-forming converters. At the transmission grid level, the system can be modeled in an aggregate manner. [7]

Key findings on resilience from dynamic converter control:

The **dynamic flexibility** of converter-based DER has the potential to overcome the challenges caused by the replacement of conventional synchronous machines and to **maintain or even improve the overall system resilience**.

The following use cases have been found to show a high **benefit for system resilience** from dynamic converter support during severe disturbances:

1. **System support during faults near the distribution grid feeder:**
   Grid-forming converters can react to such disturbances and the subsequent voltage drop by injecting reactive power to uphold the voltage level in the distribution grid and **improve the recovery from the fault**. Figure 2 (left) depicts the aggregated reactive power response of the Cigre benchmark system during a voltage step for increasing shares of grid-forming converters.
2. **Support of distribution grid disconnections (islanding):**
   During this disturbance, a black-out can be prevented if the distribution grid can temporarily rely on local production units. Figure 12 (right) shows the grid-forming converter's aggregated active power response during a temporary islanding of the Cigre benchmark system, allowing a **continuous supply of the system loads**. Note that the converter also generates the system frequency and perform a **seamless reconnection** to the transmission grid, after the disturbance has passed (not depicted here).
3. **Support during a transmission system split:**
   This is one of the most severe issues at the transmission grid level, short of a black-out, where the grid separates into **multiple synchronous areas**. Figure 3 depicts such a system split that has occurred in 2006 and is now studied with different supply and

[7] *[Source: Kai Strunz (Convener). Benchmark systems for network integration of renewable and distributed energy resources. Tech. Report 575, CIGRE, 2013)]*

control configurations. The converters additional active power injections reduce the frequency nadir and prevent subsequent generator trips and cascaded outages. Investigation over a broad range of scenarios and load distributions confirm, that equipping a small share of the new converters (5%-10%) with grid support capabilities is sufficient to **maintain the dynamic power system performance at today's level**, even if more than 50% of the synchronous generation is otherwise replaced by converters without grid support.

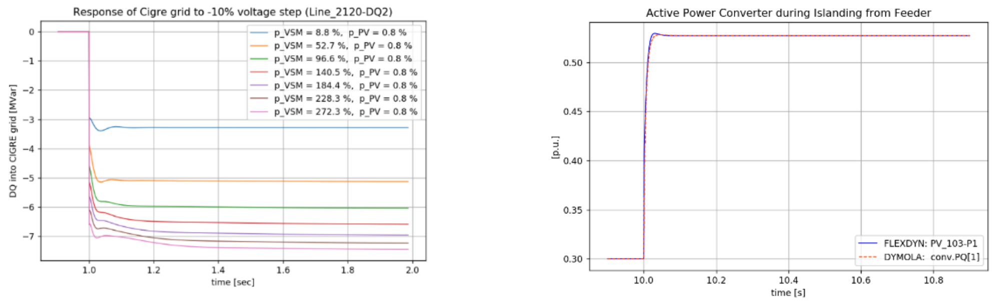

*Figure 12: **Left**: Reactive power response of the Cigre benchmark system during a fault near the feeder with subsequent voltage drop, for increasing shares of grid-forming converters. Additional reactive power injection of the converters supports the voltage level. **Right**: Active power response during a temporary islanding situation. The grid-forming converters enable continuous supply of the loads by temporarily injecting additional active power and supporting a reconnection to the transmission grid after the disturbance. [Source: own simulations and illustration]*

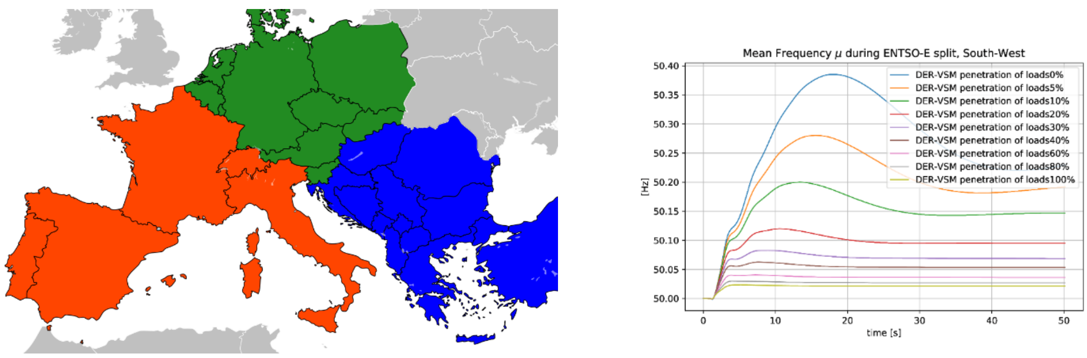

*Figure 13: **Left**: ENTSO-E transmission grid during as system split into 3 synchronous areas. **Right**: Frequency transient of the South-West region for increasing shares of grid-forming converters. The converters additional active power injections reduce the frequency nadir and prevent subsequent generator trips and cascaded outages. [Source: own simulations and illustration]*

Related projects:

ACSICON: Novel Analysis and Control Solutions for Dynamic Security Issues in the Future ENTSO-E Network with High Converter-Based Generation,
https://www.aramis.admin.ch/Dokument.aspx?DocumentID=67536

SCCER-FURIES: Critical large-scale disturbances of the future ENTSO-E system
https://www.fen.ethz.ch/activities/system-operation/sccer-furies-dynamics.html

6.2 Evaluation of ISGAN Academy webinars

The submitted evaluation forms are attached in this section.

Webinar Evaluation Form

The presented document is aimed to make easy the evaluation of the presentations proposed for the ISGAN Academy Webinar series. By analysing the corresponding slide deck, please consider the mentioned aspects and, possibly, explain your position. The listed questions represent the minimum appraisal set; please, feel free to include any comment you may have on the presentation. Thanks for your support.

The feedback provided to the Webinar Speakers is anonymised as produced by the ISGAN Academy Committee.

Title: Optimising participation of renewables generation in multiple electricity markets: Smart4RES vision, opportunities and role of forecasting.
Does the slide deck fit with the webinar title?
Yes, in principle it fits. However, when one reads the "role of forecasting in trading" in the title, one expects more quantified statements in the presentation such as "if we increase the forecasting accuracy in "*X* market by *y*% then the impact is …". Slide 20 makes an attempt along this direction.
Is the image quality sufficiently high?
Yes. However, on Slide 13, it would be nice for the audience if the legend below the figure is in English. In addition, "meteorological prediction" is not self-intuitive as, it looks like, the curve represents power prediction.
Does each slide deliver a clear message?
Some yes. Some, at least to me, not very clear. On slides 13 and 14, the text is not very helpful to interpret the graph. They are, as if, detached. Slide 30 is incomplete. Key messages slide is missing.
Is the presentation easy to understand/self-consistent?
It is self-consistent. Easy to understand.
Is the presentation too long/short?
For 30-40 minutes: The content is too intense if the presenter plans to ensure that each slide is understood and the message is conveyed.
What do you like about the presentation?
Illustrative examples always help. Slide 20 is nice.
What do you dislike about the presentation?

Please, list the errors, improvements that you suggest to specific slides.
Slide 21 would benefit from an illustrative example.

Please, provide here any other comment you may have on the presentation
The audience would benefit if the presenters provide the type of markets (day-ahead, intra-day x-hours-ahead) with forecasting horizons. Different types of resources (wind, solar, consumer, etc.) have different levels of forecasting errors (dependent on the prediction horizon) as well as different levels of uncertainties. It would be nice to demonstrate how such heterogenous resources with heterogenous statistical properties impact the trading strategy, which, it looks like (Slide 19), based on learning and heavily depends on the input. The slides with "classical problems, which never go away" are nice but it would be better to connect them to the rest of the presentation. A short discussion on how to hedge against the forecasting errors and robustify the trading strategy if the fleet can benefit from distributed energy storage systems would be nice. A short review on the state-of-the-art trading strategies for VPPs that are deployed and exploited in the industry would be nice (e.g. Next Kraftwerke, embala, etc.).

Webinar Evaluation Form

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Background information on the webinar is available in the **Annex** of this documement.
Thanks for your support.
The feedback provided to the Webinar Speakers is anonymised as produced by the ISGAN Academy Committee.

Title: Dynamic Virtual Power Plant to combine flexibilities of dispatchable and non-dispatchable RES: Posytyf project.
Does the slide deck fit with the webinar title?
Yes, partially.
Is the image quality sufficiently high?
Ok.
Does each slide deliver a clear message?
Messages are clear, but not necessarily they are always sounds. Please see my comments.
Is the presentation easy to understand/self-consistent?
Understandable but I have reservations. please see my comments below.
Is the presentation too long/short?
Ok.
What do you like about the presentation?
What do you dislike about the presentation?
The focus is not clear. It seems like they want to focus on a few tasks in WP1 but later they present the results of economic dispatch for a few types of systems without properly motivating why they are showing these analyses. Please see my comments below.
Please, list the errors, improvements that you suggest to specific slides.
Slide 10: The authors mention “system stability” as the context; however, there is no reference to work focusing on frequency or voltage stability in the project or in the presentation. **Slide 13**: (i) What do they mean by “managing specificities of decreasing global inertia of the system”? The project as a whole and the presentation do not have anything that is tackling the

"decreasing inertia" problem. They don't seem to be planning to perform dynamic stability analysis. (ii) What are the plans for resilience? They don't seem to be planning to tackle "resilience" in the traditional meaning (i.e., "ability of this system to withstand disasters, low-frequency high-impact incidents, efficiently while ensuring the least possible interruption in the supply of electricity, sustain critical social services, and enabling a quick recovery and restoration to the normal operation state"), either. (iii) What do the authors use the "dynamic network" terminology for?

Slide 14 & 21: The authors introduce a new terminology: "dynamic VPP" without substantiating the need for such a terminology. VPP concept have been in implementation in different markets (e.g., ancillary services such as secondary and tertiary control, energy market) in different countries, (e.g, US, Germany) by vendors such as Next Kraftwerke, Enbala, etc. VPP can be a combination of any resource, renewable or not, as long as the concept is aggregating the response of spatially distant resources. In my humble opinion the table on Slide 21 does not reflect the universally accepted knowledge. If the authors want to focus only on the renewables, and this would be the reason to introduce a new name, than, "dynamic" word does not reflect that. Otherwise, I cannot agree with the claim that "classic VPP focuses only on economic solution" (the last row on Slide21). In addition, non-electrochemical storage is region-dependent. Why not including electrochemical storage solutions as well? Finally, what do the authors envision or plan to do regarding the "dynamic interactions" between "DVPP" RES generators? Do they plan to investigate harmonic interactions between the converters or electromechanical oscillations contributed, etc.?

Slide 24 & 25: PV systems are rated as low on controllability and dispatchability. How about PV + electrochemical battery energy storage systems? Why not considering these hybrid systems for the future scenarios?

Slides 24 – 27: These data and characteristics are common knowledge in the power systems. What is the value of investing time in these?

Slide 33: I understand that the authors are formulating a copper-plate economic dispatch problem with ramping constraints, without representing the grid, or they use transportation model, this is not clear. Why not explicitly stating what they do with the common terminology? They use "restrictions" word to list the "constraints", which is the appropriate universally-accepted terminology. "Power variation in a time interval lower than limit" sounds like "ramping" limits, which is the terminology that could be used by the authors.

Slide 39: Is the Europe modelled with 8 nodes?

Slide 41: The authors state that solar PV and wind lack the flexibility. There are examples where the system operators are operating these units with "headroom" so that they can provide ramping up/down flexibility. Maybe, the authors can avoid making such universal conclusions but they can be more specific with their conclusions. For example "unders such and such conditions, ...".

Please, provide here any other comment you may have on the presentation

Annex

Subject:	**Dynamic Virtual Power Plant to combine flexibilities of dispatchable and non-dispatchable RES – the POSYTYF project**
Scheduled for	Nov. 18th at 15:00 – duration: 1.5h
Registration page	ISGAN - Webinar - Dynamic Virtual Power Plant to combine flexibilities of dispatchable and non-dispatchable RES – the POSYTYF project (iea-isgan.org)
Description	This webinar introduces the Dynamic Virtual Power Plant (DVPP) concept under development by the EC-funded project POSYTYF, that aims to facilitate RES integration into the electrical network. After an overall project presentation, the webinar will introduce the proposed DVPP concept and detail the first project deliverable: the definition and specification of DVPP scenarios.
Intended audience	Power system engineers, from students to senior experts.
Key messages	1. The new DVPP concept fully integrates the dynamic aspects at all levels: locally (for each RES generator), globally (for grid ancillary services and interaction with other neighbour elements of the grid) and economically (for internal optimal dispatch and participation to electricity markets) 2. A DVPP is a set of Renewable Energy Sources (RES) along with a set of control and operation procedures. This means methodologies for: • choosing the participating RES, optimal and continuous operation as a whole (especially in case of loss of natural resources - e.g., wind, sun - on a part of the DVPP), • regulation (in the dynamic sense) to ensure local objectives for each generator, • participation to ancillary services of the DVPP as a unit and to diminish negative effects of interaction with neighbour dynamics elements of the power system, • integration in both actual power systems scenarios (with mixed classic and power electronics-based generation) and future ones with high degree of RES penetration.
Speaker(s):	Bogdan Marinescu, Ecole Centrale Nantes Oriol Gomis Bellmunt, Universidad Politecnica de Catalunya Carlos Collados Rodriguez, Universidad Politecnica de Catalunya
Link to speaker bios:	**Bogdan Marinescu** was born in 1969 in Bucharest, Romania. He received the Engineering degree from the Polytechnical Institute of Bucharest in 1992, the PhD from Université Paris Sud-Orsay, France in 1997 and the

	"Habilitation à diriger des recherches" from Ecole Normale Supérieure de Cachan, France in 2010. He is currently a Professor in Ecole Centrale Nantes and LS2N laboratory where he is the Head of the **chair "Analysis and control of power grids"** (2014-2024) and the Coordinator of the European project **POSYTYF** (Research & Innovation Action, 2020-2023). In the first part of his carrier, he was active in R&D divisions of industry (EDF and RTE) and as a part-time professor (especially from 2006 to 2012 in Ecole Normale Supérieure de Cachan). His main fields of interest are the theory and applications of linear systems, robust control and power systems engineering. **Oriol Gomis-Bellmunt** received the degree in industrial engineering from the School of Industrial Engineering of Barcelona (ETSEIB), Technical University of Catalonia (UPC), Barcelona, Spain, in 2001 and the doctoral degree in electrical engineering from the UPC in 2007. In 1999, he joined Engitrol SL where he worked as Project Engineer in the automation and control industry. Since 2004, he has been with the Electrical Engineering Department of the UPC where he is Professor and participates in the CITCEA-UPC Research Group. He is involved in a number of research projects in national and international consortiums (medium-long term research oriented) and technology transfer projects with several manufacturers, operators and developers worldwide (short-term research and practical application). His research interests are focused on the understanding of modern power systems, based on power electronics (HVDC, FACTS, energy storage and renewables) and grid integration of renewable energy, especially onshore and offshore wind and solar photovoltaics. Since 2020, he is an ICREA Academia researcher. Since 2021, he is IEEE Fellow. **Carlos Collados-Rodriguez** received the Bachelor's degree in Energy Engineering and the Master's degree in Industrial Engineering from the Technical University of Catalonia (UPC), Barcelona, Spain, in 2014 and 2017 respectively. He joined CITCEA-UPC research group in 2013, where he is currently pursuing the Ph.D. degree in Electrical Engineering. His research interests include power converters, HVDC systems, grid integration of renewable energy and power system analysis, especially in power-electronics-dominated power systems.
	1. B. Marinescu, O. Gomis-Bellmunt, F. Dörfler, H. Schulte, L. Sigrist, Dynamic Virtual Power Plant: A New Concept for Grid Integration of Renewable Energy Sources, https://arxiv.org/abs/2108.00153. 2. Deliverable 1.1 when publicly released: Definition and specification of Dynamic Virtual Power Plant (DVPP) scenarios.

Webinar Evaluation Form

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Thanks for your support.
The feedback provided to the Webinar Speakers is anonymised as produced by the ISGAN Academy Committee.

Title: Optimizing the value of storage in power systems and electricity markets - the Smart4RES project**.**
Does the slide deck fit with the webinar title?
yes
Is the image quality sufficiently high?
yes
Does each slide deliver a clear message?
yes
Is the presentation easy to understand/self-consistent?
yes
Is the presentation too long/short?
ok
What do you like about the presentation?
There is coherent storyline.
What do you dislike about the presentation?
Please, list the errors, improvements that you suggest to specific slides.
Please, provide here any other comment you may have on the presentation
Slide 39: It gives the impression that the BESS size is determined by looking at only the sub-hourly predictions, which is not necessarily true.

Annex

Subject:	Optimizing the value of storage in power systems and electricity markets - the Smart4RES project
Scheduled for	December 9th at 12:00 CET – duration: 1.5h
Registration page	ISGAN - Webinar - Optimizing the value of storage in power systems and electricity markets - the Smart4RES project (iea-isgan.org)
Description	ISGAN Academy invites to to the fifth episode of the Smart4RES webinar series. The webinar will provide an industrial view on the problematic and role of storage and a discussion on utilities needs and expectation through addressing the different Smart4RES use cases. The webinar will also focus on the joint optimization and dispatch of RES power plants and storage topic through different angles. Finally, a presentation of the work done by ICCS will focus on the dispatch of RES and storage in isolated power systems including storage ancillary services and frequency security.
Intended audience	International TSOs/DSOs Storage system industrials RES producers, aggregators, grid operators RES traders Academia, Regulation bodies
Key messages	Electrochemical batteries constraints and what EDP foresees for future (coupling storage and renewables). Importance of modelling in assets management, maintenance and lifecycle. Combination of technologies, presenting VPP to the market instead of physical ones. Multi-objective optimization for RES and storage offer interpretable results to stakeholders who want to participate in multiple electricity markets. Data-driven trading solutions simplify the modelling chain of trading decisions. Necessary ancillary services for storage systems in non-interconnected island systems with high RES penetration. Dispatch of thermal units, RES and storage in non-interconnected island systems considering the frequency security and the ancillary services provided by storage devices.
Speaker(s):	Maria Inês Marques Bio Simon C. Bio Dimitrios Lagos Bio
Readings	1. Smart4res website 2. Forecasting and optimization of ancillary services provision by renewable energy sources. 3. Smart4RES: Towards next generation forecasting tools of renewable energy production.