INTERRFACE

D5.5. Single Flexibility Platform: Demonstration Description and results

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Abstract

Single Flexibility Platform demonstrator elaborates cross-border (regional) processes, models and solutions in order to attract market participants like Flexibility Service Providers and Market Operators easily to participate in individual marketplaces. The demonstrator uses IEGSA platform and its additional features that automate specific use cases.

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ACRONYMS AND ABBREVIATIONS

A	Ampere
AC	Alternating Current
aFRR	automatic Frequency Restoration Reserve
API	Application Programming Interface
BMS	Balance Management System
BRP	Balance Responsible Party
CGMES	Common Grid Model Exchange Specification
CIM	Common Information Model
CM	Congestion Management
CE	Conducting Equipment
CoBA	Coordinated Balancing Area
D	Day
DB	Data Base
DC	Direct Current
DSO	Distribution System Operator
FRR	Frequency Restoration Reserve
ECCO SP	ENTSO-E Communication & Connectivity Service Platform
ECP	Energy Communication Platform
EIC	Energy Identification Code
ENTSO-E	European Network of Transmission System Operators for Electricity
ESMP	European Style Market Profile
FCR	Frequency Containment Reserve
FR	Flexibility Register
FSP	Flexibility Service Provider
GSRN	Global Service Relation Number
H	Hour
HV	High Voltage
Hz	Hertz
ID	Identifier
IEGSA	Interoperable pan-European Grid Service Architecture
IGM	Individual Grid Models
IT	Information Technology
JSON	JavaScript Object Notation
kV	kilo Volt
kVA	kilo Volt Ampere
kVAr	kilo Volt-Ampere reactive
kW	kilowatt
kWh	kilowatt-hour
LODF	Line Outage Distribution Factors
LV	Low Voltage
M	Month
mFRR	manual Frequency Restoration Reserve
MO	Market Operator
MOL	Merit Order List
MTU	Market Time Unit
MV	Medium Voltage
MVA	Mega Volt Ampere
MVP	Minimum Viable Product
MW	Megawatt

NVSF	Node Voltage Sensitivity Factor
PV	Photo-Voltaic
PTDF	Power Transfer Distribution Factor
R&D	Research and Development
RSC	Regional Security Coordinator
SCADA	Supervisory Control And Data Acquisition
SO	System Operator
TDCP	TSO-DSO Coordination Platform
TSO	Transmission System Operator
UI	User Interface
WP	Work Package
XML	Extensible Markup Language

Executive summary

Single Flexibility Platform demonstrator elaborates cross-border (regional) processes, models and solutions in order to attract market participants like Flexibility Service Providers and Market Operators easily to participate in individual marketplaces.

The demonstrator uses the IEGSA (Interoperable pan-European Grid Service Architecture) platform developed in INTERRFACE project, which was complemented with additional components and tools and that automate specific use-cases (such as the grid and bid qualification and the settlement). IEGSA architecture was implemented in Single Flexibility Platform demonstrator almost in its full entirety.

Different flexibility use cases were investigated. Balancing use cases include well-known and standardised products: mFRR, aFRR and FCR. Two different use cases are defined for congestion management (CM): operational CM and short-term CM.

Relying on mFRR product description is proposed also for CM products in order to boost liquidity. Flexibility products for CM should be sufficiently aligned to permit the market-based flexibility allocation between these different purposes (balancing and CM) with the objective to maximise the value of flexibility services.

Identical products in different geographical markets (Finland, Estonia, Latvia) are not needed, but interoperability would enable exchange between markets. This means harmonisation of products and processes to the extent that enables easy access to market by FSPs and emergence of third-party MOs. Additionally, liquidity is increased when DSOs and TSOs use the same pool of flexibility bids.

As an additional measure, flexible grid contracts use case is described. According to this, it is a tool for the SOs to connect more customers to the grid than what would be possible with firm connection contracts. Every flexible grid connection customer will have a certain amount of flexible connection capacity SO can restrict under certain terms.

Flexibility markets and TSO-DSO coordination have many novel aspects that were encountered and developed further during the INTERRFACE project. For most of these aspects, there were no previous references from other projects and initiatives on the level that is required for conceiving a functioning flexibility market with TSO-DSO coordination. Many pilot projects have tackled parts of the process, creating, for example, standalone flexibility markets for a single buyer. But when the coordination aspects are brought to the picture, a variety of new questions arise. The INTERRFACE project also contributed to the definition of new roles, including those not included in Harmonised Electricity Market Role Model yet. This work clarifies the different tasks of emerging flexibility markets and helps in assigning responsibilities in future implementations.

<u>Operational Congestion Management</u>

- Estonia: Regarding the market processes and specific improvements to technical tools some conclusions made in case of mFRR product (Chapter 4.1.3) are as relevant for CM product. It is worthwhile to add that the availability and proper usage of grid data is especially important for congestion management. Definitely, for congestion management the location of both congestion and flexibilities must be known. This enables resource/bid qualification and bid selection processes.
- Latvia: The IEGSA platform offers processes needed in the close future, which at the moment have no alternative in Latvia. Highly valued are processes related to FSP portfolio management and TSO-DSO coordination. The coordination between the networks is cleverly imbedded in platforms grid qualification process that repeats when creating or modifying resource and resource group and when resource group pre-registered on platform submits a market bid. This process to some extent ensures operational stability between TSO and DSO network levels by evaluating the FSP resources using network information directly from TSO and DSO. The IEGSA platform has a large

potential but requires further development to accommodate solution shortcomings to reliably support network flexibility from resource provider, market and system side.

- Finland: The Finnish operational CM demonstration was successful in piloting the end-to-end IEGSA process in the planned scenarios to validate its functioning in different situations. The IEGSA solution provided the FSPs a possibility to manage their resources, offer them to markets through the connected MO, and get activation request from the respective marketplace. For the SOs, the solution introduced a possibility to procure flexibility in a coordinated manner based on the location of the resources. IEGSA performed resource-, product- and bid qualifications as planned, which worked as a prerequisite for the realization of flexibility trades. Finally, the settlement functionality determined the amount of delivered flexibility.

Short-term Congestion Management:

- Finland: Intraday pilot case proved that CM can be part of international and liquid intraday market with relatively small system level exceptions and modifications. This makes it possible for all SOs, FSPs and independent service providers to participate into regional intraday based flexibility market without any major updates to systems or operative processes.

mFRR

- Estonia: Eventually all planned steps for mFRR product (registration, qualification, trading, settlement) were successfully performed. While mFRR is a known product in Estonia, there has been basically only one provider until now. Therefore, the existing technical solutions have not been designed to facilitate the participation of a high number of FSPs and resources. However, the processes can still be finetuned both business- and software-wise. But this must be a step-by-step process while the market will become more liquid – more TSO needs and more available FSPs and resources. The business processes need to be adapted accordingly and software solutions must follow the new business requirements. Which means that the technical solution must be flexible enough to be adapted to new needs.
- Latvia: The IEGSA platform provides an array of beneficial functionalities to accommodate future FSP role and its integration in the balancing and other markets. Part of this beneficial process from new platform user creation till initial FSP resource and resource group qualification was demonstrated only once during the mFRR demonstration process as no user, product or resource and their group changes were needed. However, the mFRR demonstration process covered trading and settlement part of the process tree, starting from market bid evaluation and concluding with settlement results. Some further IEGSA improvements to accommodate current market functions and increase operational reliability were identified.

aFRR and FCR

- Initially the plan of the demonstrator was to test the aFRR and FCR products as a part of the demonstration. In early phase of the demo planning, focus was put to the most prominent products for CM. mFRR is used for transmission level CM in many countries and additionally it was seen as the most interesting product for independent aggregation in some. Also, one criterion for the products to be focused on was the usability from DSO perspective. these products were left out of the final scope of the demo, since the products can be regarded as "single purpose" compared to for example mFRR, and the products are used only by the TSO as a single buyer to buy capacity services

Flexible grid contracts

- Estonia: From the testing it can be concluded that the existing principle of flexible grid contracts could be used in the flexibility services provision, however the contractual rights and obligations are generating some constraints in the business processes and activation conditions that limit the full implementation and testing of the solution. The tests ran successfully and the flexible contract bids were generated. The contracts should be reviewed from the activation condition perspective in order to make them accessible to other participants in the flexibility market. Removing the specific conditions would allow the contracts to be activated by other market participants.

PTDF matrix-based grid qualification

- The grid qualification service made by Cybernetica was tested by Elenia. The testing concentrated on confirming that the implementation of the qualification service corresponded to the specifications, worked in different kinds of situations that could happen during the live demonstration, and provided accurate qualification results.

1. Introduction

Single Flexibility Platform demonstrator (task 5.3) of INTERRFACE project was carried out in months 12-42 in three countries – Finland, Estonia, and Latvia. The general aim was to elaborate cross-border (regional) processes, models, and solutions in order to attract market participants like Flexibility Service Providers (FSPs) and Market Operators (MOs) easily to participate in individual marketplaces.

According to the Grant Agreement: "The task will focus on the adaptation of the suitable market framework based on the work done in WP2 and WP3. The business use cases and service use cases will be described in more detail and suitable market rules and coordination schemes for Baltic-Nordic region will be defined. The platform architecture developed in task 4.2 will be parameterized and will undergo further technical testing. All the business use cases will be tested and demonstrated on real market situation. The use cases to be demonstrated are (a) congestion management (from TSO and/or DSO side); (b) frequency/balance management in TSO side, including mFRR, aFRR, FCR products and demonstration in cross-border usage; (c) flexible grid connectors, where both contracts and technical feasibility will be demonstrated; (d) trading between interested market participants, like BRPs, prosumers."

This deliverable describes the Single Flexibility Platform demonstrator in detail. The scenario, the objectives and the involved actors are presented. The description of the various use cases is included, as well as the market framework. Finally, the results are described in detail.

The demonstrator uses the IEGSA (Interoperable pan-European Grid Service Architecture) platform developed in INTERRFACE project. This deliverable summarises the main features of IEGSA relevant for Single Flexibility Platform demonstrator. More detailed description of IEGSA can be found in WP4 deliverables 4.6 (2021) and 4.7 (2022). Cybernetica as the local IT partner has developed components and tools that complement IEGSA and that automate specific use-cases (such as the grid and bid qualification and the settlement).

Transmission System Operators (TSOs) (Elering, Fingrid, AST) and Distribution System Operators (DSOs) (Elenia, Elektrilevi) participating in the demonstration defined the use cases. European Dynamics and Cybernetica were the IT partners of the demonstrator by developing the technical architecture and components of the solution, providing APIs (application programming interfaces) and user interfaces for integrating the solution with existing systems of the stakeholders, guiding the deployment of the solution by the participating System Operators (SOs), and providing administrative support. The solutions have been tested and piloted in different countries (Estonia, Finland, Latvia) and demonstrated through different flexibility products (operational Congestion Management, short-term Congestion Management, balancing (mFRR), flexible grid contracts). In piloting external MO (NordPool) and flexibility service providers (Fusebox, Kapacity.io) were engaged.

Chapter 2 of the deliverable reminds the objective and use cases of the demonstration, including, congestion management, balancing and flexible grid contracts. Chapter 3 provides the description of the demonstration – architecture, summary of IEGSA platform and components, APIs, internal SOs' developments supporting IEGSA, methods for grid qualification and summary of data model. Chapter 4 describes the results per country level implementation of different use cases. Chapter 5 provides conclusions and lessons learned.

2. Objective and use cases of the demonstration

2.1. Congestion management use cases

Two different use cases are defined for congestion management (CM): operational CM and short-term CM.

In order to solve operational hour internal congestions ("internal" as opposed to cross-border/cross-zonal congestions), TSO and DSO could use flexibility with locational information for CM. Default service criteria and product attributes could be the same as for mFRR balancing product and activation decision will be done close to real-time, i.e., one hour in advance (during H-1) and manually by a dispatcher.

In order to solve short-term planning timeframe internal congestions, TSO and DSO could use flexibility with locational information for CM. Default service criteria and product attributes could be similar to mFRR balancing product, but less strict compared to operational CM. Activation decision will be done in D-1 timeframe (grid calculations and congestion check one day in advance for every Market Time Unit (MTU) by a short-term planner.

Short-term planning congestions may rise due to outages, maintenance, or production patterns. The procurement of flexibility for CM could be seen from M-1 (month-ahead) until D-1 (day-ahead). The earlier procurement of flexibility is relevant for example for maintenance schedule approval, which, depending on SO processes, could be done month-ahead.

Relying on mFRR product description is proposed to boost liquidity. Flexibility products for CM should be sufficiently aligned to permit the market-based flexibility allocation between these different purposes (balancing and CM) with the objective to maximise the value of flexibility services. The flexibility will be procured in auctions for CM, separated from balancing, wholesale markets.

Identical products in different geographical markets (Finland, Estonia, Latvia) are not needed, but interoperability would enable exchange between markets. This means harmonisation of products and processes to the extent that enables easy access to market by FSPs and emergence of third-party MOs.

The products should be either an option (available capacity) or direct activation. However, availability products must be designed properly to avoid a decrease in market liquidity due to non-activation of contracted products. To ensure the right balance between availability and market liquidity, DSOs and TSOs will agree on how to coordinate this. Additionally, liquidity is increased when DSOs and TSOs use the same pool of flexibility bids. The objective is to demonstrate direct activation and coordination mechanisms between TSO-DSO to ensure flexibility bids won't cause further congestion in grids.

2.2. Balancing use cases

Balancing use cases include well-known and standardised products: mFRR, aFRR and FCR.

Frequency restoration reserve (FRR) "means the active power reserve available to restore system frequency to the nominal frequency and, for a synchronous area consisting of more than one LFC area, to restore power balance to the scheduled value" (Regulation 2017/1485)[1].

Manual Frequency Restoration Reserve (mFRR) is a manual change in the operation set-points of the reserve (mainly by re-scheduling), in order to restore system frequency to the set point value frequency and, for a synchronous area consisting of more than one load-frequency control area, to restore power balance to the scheduled value.

Automatic frequency restoration reserve (aFRR) is designed for a centralized automatic function intended to replace FCR and restore the frequency to the target frequency – usually 50.00Hz. In contrast to mFRR,

[1] https://eur-lex.europa.eu/eli/reg/2017/1485/oj

aFRR can be activated by an automatic control device. This control device shall be an automatic control device designed to reduce the Frequency Restoration Control Error to zero (Regulation 2017/1485).

Frequency containment is an automatic function which aims at stabilising the frequency at a steady-state value within the permissible maximum steady-state frequency deviation after disturbances in the high-voltage grid. By the joint action of all automatic devices, the process ensures the operational reliability in the synchronous area. Frequency containment reserve (FCR) "means the active power reserve available to contain system frequency after the occurrence of an imbalance" (Regulation 2017/1485).

Frequency products are defined in European legislation (network codes). Products mFRR and aFRR are to be traded on pan-European level using dedicated platforms (MARI and PICASSO, respectively). TSOs and DSOs are obliged to cooperate in order to facilitate and enable the delivery of frequency products by units located in the distribution systems (Regulation 2017/1485).

2.3. Flexible grid contracts use case

Flexible grid contracts use case was described in previous WP5 deliverable (INTERRFACE D5.2, 2021). According to this, it is a tool for the SOs to connect more customers to the grid than what would be possible with firm connection contracts. SO customer's capacity to be injected into grid or withdrawn from the grid would be restricted under certain terms or congestions in the area. Every flexible grid connection customer will have a certain amount of flexible connection capacity SO can restrict under certain terms.

Flexible grid contract applies to connections where a grid element could become overloaded as a result of transmission of the capacity desired by the customer. In such a case, the customer has a choice of whether to cover the investment cost of increasing the capacity of the overloaded grid element (through the connection fee) or agree to reduce their generation and/or demand capacity in overload situations. For the SO it means more optimal and higher utilisation rate of the grid, and less costs.

In preparing each connection offer, a power grid analysis is conducted, during which the planned generation and/or demand capacity is added to the power grid model and its impact on the electricity system is determined in various generation and/or demand limit scenarios. If the analysis shows that one or more of the grid elements are likely to become overloaded depending on the operating mode, the grid element's capacity must be increased in order to guarantee the generation and/or demand capacity desired by the customer. Besides traditional connection agreement offers, which include expenses on upgrading the grid, offers to customers could be made allowing them to use the desired connection subject to restrictions. No investments into increasing grid capacity need to be made in these cases.

Before the customer signs the connection agreement and before the making of an investment decision, SO will give the customer information about the types of generation and/or demand scenarios where the model shows potentially overloaded elements, and a statistical overview of the occurrence of scenarios that cause overload. SO also provides information about the cases in previous years where grid elements potentially causing overloads have been switched off. With this knowledge about the cost of upgrading the capacity of the potentially overloaded grid element and the likelihood of the temporary restrictions, the customer can make a better-informed decision on whether to opt for a flexible connection.

The restriction on capacity will be applied only if there is a risk of overloading grid elements, and connection agreement with the customer specifies which elements these are. If a given grid element is included in connection agreements with more than one customer, the restriction of capacity will start with the customer who established the connection to the grid most recently, and so on, until the oldest connection is reached. The restrictions on generation and/or demand capacity must be executed by the customer pursuant to the grid operator's requirements.

The need for utilizing flexible connection capacity may become evident while the SO models the operation of the electricity system at different points in time – starting from planning for the year ahead to the start of the operational hour. Customers will be notified as soon as possible of the need for a partial or full restriction placed on a flexible connection.

In the case of unscheduled restriction of a flexible connection capacity (such as a malfunction in the electricity system or extraordinary works on the grid etc.), the restriction will be implemented automatically by SO by way of remote control.

3. Description of the demonstration

3.1. Architecture

The INTERRFACE project offers the creation of a common architecture which enables the connection, data and information exchange across Europe between TSOs, DSOs, MOs, FSPs, customers, data hubs. The blend of assets, datasets, tools, services, and market models is envisioned to optimize operations and allow the introduction of standardized/harmonized services and market designs to cover the needs of more stakeholders of the energy value chain.

IEGSA's architecture is comprised of four main modules: Flexibility Register (FR), TSO-DSO Coordination Platform (TDCP), Single Interface to Market and Settlement Unit. The FR is a component that manages the flexibility resources and grants them access to specific market products (portfolio management). The TDCP handles the qualification processes which ensure that market actions don't violate the grids' technical limits. Single interface to market enables a uniform information exchange interface towards systems communicating with IEGSA. Settlement unit identifies whether the traded flexibility was delivered as promised and communicates these results forward.

IEGSA architecture (Figure 1) was implemented in Single Flexibility Platform demonstrator almost in its full entirety, except ECCo SP (ENTSO-E Communication & Connectivity Service Platform) communication.

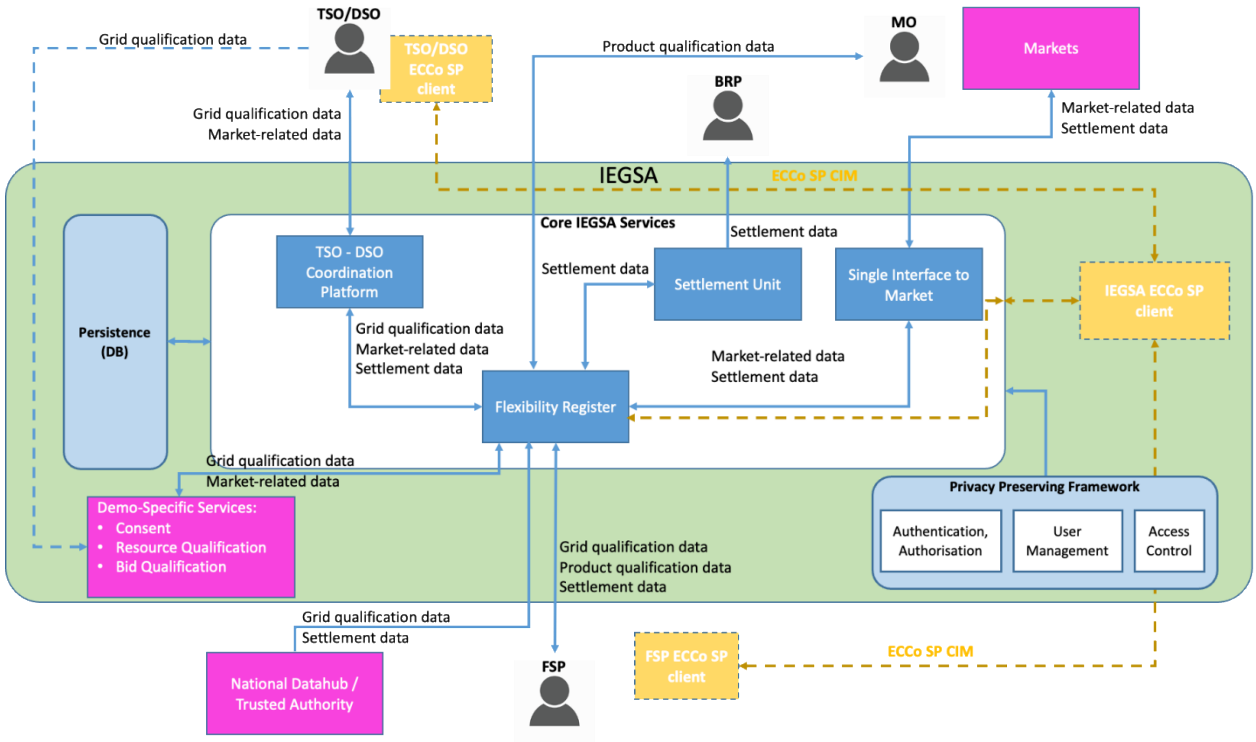


Figure 1 IEGSA Architecture

3.2. IEGSA platform

3.2.1. IEGSA core components

IEGSA core components are described in detail in INTERRFACE deliverables 4.6 (2021) and 4.7 (2022). Some notes are stressed in this sub-chapter which are highly relevant for Single Flexibility Platform demonstrator.

The FR component is mostly dedicated to the needs of FSP. It enables product registration, resource registration, creation of resource group, product qualification, checking the qualification status, checking the bid status, and obtaining information about traded bids.

Notes regarding the resource registration which requires consent granting process:

- For the Estonian case IEGSA needs to communicate with Elering's data exchange platform Estfeed. IEGSA sends the EIC (Energy Identification Code) code of the FSP and the EIC code of the resource to Estfeed through an API. Estfeed returns the confirmation about the existence of valid consent. If consent is granted, then the FSP is allowed to manage the resource further. Otherwise, this resource can no longer be accessed by the FSP.
- In other countries' implementations, the FSPs are required to guarantee that they have received the consent of the resource owner when registering the resource.

TDCP is the IEGSA component for SOs enabling qualification of the resources and bids, information about the resources in resource groups, creation of MOLs (Merit Order Lists), selection of bids and information about activated bids (trades).

Notes regarding MOLs and activation:

- While activation of bids for CM is performed through IEGSA, activation of bids for mFRR does normally not take place through IEGSA (however, CM can be activated also outside IEGSA). In the Finnish CM pilot mFRR bids were used by adding the reference to IEGSA resource groups to the bids. In this case the process followed the CM process, where activations are done through IEGSA.
- In case of Baltic countries, mFRR bids can only be activated on Coordinated Balancing Area (CoBA) platform and IEGSA will only receive the activation information. The CoBA platform enables coordinated exchange of balancing services, sharing of reserves, imbalance netting process and imbalance settlement.
- The definition of locational intra-day product is essentially treated as CM product. Therefore, incoming bids from the intraday MO shall appear in the same MOL with CM bids. APIs are established to communicate with intraday MOs which resource groups at IEGSA level are registered to provide locational intra-day products. An API is deployed also to examine the availability of NordPool bids at IEGSA and accordingly maintain them in the CM MOL or present them in the trades tab of IEGSA users.

3.2.2. IEGSA additional features

Beside the IEGSA "core" components some additional features dedicated to Single Flexibility Platform demonstrator were developed. These include grid qualification of resource, grid qualification of bid and settlement.

3.2.2.1. Grid qualification of resource

In resource qualification process, the metering points with proposed capacities are checked in order not to exceed any network limits. The process returns qualification result with passed and failed nodes (metering points). Accordingly, the nodes that violate limits are listed as failed nodes. TSO and DSO results are separated to identify which operator's network caused a node to fail. Violated limit is provided as a reason for each failed node.

Resource qualification assumes that system has access to information on the grid limitations and resources to be qualified. Two formats of grid information are supported:

- Power limit table
- Power Transfer Distribution Factors (PTDFs) together with Node Voltage Sensitivity Factors (NVSFs)

In case of power limit table format, the grid information consists of nodes, connections between the nodes, and maximum amount of load and production that can be added under each node. The summed-up resource capacities, which are compared with the node maximum capacities, are stored in a directed acyclic graph that presents the network topology.

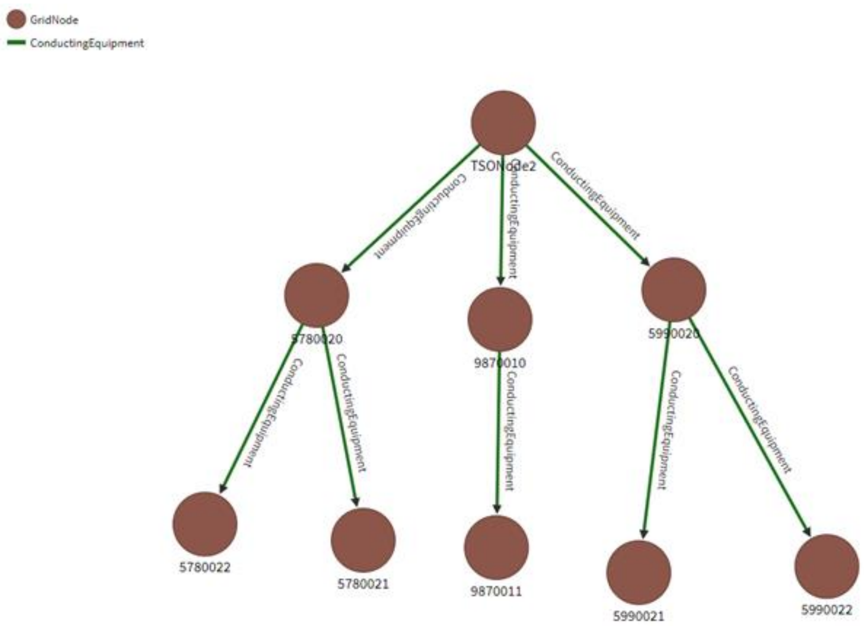


Figure 2 Example representation of a directed acyclic graph

In PTDF approach, the grid information is supplied as a list of nodes and conducting equipment connecting them. Voltage limits and forecasts are given for the nodes, and power flow limits and forecasts are given for the conducting equipment. In addition, sensitivity matrices are provided. These tell how the forecasted voltages and power flows change when resources are activated.

3.2.2.2. Grid qualification of bid

Bid qualification process differs depending on product type:

- mFRR – bid is either qualified or rejected as a single entity.
- CM – bid is broken down into partial "child" bids, which are complemented with locational information, in order to aid the SOs to identify specific bids that could relieve congestions in already identified congested parts of the network.

Bids are applied to network topology and situation is validated in order not to exceed any network limits. In case of limit violation, the bid with highest energy price is removed from the graph and appended to a list of rejected bids. Step is repeated until there are no limit violations, or every bid has been rejected.

The process returns qualification result with qualified and rejected bids. TSO and DSO results are separated to identify which operator's network caused a bid to be rejected. A violated limit is provided as a disqualification reason for each rejection.

3.2.2.3. *Settlement*

Settlement process is about verifying if FSP has activated its flexibility bid in line with SO request (a bid submitted with A37 message and acquired by SO with A40). Settlement does not know trade price and has nothing to do with financial obligations, it is only about energy volumes requested and provided.

There is a dedicated screen on the IEGSA User Interface (UI) where FSPs will be able to download the settlement results for the bid of their choice. All settlement processes initiated by IEGSA are performed through API calls.

Following data is used in settlement process:

- A40 – flexibility acquired for time period by SO (based on A37 bid offering by FSP).
- A14 – flexibility activated by FSP for time period.
- A64 – measurement data from metering points, the actual amount of energy per FSP metering point produced or consumed. It is used to calculate the actual amount of delivered flexibility.
- Baseline – estimated amount of energy per FSP metering point produced or consumed if flexibility had not been activated.

Actual flexibility delivered by FSP is calculated either based on previous hour's measurement data or baseline. In both options there are one minute measurement data for settlement period to compare either with previous hour or baseline.

3.3. Application Programming Interfaces

This chapter summarises the APIs which were developed in the Single Flexibility Platform demonstrator. APIs relating to "core" IEGSA (FSP APIs, internal APIs) are described in deliverable 4.7 (2022).

3.3.1. System Operator APIs

Table 1 List of System Operator APIs

API name	**Description**
Consent API	The Consent API is being used internally by IEGSA to check the following two aspects: 1. Whether IEGSA has resource owner's consent to process their data. 2. Whether resource owner has confirmed that they have a contract with the FSP who is using IEGSA to register the resources. In case of a negative answer IEGSA can provide the FSP feedback and block them from using the resource(s) that did not have the consent. Consent solution is dependent of location: • Estonia: Estfeed-based solution • Others: route requests to dedicated SO consent service.
Network Topology API	API allows SOs to upload simplified topological models of their network which are then used in the automated resource qualification and bid qualification processes.
Network Limits API	API allows SOs to upload forecasted up- and downregulation limits for network nodes (a.k.a. power limit tables). This API is used only if grid info is in power limit table format.
Sensitivities API	API allows SOs to upload PTDF and NVSF sensitivity matrices. This API is used only if grid info is in PTDF format.

Forecast API	API allows SOs to upload forecasted conducting equipment power flows and node voltages. This API is used only if grid info is in PTDF format.
Resource Qualification API	API performs resource qualification. Network topology and limits provided by SOs are a prerequisite for this process. The process determines which of the proposed resources comply with existing network limits.
Bid Qualification API	API performs bid qualification. Network topology and limits provided by SOs are a prerequisite for this process. The process determines which of the proposed bids comply with existing network limits.
Merit Order List API	The purpose of the API in this context is to forward merit order lists of bids from all MOs to all integrated SOs using the IEGSA platform. Also, the bids must be qualified beforehand, or they are not added to the MOL.
Activation API	The Activation API was created to allow SOs to select bids from a MOL and then inform the IEGSA platform and through this also the MO about the selection. Since the XML format comes from mFRR product context, it presumes that when the SO selects a bid, it is always still available and will eventually be activated (unless message exchange fails).

3.3.2. Market Operator APIs

Table 2 List of Market Operator APIs

API name	Description
Reserve Bid API	The reserve bid API was built to receive bids from MOs. The main use case is to submit the bids for bid qualification after a gate closure time, although continuous markets without a gate closure are also supported.
Activation API	API to receive bid activations from MO.
Cancellation API	API to receive bid cancellations from MO.
Document Retrieval API	The purpose of the API is to allow MOs to receive various documents from the IEGSA platform.
Nord Pool API	Intermediary between Nord Pool and IEGSA, converts Nord Pool orders into IEGSA bids and vice versa. Converts IEGSA activation order documents to Nord Pool order matching requests. Provides list of IEGSA FSP resource groups to Nord Pool.
Settlement API	Settlement API enables Settlement process for MO or SO on checking if FSP has fulfilled its offer (a bid given with A37 and acquired by SO with A40). The same API is used by SO.

3.4. Internal developments supporting IEGSA

3.4.1. Fingrid

To meaningfully test the developed IEGSA system and verify its processes, the principle for the internal development was to utilize as much as possible the current systems and operational processes as the basis for connecting to IEGSA. This also supports the evaluation of the scalability of the developed process and the exploitability of the results. Internal development of Fingrid was focused on two topics: creating a methodology to provide the grid data needed by the IEGSA process and the connection of the Balance Management System (BMS) to the IEGSA platform. The development done for these purposes was novel from the TSO's perspective and enabled a design that best benefits both the IEGSA process testing and the evolution of the internal TSO systems and capabilities.

3.4.1.1. Grid data

The resource and bid qualification processes of IEGSA use different grid models. The purpose of the resource qualification is to do an initial prequalification of all the resources added to the FR and find out whether there exist situations where the respective resources can cause problems to the grid. For this purpose, a grid model is needed to represent a situation where the grid is in a state which has a high loading and generation including high power transfers on different grid components. Thus, this model gives the best estimate for the process to find out if the resource can cause problems in a high loading situation.

For this need, three seasonal grid models were used to find the most limiting situation for the respective resources. These seasonal models are used by Fingrid's operational planning to examine extreme grid situation typical for winter, summer, and inter-seasonal circumstances. The bid qualification, on the other hand, needs a grid model that reflects as real-time state of the grid as possible, so that it can be used to determine whether each individual bid could cause problems for the grid in that specific point in time. For this purpose, Fingrid developed the capability to utilize grid models used in short-term operational planning and thus gives the best estimate of the grid state for the following two days. This grid model is used in Fingrid's internal processes to provide the Individual Grid Models (IGMs) for the common Nordic operational planning conducted by the Nordic Regional Security Coordinator (RSC). Also, a capability was built to use real-time measurements and switching state from the grid monitoring system (Supervisory Control And Data Acquisition, SCADA) to get grid information for the process of the most recent data available.

Both qualification processes utilize a grid model that consists of a grid topology and available up and down regulation capacities for each node in the topology. To acquire this information, a calculation model was created to determine these values based on the source data described above. The calculation in both cases (for the static resource qualification model and the more dynamic bid qualification data) is similar. A Python script was developed in the project by Fingrid to run PSS/E model simulations through an API and to generate files containing node capacities. The model takes each topology node individually and starts adding generation to the forecasted level of the node in 10 MW steps until a limit is found where operational safety limit is exceeded at any point in the grid (transformer or line load capacity or voltage limit). The last value which didn't have any components overloading is assigned to the maximum up-regulation power for the node. Then, same process is conducted by adding consumption for each node in order to find the maximum downregulation of the node. When all nodes of the topology have been calculated, the information can be sent to IEGSA. The process flow of the calculation is depicted in Figure 3.

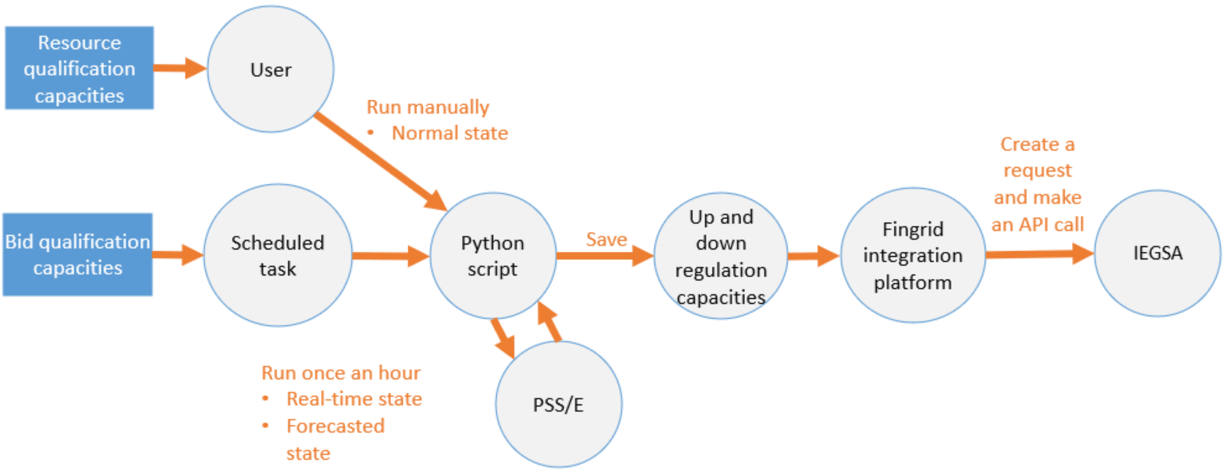


Figure 3 Description of the process which was created to provide the grid data needed by the IEGSA process

The scheduled grid data calculation is run once per hour using the two available grid models described above. An example of the performed calculation is presented in Table 3 Example of a grid calculation run at 10 AM. The presented calculation would be run at 10 AM with the validity periods given in the table. This data would hence be available for qualifying the bids for the hour starting at 11 AM. With this method, all the hours of the day are updated hourly using either the IGM process data or the real-time model from SCADA.

Table 3 Example of a grid calculation run at 10 AM

Input data	Validity period for results
Real-time state	10:00–12:00
Forecasted state at 12:00	12:00–18:00
Forecasted state at 18:00	18:00–10:00 next day

Due to the IEGSA platform's nature as an R&D project system, the input data derived from the operational systems was not used in the demonstration. Still, the internal development proved that it is feasible to determine the needed grid data values from operational systems. This work also increased the understanding about the requirements towards each SO using a common system like the IEGSA platform to conduct coordinated flexibility utilization.

3.4.1.2. Balance management system

The IEGSA architecture contains the role of MO which acts between the FSP and the IEGSA platform used by the SOs. The task of the MO is to collect bids from the FSPs and pass them on to IEGSA. In the Finnish demonstrator, one of these MO platforms was the BMS of Fingrid. Even today, the TSO uses mFRR bids for the occasional CM actions needed to remove bottlenecks in the grid. Thus, it was a natural choice to include this market as one of the sources of CM bids of IEGSA.

Based on this decision, Fingrid developed its BMS to integrate with the IEGSA platform and its processes. This included changes to the internal data structure of the system to enable asset database objects to be mapped to resource groups modelled in IEGSA. In addition, the integration required development to allow the bids submitted by FSPs to move from the TSO system to IEGSA. Similarly, the activation requests from

IEGSA needed to be received and processed by the BMS. Further development was initiated to build information exchange with the piloting partner acting in the role of FSP. Communication took place over the ENTSO-E's Energy Communication Platform (ECP). This choice also reflects the urge of the project partners to pursue the use of solutions already being used by existing processes. In this development, existing data formats used within the current mFRR market scheme information exchange were used. The information exchange between the FSP, BMS and IEGSA in the Finnish demo is presented in Figure 4.

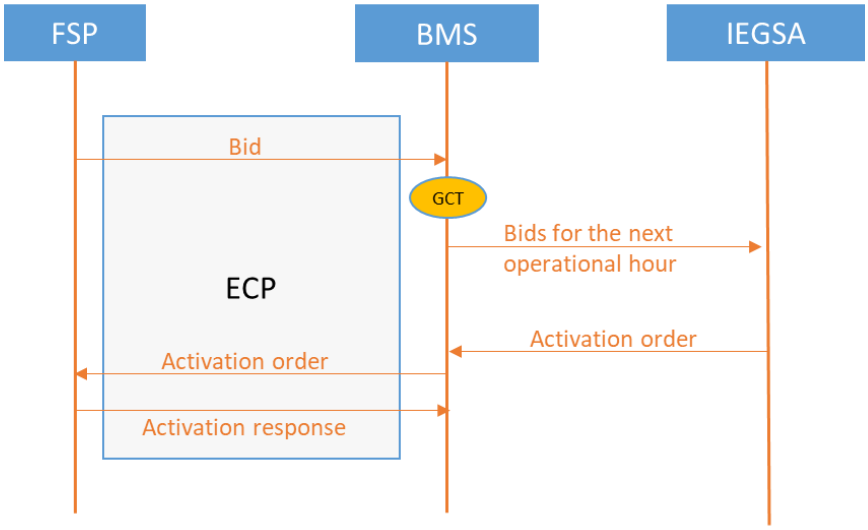


Figure 4 Information exchange implemented to connect the BMS to IEGSA and communicate with FSPs

3.4.2. Elering

3.4.2.1. Balance management system

For the market information exchange and interface between the FSPs and IEGSA from Elering side additional configurations and changes were made to Balance management system that is for day-to-day operations used for market data interface for day-ahead, intraday and reserve markets. The development efforts are listed in Table 4.

Table 4 Developments of Elering's BMS

Description of development	Functional need	Time and effort spent
Accepting Bid documents from the FSP	Needed to collect all relevant bids from market participants as an input for the IEGSA system	1 day. As currently Bid documents are accepted for reserve markets, only minor setting changes were needed.
Visualising the sent mFRR and CM bids	To verify the data sent is correct	1 day. Using existing functionality to modify views.
Sending mFRR and CM bids to IEGSA	Bid collecting for the BID management	Up to 3 days. Implementation around 1 day, however during testing the Bid forwarding functionality proved to be problematic and quite a lot of time was spent on debugging.
Accepting the MOL documents	Accepting the final MOL list as an input for the activation process	1 day. As currently MOL documents are accepted for

		reserve markets, only minor setting changes were needed.
Sending the Activation Order	Activation order sending for the market participants and information forwarding to the IESGA platform	2 days. Required the modification of existing formulas and message configurations.

3.4.2.2. Estfeed data exchange platform

For sharing the mandates (consent) information between the Estfeed and IEGSA from Elering side additional interface was created. Estfeed allows for granting data access rights to energy suppliers, applications, and natural persons, on the basis of which the specified individuals shall obtain access to grantors metering data. An access right is a right granted to a legal person (energy seller, or an application or information system managed by a legal person) or to a natural person to request and receive private data (in this case metering data) related to the grantor of the right from data sources that have joined the Estfeed platform. Data can only be accessed through the interfaces provided by Estfeed. The developments are listed in Table 5.

Table 5 Developments of Estfeed platform

Description of development	Functional need	Time and effort spent
Estfeed adapter for IEGSA	Needed for sharing mandates information between Estfeed and IEGSA	About 4 weeks. Interfacing with Estfeed consists of several steps: configuring environments, access granting, configuring firewall for web interfaces, generating certificates, installing, and interfacing the adapter in x-road, configuring firewall to access adapter, configuring application connectivity, subscribing to services, granting mandates, testing, verifying.

3.4.3. AST

In the Latvian deployment of IEGSA the SO and MO side is represented by AST, the Latvian TSO. This is due to lack of a national DSO representative in the project and therefore, this subsection covers only the internal developments on AST side.

The INTERRFACE flexibility platform known as IEGSA has been deployed on AST servers with limited external communication only to AST. Limiting external communication allowed to ensure maximum data security while using real market data for flexibility platform testing and demonstration purposes. The approach was possible as for the purposes of piloting, AST represents all the operator roles in the Latvian demo – TSO, DSO and MO. Moreover, another external communication was required between the flexibility platform and the FSP. In this case the necessary FSP related data is routed through AST internal systems to the flexibility platform on behalf of the involved FSP as all the necessary data is already flowing through the internal systems, therefore no additional external channels were needed.

For testing and demonstration purposes of IEGSA, AST had ensured all necessary data exchange between IEGSA and AST internal systems. This was achieved by creating support tools between the existing internal systems and the IEGSA, therefore existing systems had not been altered and necessary communication for the testing and demonstration could be flexibly adopted. The created support tools perform data extraction, gathering, processing, formatting, and exchange, and operate automatically but can also be operated manually. The main data exchange flows are identified in the simplified communication depiction in Figure 5.

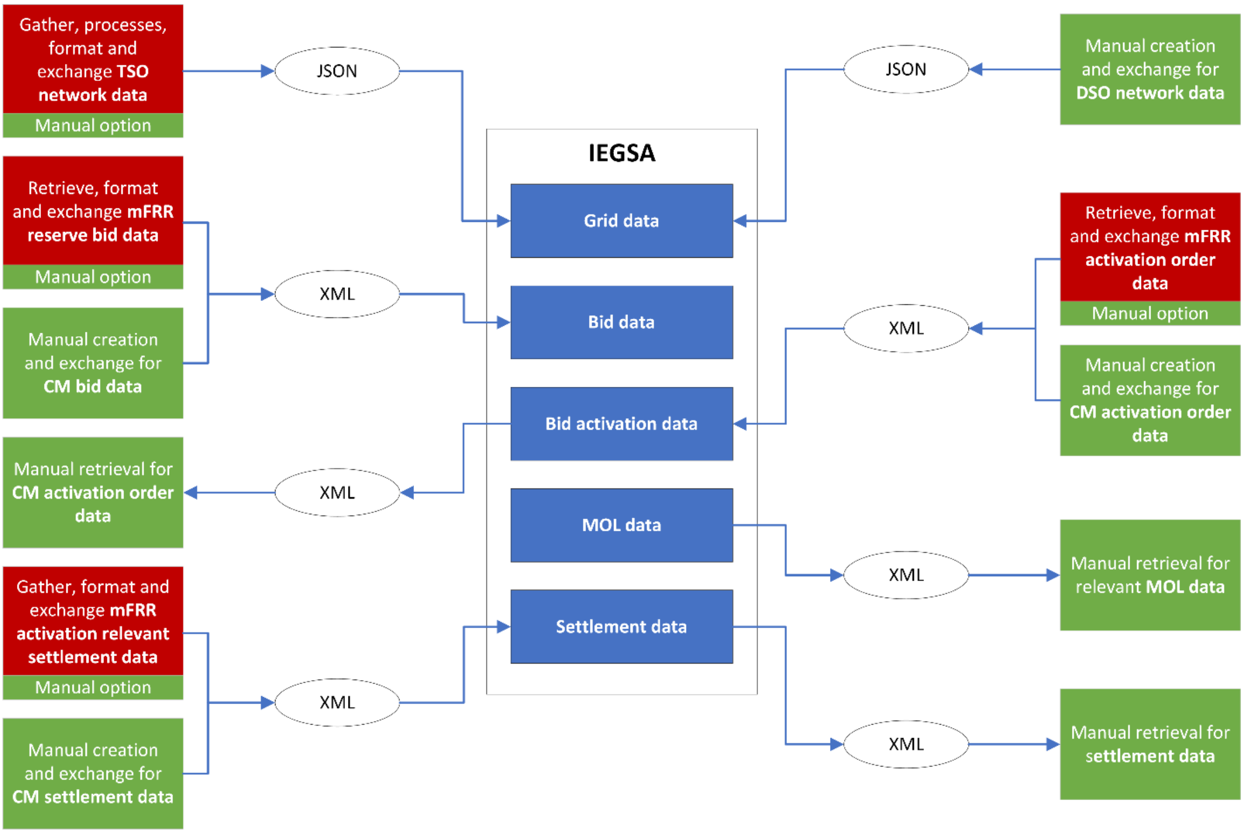


Figure 5 Data exchange flow and tool overview

The Figure 5 information is divided in three main parts. The middle part represents the IEGSA platform and divides data into five categories – grid, bid, bid activation, MOL and settlement. Parts on the outer edge of the figure represents the communication from AST side, where red rectangles are the automated support tools and green rectangles are the manual inputs. Last part is the connection between IEGSA and AST system, represented as an arrow and data format, the arrow shows main data exchange direction. Further AST internal developments will be described based on IEGSA`s five data categories, see Figure 5.

3.4.3.1. Grid data

In IEGSA grid data represents a set of SO network information. This information includes SO network topology and topology point power flow limits, which is provided by the TSO and DSO for their respective networks.

AST provides necessary grid data for the TSO and DSO, where TSO network is represented with real network information, but the DSO has simulated representation for different test scenarios. The TSO network topology is updated and changed manually, but TSO network flow limits are provided by an automated grid data support tool. This tool extracts the grid element information from the existing internal systems, process it through an algorithm, formats information into appropriate data exchange format and sends it to IEGSA flexibility platform through the pre-defined API channels.

The TSO network topology consists of 62 substation points, including 4 main generation station substation and 58 TSO/DSO border substations. The 58 TSO/DSO border substations from all similar substations had been selected based on the available power flow limits, as these substations have under 2 MW of available connection capacity for generation and/or consumption of which 22 substations available connection capacity has reached 0 MW. This TSO topology is then further supplemented with a simulated DSO network topology connecting to these critical substation points. Structure of the DSO network topology and its network limits is created manually on scenario basis and does not represent real network data. During IEGSA flexibility platform testing and demonstration both SO network topologies are uploaded manually.

Once TSO network topology is provided, the grid data tool determines each topology point power flow limits. This is achieved by an algorithm which forecasts each network topology component flow, based on historical data, and further considering forecast flow direction adds or subtracts flow amount from the installed capacity of the specific component. The power flow forecast algorithm utilizes archived grid element flow information of the last four weeks and based on this information can carry out forecast for the day-ahead or week-ahead period with hourly resolution. During the flexibility platform demonstration, a weekly forecast was used to minimize the added constraint on AST internal system communication. The active power flow forecast is calculated as follows:

$$P(i)_{D+1} = \frac{(P(i)_{D-7} + P(i)_{D-14} + P(i)_{D-21} + P(i)_{D-28})}{4} + (P(i)_{D-7} - P(i)_{D-14}) \quad (1)$$

where *(i)* – hour e.g. 10:00 – 11:00;

$P_{D-(7\div28)}$ – the grid element historic active power flow 7÷28 days prior.

Following the results of the power flow forecast, the grid data tool can derive available UP and DOWN regulation limits, based on forecast results and specific grid element installed capacity. Active power UP and DOWN regulation limits are calculated as follows:

$$Pup(i)_{D+1} = (P_{cap} + P(i)_{D+1}) \quad (2)$$

$$Pdown(i)_{D+1} = (P_{cap} - P(i)_{D+1}) \quad (3)$$

where *(i)* – hour e.g. 10:00 – 11:00;

P_{cap} – the grid element installed active power capacity;

P_{D+1} – the grid element forecasted active power flow.

Once the grid data tool algorithm has calculated power flow limits it is then formatted into JSON format message and uploaded to IEGSA flexibility platform via pre-defined API data exchange channel. This process is automatically repeated on a daily or weekly interval, based on support tool settings.

3.4.3.2. Trade data

The trade data includes bid data, bid activation data and MOL data, represented in Figure 5. This set of information represents the market process from market bid submission till market bid activation. The process from IEGSA flexibility platform perspective is between it and the respective MO, however, outside of IEGSA the MO exchanges data also with the FSPs.

IEGSA platform in Latvia accommodates two market products – mFRR and CM. Product mFRR is a standard Baltic balancing market product used in the daily operations of the TSO. However, CM is a new proposed product within the INTERRFACE project and currently is not used in the Latvian electricity market. Considering product differences, it was possible for AST to provide real balancing market data to IEGSA for the mFRR product, but only simulated market data for CM.

Per Figure 5, necessary data on bids and bid activation is provided automatically for mFRR product with an option to provide information also manually. There are two separate bid and bid activation forwarding support tools that each retrieve, format, and forward related market bid data to IEGSA pre-defined APIs sourced from the local balancing market. The information provided to IEGSA contains real market data and contains mostly unaltered information with additional specifications added per IEGSA flexibility platform data exchange format. However, for the CM product as a test product all market bid related information is simulated and scenario-based.

Related to bid data is also the MOL data. This information is collected and examined manually during testing and demonstration of IEGSA flexibility platform because although input contains real market information, at least in case of mFRR product, the output is not used to alter real balancing market information.

3.4.3.3. Settlement data

The IEGSA flexibility platform for its settlement process requires information from the FSP related to the delivered market bid. The FSP must provide information stating which FSP flexibility resources were activated and specify their individual activation volumes, and after the delivery also provide metering data for respective flexibility resources.

Per Figure 5, AST has created a settlement support tool to automate relevant mFRR product bid settlement data forwarding to the IEGSA platform with option to provide input manually. Settlement data is provided by AST on behalf of the involved FSP and this was possible as the necessary data is already exchanged between AST and the FSP in question. Therefore, no new communication channels were created due to lack of necessity and to maintain high data security. However, during the testing and demonstration of IEGSA the settlement results from IEGSA are retrieved and examined manually as this information is not used to alter real balancing market settlements due to limited assessment accuracy.

Regarding CM product, similarly as for other processes described beforehand the settlement data input and output is provided and retrieved manually per scenario basis.

3.4.3.4. Further development needs

Latvia was represented only by the TSO in the testing and demonstration of IEGSA platform. This allowed to maximize real market data exchange security with limited external communication, but in turn also limited bi-SO system integration as the singular SO representative. The supplement of a DSO would add authenticity to DSO network information and allow to fully comprehend SO coordination. During the planning, testing and demonstration it has been envisioned how such coordinated operation would be carried out, but practical experience may alter the perspective.

Furthermore, currently a new BMS is under development at AST, but it could not yet be used during the testing and demonstration of IEGSA flexibility platform. However, this integration would be necessary for successful future utilization of the flexibility platform.

3.4.4. Elenia

During the first phase of the demonstration, Elenia sends TSO-DSO Coordination platform (qualification service) power limit tables and a simplified network topology. The simplified topology contains information on how metering points in the demonstration network are connected to selected upper-level components. Topology contains the following network levels:

- Metering point
- Low voltage feeder fuse
- Distribution transformer
- Medium voltage feeder
- Primary transformer
- TSO-DSO connection point

The topology contains information how these components are connected to each other. However, the more numerous line and cable sections connecting these components are not included to the simplified network model. If it is known that a certain line section acts as a bottleneck, it could be added to the modelled network components. The power limit table tells how much load or production can be added under each component without overloading them.

3.4.4.1. *XPower database*

Elenia's network information is stored in XPower database and to get the necessary information needed in the formation of power limit tables, a custom Access view was created to this database. This view combines data from several different tables, so that we get the following information for each metering point:

- Metering point ID
- Connection point ID
- Low voltage (LV) feeder fuse ID
- LV feeder fuse size (A)
- Distribution transformer ID
- Distribution transformer nominal capacity (kVA)
- Distribution transformer maximum loading (yearly peak, % of nominal capacity)
- MV feeder ID
- MV feeder overcurrent protection set point (A)
- MV feeder maximum load (yearly peak, A)
- Primary transformer ID
- Primary transformer nominal capacity (MVA)
- Primary transformer maximum load (yearly peak, % of nominal capacity)
- Substation ID
- Substation name (connects to TSO-DSO connection points through separate mapping table)

The formation of a power limit table is started by making a query to this database view. We get information for a selected group of metering points, and the results are exported to an Excel file.

3.4.4.2. *Octave*

The next steps have been automated with an Octave script that:

- Reads the Excel file
- Forms a simplified network topology based on the information in the Excel
- Writes the topologies into JSON file that is compatible with the format used by the qualification service
  - Identical topologies (and later power limit tables) are created for resource qualification and bid qualification
- Calculates how much load or production can be added below each studied network component
  - All loads are assumed to have a power factor of 0.98
  - All minimum loadings are assumed to be zero
- Writes the power limit tables into JSON file that is compatible with the format used by the qualification service
  - The power limit table validity time is set to one year
- Saves the JSON files into an online file storage (within our intranet). These files are:
  - Topology for resource qualification
  - Topology for bid qualification
  - Power limit table for resource qualification
  - Power limit table for bid qualification

3.4.4.3. *Frends*

Frends integration platform is used to send the JSON files to qualification service's API endpoints. Frends reads the new JSON files automatically from the online file storage, sends them, and archives the sent files. If the API endpoint returns an error, e-mail notification is sent to the operator. Figure 6 shows the steps from start to finish.

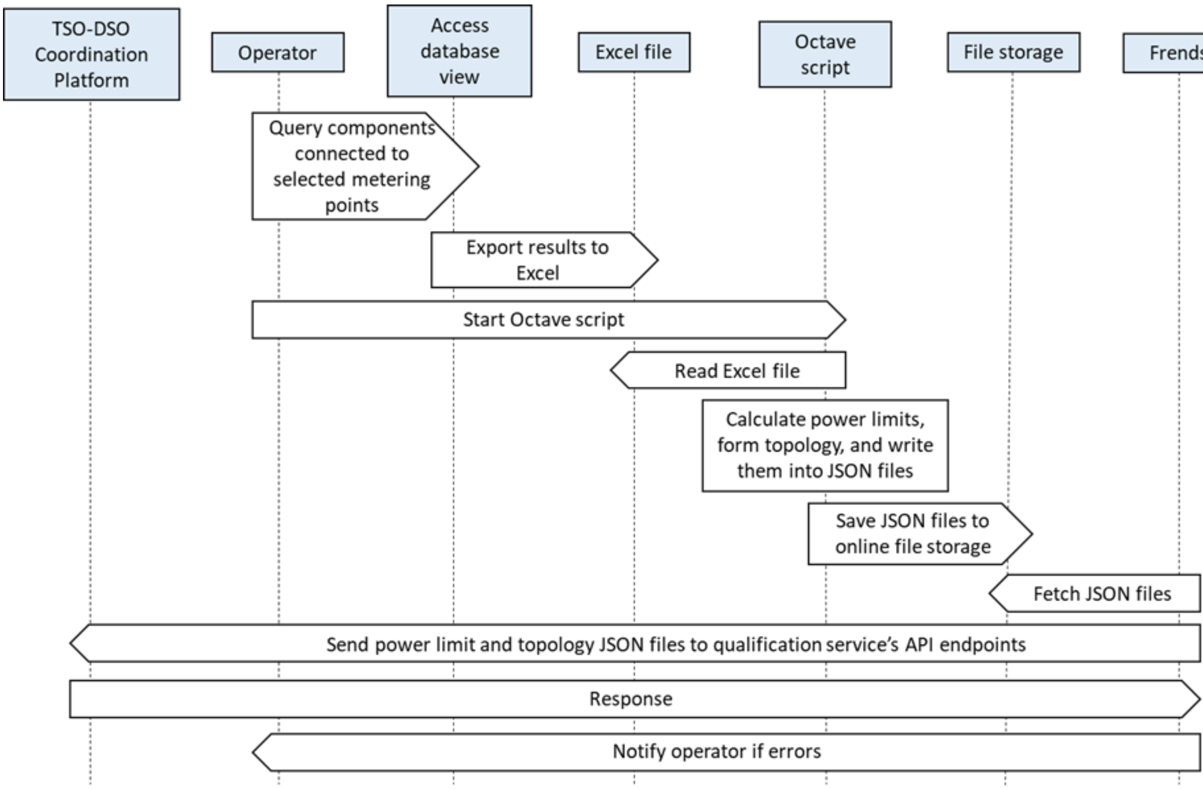


Figure 6 Sequence diagram for power limit table creation in Elenia

3.4.4.4. Further development needs

The method for creating power limit tables, described in section 3.5.1.1, is limited by the present capabilities of Elenia's network information system. These limitations include:

- Only the yearly maximum loading (previous year) is available for the network components in the XPower database
  - Minimum loading is not available and zero minimum load is assumed. This leads to inaccuracies in the estimated available upregulation capacities.
  - The use of yearly maximum values restricts available downregulation capacity during summer when the loads are smaller.
- Maximum loadings for LV fuses were not available in XPower database
  - Available downregulation capacity for LV fuses could not be calculated
  - Available upregulation capacity for LV fuses is based on the zero minimum load assumption.

Most of the limitations above could be fixed with moderate system development. Most of the data and calculations already exists, and it is only a matter of making these available for power limit table creation. For example, the previous month network loadings are already computed as a part of monthly network monitoring calculation. This should enable change from yearly to monthly maximum loads and the minimum loads could be derived from these calculations. Power flow limits for metering points were not defined in this demonstration. However, also these could be added since the metering point fuse sizes limiting the power flow are known and the smart meters have recorded the historical loads. Smart meter measurements could also be summed to LV fuse level.

More development would be needed to get accurate power limit forecasts. Presently the network calculation is based on previous year's historical load, and this does not enable accurate forecasting since many loads are dependent on the outdoor temperature and temperatures vary from year to year.

Overall, the Elenia's method for creating power limit tables is still on a prototype phase. The level of automation could be improved by querying the Access table view automatically but this was not implemented because in the demonstration the operator needs to select the metering points manually anyway. Furthermore, the Octave script could be replaced with a program written with a proper programming language. However, the further development efforts were directed towards developing the PTDF matrix-based grid qualification, which was tested in the next phase of the demonstration.

Section 3.5.2 describes in detail the developed PTDF (and NVSF) matrix -based grid qualification procedure and calculation of sensitivity matrices. The PTDF matrix-based grid qualification was left to prototype stage, even more so than the power limit table-based grid qualification. The calculation of PTDF and NVSF matrices, and formation on related JSON files were automated with Octave scripts, but the network and consumption data were fed to Octave manually and the JSON files were sent to the qualification service's API endpoints manually through the Swagger UI.

3.5. Methods for grid qualification

In Single Flexibility Platform demonstrator of INTERRFACE project, there are three options for grid qualification:

1) Power limit tables
2) PTDF matrices
3) Grid qualification done by SO

In the first two options, calculations related to grid qualifications are done on the TDCP`s qualification service module.

3.5.1. Power limit table-based grid qualification

The power limit table-based grid qualification, has been designed to be a low threshold MVP (Minimum Viable Product) solution. This method offers simple and easy to understand way to communicate the most crucial network bottlenecks to the TDCP.

3.5.1.1. Basic principle

The power limit tables tell how much free capacity there are on selected key network components. The key network components can be for example:

- Primary transformers
- Medium voltage feeders (power limiting factor: feeder protection relay over current setting)
- Distribution transformers
- Low voltage fuses

The idea is to select network components where power flow-based bottlenecks are most likely to appear. The power limit tables, calculated by SOs, tell how much upward or downward flexibility can be activated below each component, without causing overloading.

Figure 7 shows an example of a distribution network with power and current limits on different network components. In addition to these limits, the load of the network must be known before the values in the power limit table can be calculated. For example, the free capacity of a transformer is determined by its nominal capacity and loading without flexibility activation. Table 6 shows some examples for power limits, loadings, and capacities available for flexibility. Only the data in the last two columns is sent to the TSO-DSO Coordination Platform. The maximum upregulation and maximum downregulation values are calculated separately based on minimum and maximum loadings without flexibility activations and it is assumed that flexibility affects only to active power. This leads to following equations:

$$P_{\max,\text{upregulation}} = \max\left(0 - \left(\pm\sqrt{S_{lim}^2 - Q_{\min,load}^2} - P_{min,load}\right)\right) \tag{1}$$

$$P_{\max,\text{downregulation}} = \max\left(\pm\sqrt{S_{lim}^2 - Q_{\max,load}^2} - P_{max,load}\right) \tag{2}$$

where S_{lim} is the component's bi-directional power flow limit

Q_{min} and Q_{max} are reactive loads during minimum and maximum loading situations

P_{min} and P_{max} are active loads during minimum and maximum loading situations

Production is handled as negative load.

For resource qualification, seasonal or yearly maximum and minimum loads can be used to calculate the maximum amounts of upregulation and downregulation. The resource qualification is indicative in nature and the final qualification of flexibility happens during the bid qualification. For bid qualification, temporally more precise power limit tables can be used. Power limits can be defined, for example, with hourly intervals. If hourly loading information necessary for calculating hourly power limits are not available, the power limit tables used in resource qualification can also be used for bid qualification. However, it should be noted that this approach allows less flexibility to be activated, since all hours are treated the same as the worst-case hour.

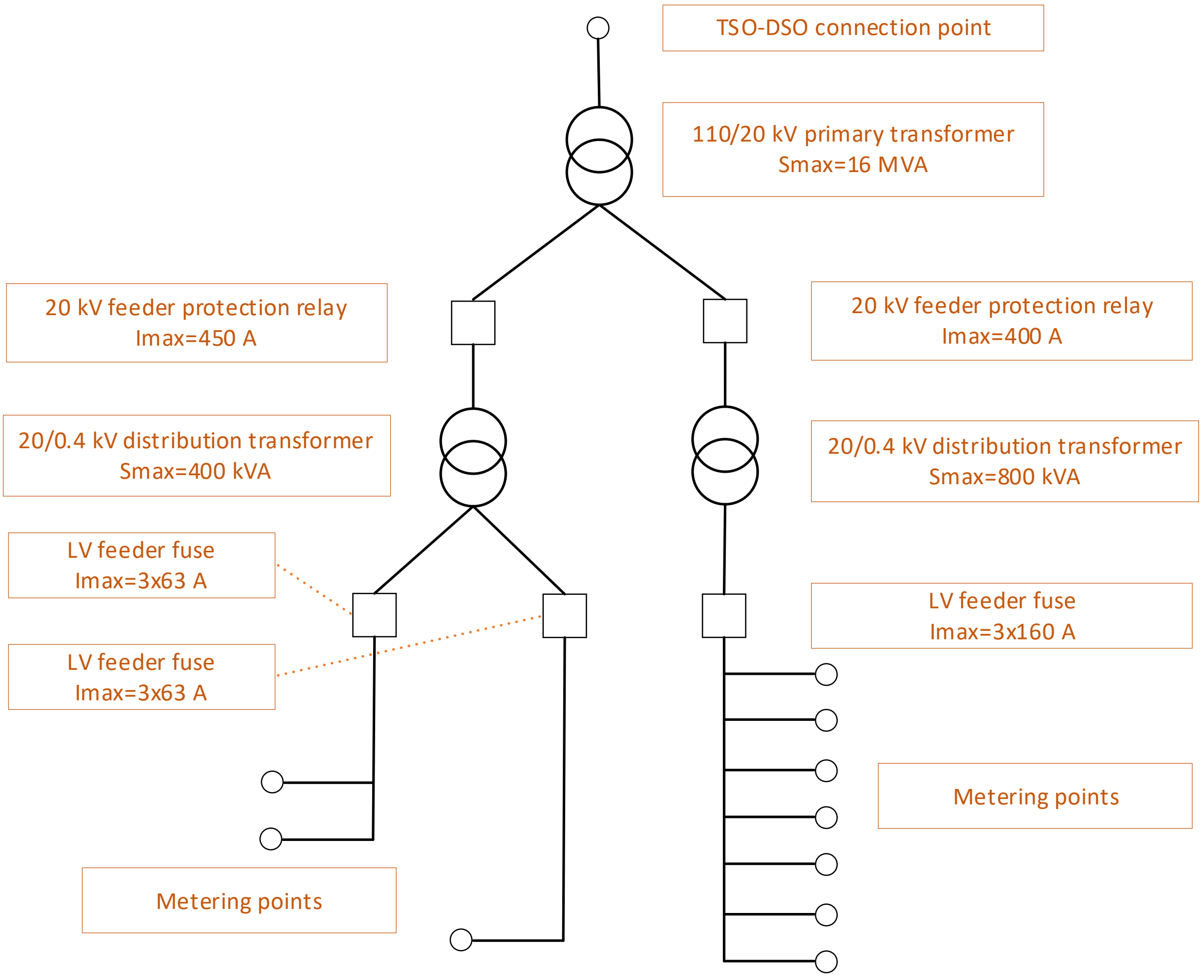


Figure 7 Example network with power flow limiting components

Table 6 Example of power limits, loads, and free capacity calculation results

Component	Power flow limit	Maximum load		Minimum load		Free capacity available for flexibility (cos φ=1)	
	kVA	kW	kVAr	kW	kVAr	Max. upregulation (kW)	Max. downregulation (kW)
Primary transformer	16000	14500	3200	3700	680	19686	1177
MV Feeder (Imax=400 A)	13856	4260	830	1200	260	15054	9571
Secondary transformer	400	235	40	78	19	477,5	163,0
LV fuse (3x63 A)	43,6	31	6	-20	-3	23,5	12,2

Power limit tables and a simplified network topology can be sent to TDCP`s qualification service. The simplified topology contains information on how metering points in the demonstration network are connected to selected upper-level components. Topology can contain the following network levels: metering point, low voltage feeder fuse, distribution transformer, medium voltage feeder, primary transformer, TSO-DSO connection point.

3.5.1.2. Power limit table exchange

The SOs interact with IEGSA by sending topologies and power limit tables to the qualification service module. This can be done automatically through API endpoints or manually through Swagger UI.

The power limit tables are sent to qualification service API endpoints as JSON files. Each file contains power limits for one or more-time intervals. Even though the power limits stem physically from conducting equipment, the limits are associated to network nodes in the power limit table file. The limits are connected to a node below the conducting equipment (on the side closer to the metering point).

Radial network is assumed and therefore there can be only one conducting equipment above each node. If the limits had been connected to a node above the conducting equipment and the network contained branches, the limits would not be unambiguous as they could refer to more than one conducting equipment.

In the power limit table JSON file, following information is given for each node:

- Node ID (string)
- Maximum downregulation in kilowatts
- Maximum upregulation in kilowatts

Figure 8 shows a simple 3-bus example network, for which a power limit table JSON file is shown below:


```
[{
  "network-limit-time-interval": "2022-02-13T00:00Z/2023-02-13T00:00Z",
  "network-limits": [
    {
      "node-id": "LV-node-1",
      "max-down-regulation-kW": 235.000,
      "max-up-regulation-kW": 335.000
    },
    {
      "node-id": "Metering-point-1",
      "max-down-regulation-kW": 30.851,
      "max-up-regulation-kW": 130.851
    }
}]
```


In this file, limits stemming from the LV fuse are connected to metering point 1 and limits stemming from the distribution transformer nominal capacity are connected to LV node 1. No limits are given for the medium voltage (MV) node 1 because there are no conducting equipment above this node. This example contains limits for only one time interval but limits for several different time intervals can be included into the same file.

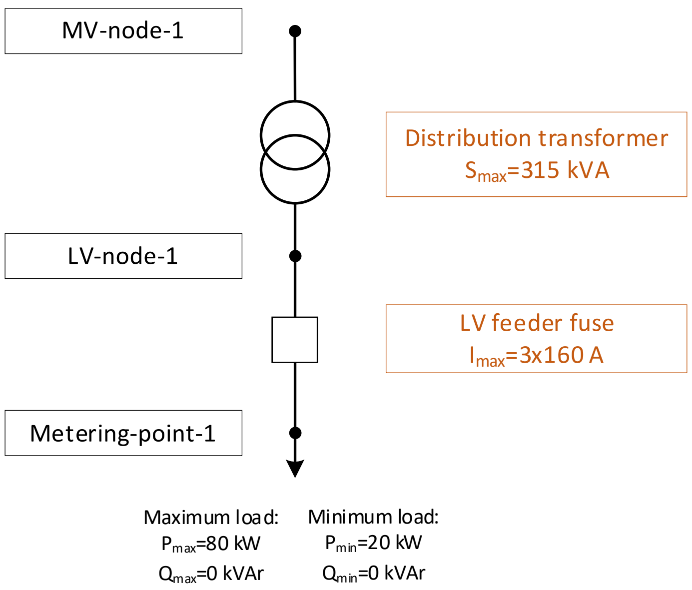


Figure 8 3-bus example network

3.5.1.3. Network topology exchange

The qualification service supports two different topology formats:

1) Topology with *grid-node-connections*
2) Topology with *conducting-equipment*

The first one is used with power limit tables and the latter can be used with both power limit tables and PTDF matrices. The topology with conducting equipment is described in detail in chapter 3.5.2.3 and only the simpler grid-node-connection-based topology is described here. Topologies with grid node connections contain two parts: grid nodes and grid node connections. The grid nodes part contains node ID, grid node type (e.g. TSO_DSO_CONNECTION_POINT, METERING_POINT, HIGH_VOLTAGE_FEEDER, PRIMARY_SUBSTATION, MEDIUM_VOLTAGE_NODE), node name, nominal voltage in kilovolts, maximum voltage in kilovolts, minimum voltage in kilovolts.

The grid node connection part contains information how the nodes are connected to each other. This information includes the node ID and SO's EIC number for *connected-from-node* and the node ID for *connected-to-node*. Only radial networks are supported. There can be only one node ID associated with *connected-from-node* but several node IDs under the *connected-to-node*.

The JSON formatted topology file for the 3-bus example network shown in Figure 8 looks like this:


```
{
 "grid-nodes": [
  {
   "node-id": "MV-node-1",
   "grid-node-type": "MEDIUM_VOLTAGE_NODE",
   "node-name": "Distribution transformer primary",
   "nominal-voltage-kV": 20,
   "max-voltage-kV": 21.1,
   "min-voltage-kV": 19.7
  },
  {
   "node-id": "LV-node-1",
   "grid-node-type": "LOW_VOLTAGE_NODE",
   "node-name": "Distribution transformer secondary",
   "nominal-voltage-kV": 0.400,
   "max-voltage-kV": 0.440,
   "min-voltage-kV": 0.360
  },
  {
   "node-id": "Metering-point-1",
   "grid-node-type": "METERING_POINT",
   "node-name": "Customer metering point",
   "nominal-voltage-kV": 0.400,
   "max-voltage-kV": 0.440,
   "min-voltage-kV": 0.360
  }
 ],
 "grid-node-connections": [
  {
   "connected-from-node": {
    "node-id": "MV-node-1",
    "system-operator": "55X-00000000074F"
   },
   "connected-to-node-id": [
    "LV-node-1"
   ]
  },
  {
   "connected-from-node": {
    "node-id": "LV-node-1",
    "system-operator": "55X-00000000074F"
   },
```

```
      "connected-to-node-id": [
        "Metering-point-1"
      ]
    }
  ]
}
```


The node IDs are formatted as strings, even though they are often numbers e.g., GSRN (Global Service Relation Number) numbers for the metering points. The grid node type must be chosen from the enumerated list shown above. The node name can be any descriptive string and the voltages are given in kilovolts. If the uppermost node is a TSO-DSO connection point, it is assumed to belong to the TSO network and subsequently TSO EIC number must be given to the system operator field.

3.5.1.4. Calculations within the qualification service

When the qualification service receives a qualification request, it chooses the appropriate qualification method that has been configured for that particular SO and either performs the qualification locally using network topologies and power limit tables submitted by the SO or delegates the decision to a SO`s web service API endpoint. The former option is described here.

*Resource qualification*The qualification service calculates how much up- and downregulation capacity there is at each node and compares these aggregated capacities to the maximum up- and downregulation capacities given in the power limit tables. Nodes where the maximum capacity is exceeded, are added to a list of "failed nodes". Whereas nodes where the maximum capacity is not exceeded, are added to a list of "passed nodes". The failed and passed nodes, as well as the violated limits are then communicated to the FR. The FR assigns flexibility resources connected to failed nodes a yellow traffic light, and the resources connected to passed nodes are given a green traffic light. Yellow traffic light means that there is at least one time interval (e.g., hour) during the present validity period of the network limits (e.g., season or year), when the flexibility activation can cause a network congestion. However, this does not mean that the resource could not be activated during the other time intervals. In IEGSA UI, if a resource group has one or more resources with a yellow traffic light, "Qualified with Restriction" text is shown in resource group's info box, and individual resources causing this are highlighted with orange colour. Correspondingly, green traffic light is shown with green "Qualified" text. The green traffic light means that the flexibility resource activation cannot cause a network congestion during the present validity period. TSO and DSO results are separated in qualification service's output to identify which operator's network is limiting flexibility resource activations.

Bid qualification

The sums of bids are compared to power limits similarly to the resource qualification, except the time intervals are more specific since bids have accurately defined start and end times. In the beginning, all bids are added to the list of accepted bids. In case of a limit violation, new bids with the highest energy prices are removed from the list and appended to a list of rejected bids. This is done until there are no limit violations or every new bid has been rejected. The process returns qualification result with qualified and rejected bids. TSO and DSO results are separated to identify which operator's network caused a bid to be rejected. A violated limit is provided as a disqualification reason for each rejection.

Bid qualification process differs depending on bid product type.

- mFRR – a bid is either qualified or rejected in its entirety.
- CM bids – a bid is broken down into partial "child" bids, which are complemented with locational information, in order to aid the SOs to identify specific bids that could relieve congestion in already identified congested parts of the network.

3.5.2. PTDF matrix-based grid qualification

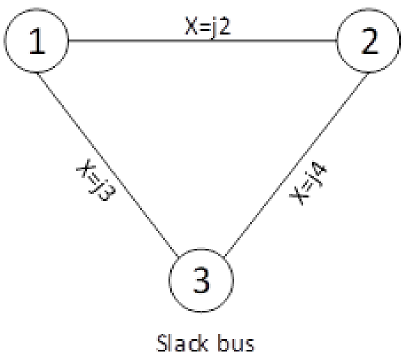
The power limit table-based grid qualification method developed earlier in the INTERRFACE project, was designed to be a barebone MVP solution. The power limit table approach makes many simplifications:

- Only the most crucial power flow limiting network components are modelled
- Power flow limits are given for network nodes, even though the limits stem from the conducting equipment.
- Power losses are not considered
- Voltage constraints are not considered
- Meshed networks are not supported

These shortcomings mean that there is a lot of room for improvement. A more comprehensive solution would be to do a full load flow calculation in the TDCP. To do this, the SOs would need to send their detailed network models to the coordination platform. While this could be technically possible, thanks to emerging utilization of Common Information Model (CIM) models for the exchange of electrical network asset and measurement data (ENTSO-E, 2016)[2], it is uncertain if all SOs would be willing to share this detailed information about their core assets. For this reason, the use of PTDF and NVSFs was proposed. Grid qualification that is based on PTDF and NVSF matrices can solve the above-mentioned shortcomings of the power limit table-based approach, while offering only a fuzzified view to network assets.

3.5.2.1. Background

PTDF and NVSF matrices present a linearized approximation to how network power flows and node voltages change, when power injections, i.e., load or production, in the network change. Figure 9 presents a small example network and its PTDF matrix. This matrix tells us that if 1 MW of generation is added to node 1, 33 % of this power will flow through the line 1 to 2 and 67 % will flow through the line 1 to 3. If 1 MW of consumption is added, the effect will be the same but in reverse, i.e., the line flows will be to the opposite direction.



$$PTDF = \text{Line}\ \begin{matrix} \\ 1-2 \\ 1-3 \\ 2-3 \end{matrix} \overset{\text{Node}}{\begin{matrix} 1 & 2 & 3 \\ \end{matrix}} \begin{bmatrix} 0.33 & -0.44 & 0 \\ 0.67 & 0.44 & 0 \\ 0.33 & 0.56 & 0 \end{bmatrix}$$

Figure 9 PTDF matrix example (adapted from Nordic RSC, 2018)

The size of the PTDF matrix is MxN, where M is number of lines and N the number of nodes in the network. The size of NVSF matrix is NxN, as each factor tells us how the node voltage changes if node power injections change.

<u>*PTDFs in transmission network calculation*</u>

PTDFs are common in transmission network analysis. They are often used for available transfer capacity assessments, power system operation, planning of energy transactions and network additions, steady-state security applications, and economic assessments (Šošić et al., 2014)[3]. Applications related to CM are

[2] https://eepublicdownloads.entsoe.eu/clean-documents/CIM_documents/IOP/160715_CGMES_IOPreport2016.pdf
[3] https://infoteh.etf.ues.rs.ba/zbornik/2014/radovi/ENS-1/ENS-1-6.pdf

also very common. In the deregulated environment, the TSOs must ensure that trades made in the energy markets do not cause congestions. A practical example can be found from (Nordic RSC, 2018)[4] where it is described in detail how PTDFs are used in Nordic Capacity Calculation Region as a part of flow-based capacity calculation. The capacity calculation determines how much power can be transferred between bidding zones and these limits act as constraints in the day-ahead and intraday market coupling algorithms.

In transmission network security analysis also Line Outage Distribution Factors (LODF) are used. LODFs are defined as the changes in the line power flows due to the disconnection of a particular line. Avoiding cascading faults is critical for power system security. In meshed transmission networks, when fault trips a line section, the power flow shifts instantly to adjacent transmission lines. In this situation it is important to calculate quickly what is the new power flow on the adjacent line, and if it gets overloaded, calculate how this congestion can be alleviated. In this time-critical situation SOs want to avoid recalculation of the power flow solution and use PTDFs and LODFs instead. Linear sensitivity factors are preferred on the account of the ease and speed of calculation, especially when applying optimization algorithms that consider numerous possible options for CM. (Ulasi et al., 2019)[5]

The transmission network power flow calculation can be accelerated by using DC (direct current) power flow, which is significantly faster than AC (alternating current) power flow. However, using of PTDF and LODF linear sensitivity factors to estimate transmission line flows from a known operation point is even faster than DC power flow and provides equally accurate results (Ulasi et al., 2019). The downside of sensitivity factors is that they need to be calculated beforehand and remain valid only as long as the network is unmodified.

PTDFs in distribution network calculation

The use of PTDFs is not very common in distribution network analysis. However, there are some academic papers and theses that suggest their usage for various tasks. González and Gómez (2008) and Ladwal (2020)[6] propose distribution tariff calculation methods that utilize PTDFs. Meng (2014)[7] presents a generalized optimal power flow program that uses PTDFs in loss factor approximation. Khorasany et al. (2017)[8] propose a transactive energy market platform for peer-to-peer trading that uses PTDFs to calculate distribution network subscription charges. In this platform, market subscribers pay a subscription charge for utilizing the distribution network and this charge is used as a price signal to reduce the possibility of overload in the distribution network. Similarly, Moret et al. (2020)[9] use PTDFs for loss allocation in joint transmission and distribution peer-to-peer markets.

3.5.2.2. Calculation of distribution network sensitivity matrices

Many commercial power system modelling and analysis software are can calculate PTDF matrices, for example, DIgSILENT PowerFactory (2022), PowerWorld (2022), and PandaPower (2022). However, in this project, the capability to calculate network sensitivity matrices is built from the ground up. The principles of sensitivity matrix calculation have been described in numerous literary sources. In general, the PTDF matrices can be calculated either by using incremental method (Šošić et al., 2014) or by leveraging susceptance matrices (Chatzivasileiadis, 2018)[10].

[4] https://nordic-rsc.net/wp-content/uploads/2018/10/Stakeholder-consultation-document-and-Impact-Assessment-for-the-Capacity-Calculation-Methodology-Proposal-for-the-Nordic-CCR.pdf
[5] https://irejournals.com/formatedpaper/1701223.pdf
[6] http://junikhyatjournal.in/no_2_aug_20/9.pdf
[7] https://scholarsmine.mst.edu/cgi/viewcontent.cgi?article=3502&context=doctoral_dissertations
[8] https://www.researchgate.net/publication/324184395_Auction_based_energy_trading_in_transactive_energy_market_with_active_participation_of_prosumers_and_consumers
[9] https://arxiv.org/pdf/2001.05396.pdf
[10] https://arxiv.org/pdf/1811.00943.pdf

The incremental method is simple and easy to understand. Only the following steps are needed to calculate the PTDF matrix:

1) Calculate base case power flow
2) Make a small incremental change to power injection in one node
3) Re-calculate the power flow
4) For each line, find out how much the power flows changed compared to the base case and divide this change with the increment made in step 2
5) Repeat steps 2–4 for all network nodes.

This above procedure is correct by definition, and accurate values are obtained if AC power flow is used. Downside is the long computing time. However, the computing time does not matter that much, because the same PTDF matrix can be used until the network topology or parameters change. Once the PTDF matrix has been calculated, its use is equally fast regardless of the method that was used in its calculation.

A faster way to calculate the PTDF matrix is:

$$PTDF = B_{line} \times \overline{B}_{bus}^{-1} \tag{4}$$

Where B_{line} is the line susceptance matrix

$\overline{B}_{bus}^{-1}$ is a bus susceptance matrix, from where the rows and columns corresponding to the slack bus have been removed (Chatzivasileiadis, 2018).

However, this DC-PTDF -method is valid only for transmission networks where we can assume that X>>R. Third option is to use AC-PTDF method, which doesn't make any assumptions on the network (Kumar & Kumar, 2011)[11]. In AC-PTDF, the effect the power injection changes have on node voltage angles and magnitudes is calculated first and then these sensitivities are used to calculate the effect on line power flows. This method suits the needs of INTERRFACE project since we want to calculate the NVSFs anyway.

Node voltage sensitivity factors

We start the calculation of NVDFs by running a base case load flow calculation and extracting the Jacobian matrix from this calculation. In this case we used the Power System Toolbox developed by Chow, Cheung, and Rogers (1991-2008) but any other load flow program that is based on Newton-Raphson method and utilizes full Jacobian matrix could have been used. Once the Jacobian matrix (J) is known, we can calculate the changes in node voltage angles ($\Delta\delta$) and magnitudes ($\Delta|V|$):

$$\begin{bmatrix} \Delta\delta \\ \Delta|V| \end{bmatrix} = [J]^{-1} \begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} \tag{5}$$

where ΔP is $(N-1) \times (N-1)$ diagonal matrix populated with 1 kW values

ΔQ is $(N-1) \times (N-1)$ zero matrix

N is the number of nodes.

The final node voltage sensitivities are calculated from per unit valued $\Delta|V|$ considering the direction of power change, different voltage levels, and scaling. In this project, the NVSFs are given in kilovolts per added megawatt (load), meaning that the sensitivity factors for radial network will be negative.

$$NVSF_{kV,MW} = \begin{bmatrix} 0 & 0 \\ 0 & 0 - \Delta|V| \times 1000 \times V_n \end{bmatrix} \tag{6}$$

Where V_n is a $(N-1) \times (N-1)$ matrix of node nominal voltages in kilovolts, excluding node 1.

[11] https://www.researchgate.net/publication/263673987_ACPTDF_for_Multi-transactions_and_ATC_Determination_in_Deregulated_Markets

Power transfer distribution factors

Next, the PTDF matrices are calculated utilizing the AC-PTDF method. We start by defining the base case situation as the maximum amount of extra load the network can handle without exceeding line current or node voltage limits. The network loads are increased incrementally until the first congestion happens, and that is our base load situation. The reason for taking this approach is to ensure that the inevitable linearization errors are, more often than not, to the direction that is safe for the SO.

Newton-Raphson -based load flow is run for the base case, and the Jacobian matrix and node admittance matrix are extracted from this calculation. Equation (5) is then used to calculate how individual active power changes (ΔP) affect node voltage angles and magnitudes. These angle and magnitude changes, and node voltages from the base case, are then used to calculate the new changed node voltages. Once the new node voltages are known, the new line currents and power flows can be calculated using basic power flow equations. In this case we can use the already calculated admittance matrix (Y):

$$I_{new,sr} = Y_{sr} \times \left(V_{new,r} - V_{new,s}\right) \tag{7}$$

$$S_{new,sr} = V_{new,s} \times I^*_{new,sr} \tag{8}$$

$$P_{new,sr} = real\left(S_{new,sr}\right) \tag{9}$$

Where $I_{new,sr}$ is the new current flow between sending node *s* and receiving node *r*

$V_{new,r}$ is the new voltage in node *r*

$S_{new,sr}$ is the new apparent power flow between nodes *s* and *r*

$P_{new,sr}$ is the new active power flow between nodes *s* and *r.*

Once the new power flows are known, they can be compared to the base power flows and the elements of the PTDF can be calculated as follows:

$$PTDF_{i,j} = \frac{P_{new,ij} - P_{base,i}}{\Delta P_j} \tag{10}$$

Where $P_{new,ij}$ is the new active power flow on line *i* when power injection on bus *j* changes

$P_{base,i}$ is the base active power flow on line *i*

ΔP_j is the active power change on bus *j.*

Since the effects of active power changes are calculated individually, the calculation can end up having two levels of loops. With vectorization and matrix operations the loops can however be eliminated. This way, the AC-PTDF calculation is several times faster than calculation using the incremental method. If the network contains several voltage levels, the size of ΔP can be varied so that larger values are used in stiffer parts of the network.

3.5.2.3. Data exchange with IEGSA

The system operators interact with IEGSA by sending topologies, PTDF and NVSF matrices, and forecasts to the qualification service module. This can be done automatically through API endpoints or manually through Swagger UI.

Network topology exchange

The qualification service supports two different topology formats:

1) Topology with *grid-node-connections*
2) Topology with *conducting-equipment*

The first one is used with power limit tables and the latter can be used with both power limit tables and PTDF matrices. The topology with grid node connections is described in chapter 3.5.1.3 and only the conducting equipment-based topology used with PTDF matrices is described here.

Topologies with conducting equipment contain two parts: grid nodes and conducting equipment. The grid nodes -part is almost identical with the equivalent part in the previously described topology with grid node connections. The only difference is that the number of allowed grid node types is fewer:

- Grid node type has to be one of the following:
    - METERING_POINT
    - LOW_VOLTAGE_NODE
    - MEDIUM_VOLTAGE_NODE
    - HIGH_VOLTAGE_NODE
    - TSO_DSO_CONNECTION_POINT

The conducting equipment part contains not only the connected to and from nodes but also details for the conducting equipment. For each conducting equipment, the following information is expected:

- Connected from node
    - Node ID (string)
    - System operator EIC number (string)
- Connected to node ID (string)
- Conducting equipment ID (string)
- Conducting equipment type, which must be one of the following:
    - Connection cable
    - LV fuse
    - LV breaker
    - MV breaker
    - HV (high voltage) breaker
    - MV/LV transformer
    - HV/MV transformer
    - LV overhead line
    - MV overhead line
    - HV overhead line
    - LV underground cable
    - MV underground cable
    - HV underground cable
- Conducting equipment name (string)
- Maximum apparent power flow in kilovolt-amperes

As can be seen, the topology with conducting equipment contains both node voltage and conducting equipment power flow limits. These limits are utilized in the PTDF matrix-based grid qualification and no separate power limit table is needed.

The topology is sent to the qualification service as a JSON file. Figure 10 shows a simple example network and Figure 11 shows a topology file for this network. Note that the TSO-DSO connection point is not included to the grid nodes submitted by the DSO. Instead, a connection to the TSO-DSO connection point is made with the uppermost conducting equipment and here the DSO must refer to the connection point with an ID given by the TSO. In addition, the TSO EIC number must be given, so that the connection is unambiguous and connection is not made to wrong TSO that happens to have a node with the same ID.

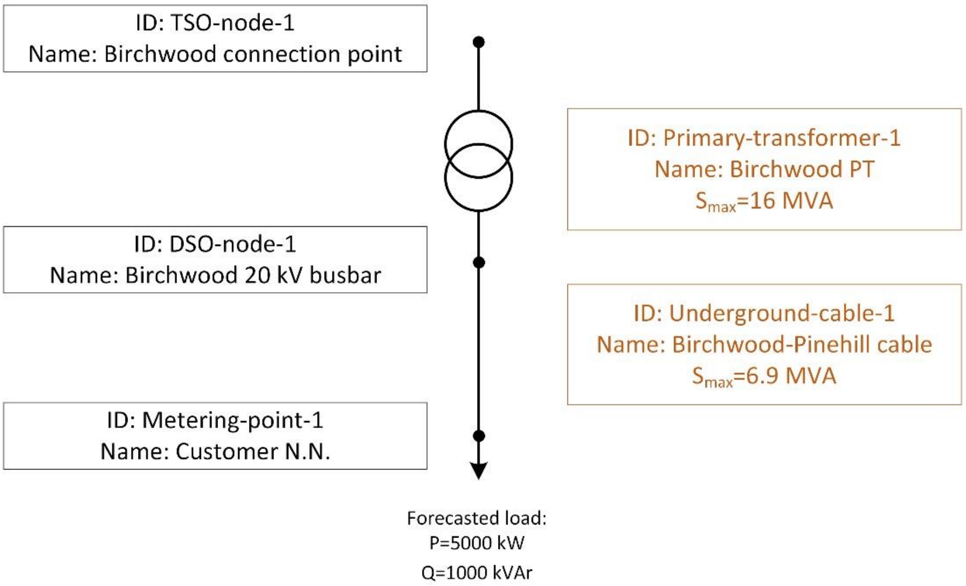


Figure 10 3-bus example network

```
{
  "grid-nodes": [
    {
      "node-id": "DSO-node-1",
      "grid-node-type": "MEDIUM_VOLTAGE_NODE",
      "node-name": "Birchwood 20 kV busbar",
      "nominal-voltage-kV": 20,
      "max-voltage-kV": 21.1,
      "min-voltage-kV": 19.7
    },
    {
      "node-id": "Metering-point-1",
      "grid-node-type": "METERING_POINT",
      "node-name": "Customer N.N.",
      "nominal-voltage-kV": 20,
      "max-voltage-kV": 21.1,
      "min-voltage-kV": 19.7
    }
  ],
  "grid-node-connections": [
    {
      "connected-from-node": {
        "node-id": "TSO-node-1",
        "system-operator": "90X8002B1001B364"
      },
      "connected-to-node-id": "DSO-node-1"
      "conducting-equipment-id": "Primary-transformer-1"
      "conducting-equipment-type": "HV/MV transformer"
      "conducting-equipment-name": "Birchwood PT"
      "max-apparent-power-flow-kVA": "16000.000"
    },
    {
      "connected-from-node": {
        "node-id": "DSO-node-1",
        "system-operator": "55X-00000000074F "
      },
      "connected-to-node-id": "Metering-point-1"
      "conducting-equipment-id": "Underground-cable-1"
      "conducting-equipment-type": "MV underground cable"
      "conducting-equipment-name": "Birchwood-Pinehill cable"
      "max-apparent-power-flow-kVA": "6900.000"
    }
  ]
}
```


Figure 11 Example of a topology file with conducting equipment

PTDF exchange

PTDF matrices are communicated to the qualification service with JSON files. At the beginning of the file, the matrix ID, name, and description are given. Then the following parameters are given for each individual PTDF:

- Matrix ID (string)
- Factor ID (string)
- ID of the assessed conducting equipment (string)

- ID of the influencing topological node (string)
- Sensitivity factor value (number)

The size of the PTDF matrix is $N_{nodes} \times N_{cnecs}$ and with large networks the size of the JSON-file can become very large. Luckily the PTDF matrices are typically sparse, meaning that many of the sensitivity factor values are zeros, and the file size can be reduced significantly with sparse PTDF matrices. In a sparse matrix, only the non-zero values are given. During the qualification process, missing sensitivity factor values are effectively treated as zeros, if sparse matrices are enabled in the qualification process settings. If the sparse matrices are disabled, missing sensitivity factor values are treated as errors and the qualification fallback functionality reverts the qualification back to the power limit table-based grid qualification. Figure 12 shows a sparse PTDF-file example for the 3-bus test network in Figure 10.


```
{
  "PTDF-matrix": {
    "matrix-id": "450112",
    "matrix-name": "PTDF-example",
    "matrix-description": "PTDF matrix for the 3-bus example network"
  },
  "PTD-factor": [
    {
      "matrix-id": "450112",
      "factor-id": "450112-1-2",
      "id-of-assessed-conducting-equipment": "Primary-transformer-1",
      "id-of-influencing-topological-node": "DSO-node-1",
      "sensitivity-factor-value": 1.0003
    },
    {
      "matrix-id": "450112",
      "factor-id": "450112-1-3",
      "id-of-assessed-conducting-equipment": "Primary-transformer-1",
      "id-of-influencing-topological-node": "Metering-point-1",
      "sensitivity-factor-value": 1.0058
    },
    {
      "matrix-id": "450112",
      "factor-id": "450112-2-3",
      "id-of-assessed-conducting-equipment": "Underground-cable-1",
      "id-of-influencing-topological-node": "Metering-point-1",
      "sensitivity-factor-value": 1.0058
    }
  ]
}
```


Figure 12 A sparse PTDF file example for the 3-bus test network

NVSF exchange

NVSF matrices are communicated with JSON-files very similar to the ones used with PTDF matrices. The only change to name value pairs is that instead of assessed conducting equipment, IDs are given for assessed topological nodes. The size of a NVSF matrix is $N_{nodes} \times N_{nodes}$ and it is not sparse. It should be noted, that in this project the NVSF values are given in kilovolts per added megawatt and this can result in quite small values. Therefore, the sensitivity factor values must be given with enough significant digits. In the INTERRFACE demonstration, nine significant digits were used.

Load forecast exchange

The SOs can upload network state forecasts with different granularities. The forecast granularity can vary depending on the SO`s forecasting capability and time horizon. For example, hourly forecasts can be given for the next day and worst-case forecasts can be given for a week, month, or season. The qualification service can handle multiple intersecting forecasts. This means that the system operator can first upload, for example monthly base forecast, and then closer to the operation day upload more accurate hourly forecasts. Only the latest forecast for each time interval is considered in the grid qualification.

The forecast is sent to the qualification service as a JSON file. Figure 13 shows forecast for the 3-bus example network in Figure 10. The forecast file contains conducting equipment power flow forecasts and node voltage forecasts. One forecast file can contain forecasts for several time intervals, although only one time interval is shown in Figure 13. The length of the time intervals is not limited, it can be shorter than one hour or can span several years.


```json
{
  "power-flow-forecast-time-interval": "2022-03-13T00:00Z/2023-03-13T00:00Z",
  "power-flow-forecasts": [
    {
      "conducting-equipment-id": "Primary-transformer-1",
      "active-power-flow-forecast-kW": 5087.389,
      "reactive-power-flow-forecast-kVAr": 1021.196
    },
    {
      "conducting-equipment-id": "Underground-cable-1",
      "active-power-flow-forecast-kW": 5000.000,
      "reactive-power-flow-forecast-kVAr": 1000.000
    }
  ],
  "node-voltage-forecast-time-interval": "2022-03-13T00:00Z/2023-03-13T00:00Z",
  "node-voltage-forecasts": [
    {
      "node-id": "DSO-node-1",
      "node-voltage-forecast-kV": 20.600
    },
    {
      "node-id": "Metering-point-1",
      "node-voltage-forecast-kV": 20.345
    }
  ]
}
```


Figure 13 Example of a forecast file

3.5.2.4. Calculations within the qualification service

This section briefly describes the principles on how the PTDF and NVSF matrices are used as a part of resource and bid qualification. For both resource and bid qualification, the calculations done in the qualification service start with the power flow qualification after which the node voltage qualification is performed. In resource qualification, the results of power flow and node voltage qualification are combined after they are both ready. In bid qualification, information on which bids were rejected during the power flow qualification is communicated to the node voltage qualification, i.e., node voltage qualification is done only for the bids that have passed the power flow qualification. The node voltage qualification doesn’t have feedback loop back to the power flow qualification.

In both resource and bid qualification, power flow and node voltage qualifications have two phases:
1) Check the simultaneous effect all downregulation resources or bids
2) Check the simultaneous effect all upregulation resources or bids.

Since at the time of resource qualification we don't know which resources will be offered to the markets and at the time of bid qualification we don't know which bids will be accepted and later activated, we assume the worst-case situation where all resources or bids to same direction are activated. This will lead into conservative but safe qualification results. If the net effect of down- and upregulation resources or bids had been studied, congestions could have been possible, if resources or bids had been activated unevenly from down- and upregulation sides. The netting method would also have been susceptible to gaming by FSPs.

Power flow qualification

Downregulation phase for resource power flow qualification goes through the following steps:

1) Calculate the total amount of downregulation resources can supply to each node.
2) Calculate for all conducting equipment how power flows change, if all downregulation resources are activated. The new active power flow for conducting equipment *i*, is calculated using the power flow forecast, PTDF matrix and node specific downregulation capacities determined in step 1.

$$P_{new,i} = P_{forecast,i} + \sum_{j=1}^{n} \left(PTDF_{i,j} \times P_{down,j} \right) \tag{11}$$

Where $P_{new,i}$ is the new active power flow on conducting equipment *i*

$P_{forecast,i}$ is the forecast for active power flow on conducting equipment *i*

n is the number of nodes

$PTDF_{i,j}$ is the sensitivity of power flow on conducting equipment *i* to power injection on node *j*

$P_{down,j}$ is the total amount of downregulation in node *j*.

After the new active power flows have been calculated, the new apparent power flows are calculated as follows:

$$S_{new,i} = \sqrt{P_{new,i}^2 + Q_{forecast,i}^2} \tag{12}$$

3) Compare the new apparent power flow to the maximum apparent power flow and calculate the power flow margin.

$$S_{m\arg in,i} = S_{max,i} - S_{new,i} \tag{13}$$

4) If power flow margins in all nodes are positive, the downregulation resources can never cause congestions and all resources can be qualified (given a green traffic light). If any negative power flow margins exist, continue to step 5, else end resource power flow qualification.

5) Qualify with restrictions (give a yellow traffic light) those resources that can contribute to congestions. This information can be found from the PTDF matrix. For each conducting equipment with negative power flow margin, PTDF values above a selected threshold are searched and all resources located in the corresponding nodes are qualified with restrictions. In this project, where only radial networks were considered, the sensitivity threshold was set to 0.5 as we only needed to distinguish zero values from values close to one. But in meshed networks this threshold should be considerably lower since all values between zero and one are possible.

The upregulation phase for resource power flow qualification is very similar, the main difference is the direction of the active power flow change. Steps 1-4 are similar also for the bid power flow qualifications. Only the step 5 is different, here congestion causing bids are filtered out one by one starting from the most expensive bids. The sub-steps for downregulation bid power flow qualification step 5 are:

1) Select all congested conducting equipment
2) Filter out conducting equipment that supply other congested conducting equipment
3) Loop through all remaining conducting equipment and do the following:
    a. Find nodes below selected conducting equipment
    b. Find bids associated with nodes found in step 3a
    c. Reject the most expensive bid from the bid group found in step 3b
    d. Recalculate the active power flow for the selected conducting equipment

$$P_{new,i} = P_{old,i} - PTDF_{i,j} \times P_{rejected\ bid,j} \tag{14}$$

    e. Recalculate the apparent power flow with equation (12)
    f. Recalculate the apparent power flow margin with equation (13)
    g. If the power flow margin is still negative, return to sub-step 3c
4) If any negative power flow margins are still left, return to step 2 in the main algorithm, else end bid power flow qualification.

When considering power flow limits in a radial network, bid rejections in the congested area can be done purely based on price, because the difference of network effects of bids in different locations are marginal (as long as they are within the same congestion area). In meshed networks, the selection of bids is not that simple, but the further development of bid selection methods is left to future work.

Node voltage qualification

Downregulation phase for resource node voltage qualification goes through the following steps:

1) Calculate the total amount of downregulation resources can supply to each node.
2) Calculate for all nodes how voltages change, if all downregulation resources are activated. The new node voltages are calculated using the node voltage forecast, NVSF matrix and node specific downregulation capacities determined in step 1.

$$V_{new,i} = V_{forecast,i} - \sum_{j=1}^{n} \left(NVSF_{i,j} \times P_{down,j} \right) \tag{15}$$

Where $V_{new,i}$ is the new voltage magnitude on node *i*

$V_{forecast,i}$ is the forecast for voltage on node *i*

n is the number of nodes

$NVSF_{i,j}$ is the sensitivity of voltage on node *i* to power injection on node *j*

$P_{down,j}$ is the total amount of downregulation in node *j*.

3) Compare the new node voltages to the minimum node voltages and calculate the node voltage margin.

$$V_{m\arg in,i} = V_{new,i} - V_{min,i} \quad (16)$$

4) f all node voltage margins are positive, the downregulation resources can never cause congestions and all resources can be qualified (given a green traffic light). If any negative node voltage margins exist, continue to step 5, else end resource node voltage qualification.
5) Qualify with restrictions (give a yellow traffic light) those resources that can contribute to minimum voltage congestions. For each node with negative node voltage margin, influencing topological nodes with negative NVSF values are searched and then all resources located in these nodes are qualified with restrictions.

As before, the upregulation phase for resource node voltage qualification is very similar, the main differences are the direction of the active power flow change and comparison to maximum node voltages. Steps 1-4 are similar also for the bid node voltage qualifications. Step 5 in the bid node voltage qualification rejects the congestion causing bids one by one. This step 5 includes the following sub-steps:

1) Select the most congested node (the one with the smallest voltage margin) referred from now on as node *x*.
2) Select the node that has the highest voltage sensitivity in relation to node x
    a. Select the row associated to node x from the NVSF matrix
    b. Find out which node (that still contains bids) has the highest sensitivity value in this row. Denote this node as node *y*.
3) Reject the most expensive downregulation bid in node y and set the qualification status of this bid to “Not Qualified”.
4) Recalculate voltage margin for node x

$$V_{m\arg in\, new,x} = V_{m\arg in\, old,x} - NVSF_{x,y} \times P_{rejected\, bid,y} \quad (17)$$

5) Check if more bid rejections in node y are needed. If the new voltage margin is negative and there are bids still left in node y, return to sub-step 3, else return to step 2 in the main algorithm.

In step 5, the bids are rejected firstly based on their network effect and secondly based on their price. In case of network voltages, rejecting bids based purely on price can lead to situations where bids that have little or no effect to the congestion are rejected. Further development could include a rejection metric that considers both the bid price and voltage sensitivity, e.g., product of price and sensitivity.

3.6. Data model

Single Flexibility Platform demonstrator contributed to data modelling by providing its use cases data attributes’ descriptions. Based on this, some new extensions to the existing profile groups ESMP

(European Style Market Profile) and CGMES (Common Grid Model Exchange Specification) of CIM are proposed by ENTSO-E in INTERRFACE deliverable 4.5 (2021).

The following CIM profiles were elaborated in D4.5 (2021) whereby new profiles were derived for product qualification and resource qualification processes (the latter includes both ESMP and CGMES profiles as listed below):

- ESMP
    - Resource Qualification Market Document (New)
    - Product Qualification Market Document (New)
    - Acknowledgement Market Document (Existing)
    - Reserve Bid Market Document (Existing)
    - Activation Market Document (Existing)
- CGMES
    - CGMES profile fragments (for the purpose of demonstration)
    - PTDF matrix Profile (New)
    - Voltage factor matrix Profile (New)

4. Results of the implementation

4.1. mFRR Estonia

4.1.1. Test scenario

The aim of the scenario is to provide mFRR bids for TSO to enable regulation of system imbalances, using sample data. It included registration of at least 3 resources on IEGSA amounting to at least 2 MW up or down capacity by FSP; generation of a resource group consisting of the registered resources by FSP; submitting mFRR bids during a day by FSP; TSO activation of mFRR bids; TSO balance settlement based on data provided by FSP.

Testing was conducted with sample data according to IEGSA guidelines and processes, with some simplifications:

- consent service: no relation with metering point ID, consent was linked with sample data;
- grid qualification: all resources and resource groups and bids were automatically qualified as green with the status “Qualified” and no other statuses were shown.

The scenario was performed based on IEGSA’s first release.

Table 7 Messages exchanged in mFRR (and CM) Estonia implementation

Data content	Message format used
Bid data forwarding from market participants (A37)	ENTSO-E Bid document format
Bid data forwarding to IEGSA platform (A37)	Bid_MarketDocument xmlns="urn:iec62325.351:tc57wg16:451-3:biddocument:7:0"
Receiving the Merit Order (A43)	MeritOrderList_MarketDocument xmlns="urn:iec62325.351:tc57wg16:451-7:moldocument:7:3"
Sending the Activation Order (A40)	Activation_MarketDocument xmlns="urn:iec62325.351:tc57wg16:451-7:activationdocument:6:1"
Reserve schedule (A14)	PlannedResourceSchedule_MarketDocument xmlns="urn:iec62325.351:tc57wg16:451-7:plannedresourcescheduledocument:6:0"
Reserve confirmation (A14)	ResourceScheduleConfirmation_MarketDocument xmlns="urn:iec62325.351:tc57wg16:451-7:resourlivescheduleconfirmationdocument:6:0"

4.1.2. Test scenario results

In this scenario, the resource registration, resource group building, bid submission, MOL creation, activation order sending, activated volumes sending, and settlement results. Bid submission consisted of two steps: FSP submitted the bid to Elering’s BMS; BMS forwarded the bids to IEGSA. An independent FSP (Fusebox) participated in testing by providing data, using the APIs and evaluating the results. Eventually, all planned steps were successfully performed.

mFRR product had clear minimum and maximum parameters defined and automatic qualification check was made for resource groups, comparing resource list parameters to product parameters (Figure 14). It is good that FSP can see the activated trades / bids and get an overview of settlement results. IEGSA integration guide and IEGSA user manual documents were informative enough and in general, contained the needed explanations.

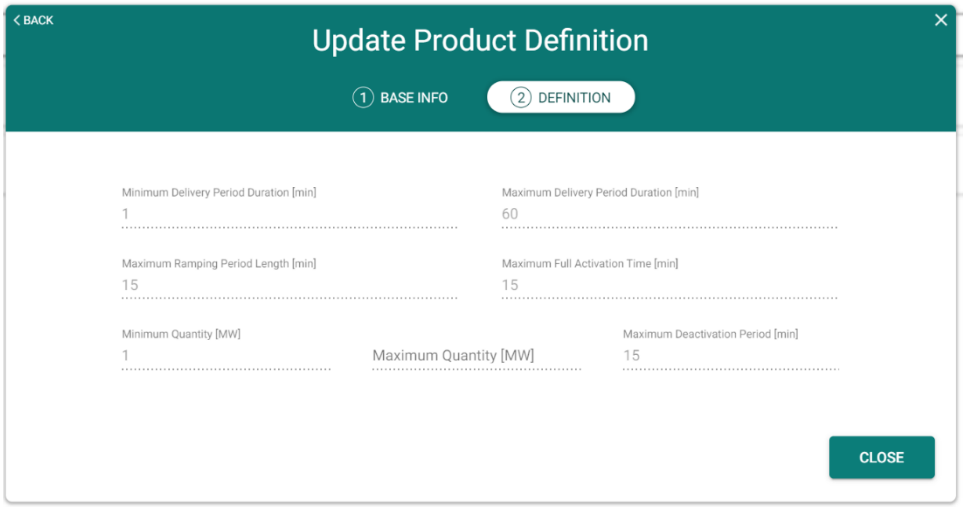


Figure 14 Product parameters information

The option to delete previously defined resource or resource group was added in the second IEGSA release. Additionally, all changes are archived, meaning if resource/group is modified or deleted, the old version is stored in archive tab of the resource/group.

After initial creation of a new resource group the giving a green light to the user (Figure 15). At the same time the MO had not approved the product prequalification yet, as per IEGSA requirement, and therefore the status was shown as “Pending Qualification” in Resource Group form (Figure 16).

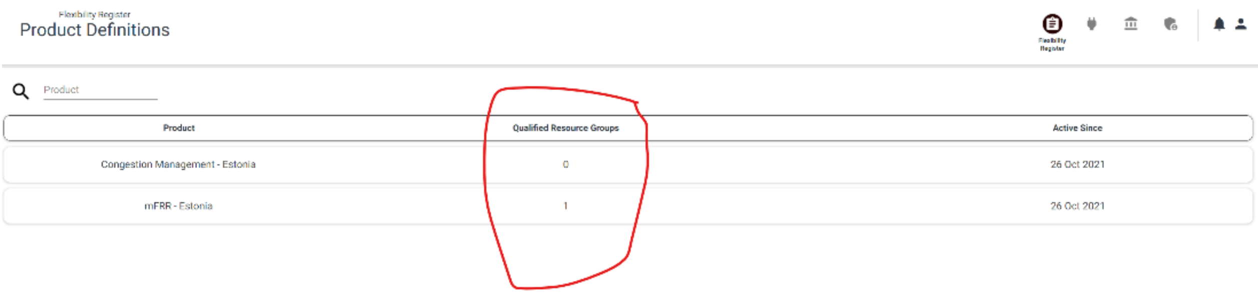


Figure 15 Qualification information in Product Definitions form

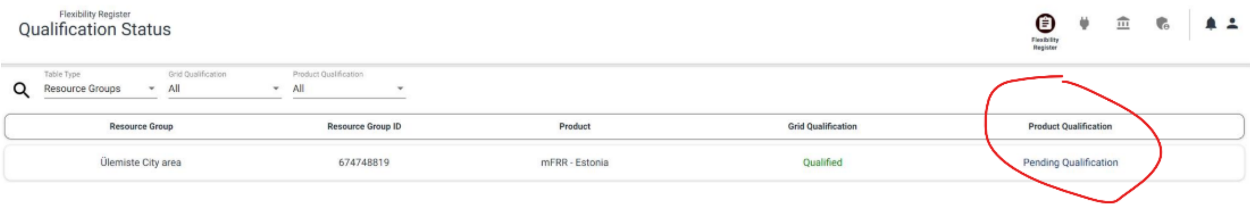


Figure 16 Qualification Status information

4.1.3. Conclusions

Eventually all planned steps for mFRR product (registration, qualification, trading, settlement) were successfully performed. While mFRR is a known product in Estonia, there has been basically only one provider until now. Therefore, the existing technical solutions have not been designed to facilitate the participation of a high number of FSPs and resources.

Also, the EU requirements are changing, potential new network code for demand response is under discussion. Mainly with the aim to attract low voltage connected distributed resources to the market, including demand side.

The concept and tools developed within INTERRFACE tackle these issues and provide a sufficiently streamlined solution especially for smaller FSPs to enter and participate in the market. The concept clearly enables not only the participation of FSPs of any size and technology, but also the participation of third-party Market Operators (whereas for mFRR it is currently TSO). Last-but-not-least, most obviously for mFRR product the cross-border harmonisation is increasingly required – commonly defined technical tools can support this.

However, the processes can still be finetuned both business- and software-wise. But this must be a step-by-step process while the market will become more liquid – more TSO needs and more available FSPs and resources. New circumstances will reveal further challenges and further opportunities. The business processes need to be adapted accordingly and software solutions must follow the new business requirements. Which means that the technical solution must be flexible enough to be adapted to new needs.

Specific conclusions related to some processes follow, both from business and technical perspective.

Grid qualification. Conceptually, separated processes for 'product qualification' and 'grid qualification' have been introduced and these are well supported by IEGSA. While the product qualification is relevant in prequalification phase and means checking whether a resource group meets the requirements of a specific product, the grid qualification takes place in both prequalification phase and trading phase – called 'resource qualification' and 'bid qualification' respectively. Indeed, while more and more resources in the medium and lower voltage end will be available in the flexibility market, the negative impact on physical grid potentially resulting from resources' activation has to be avoided. This can be improved, by taking such grid constraints into account based on real-time data.

Verification. New approaches are needed in case of small, distributed resources to check if they had delivered what they were asked for. This means baseline accuracy and access to sub-meter data. SCADA connections and balance schedules (for individual resource) are not available in this case. Also metering on connection point level may not be sufficient always because behind one connection point there are many different resources (and not all of them are participating in flexibility provision) and also the data granularity is very fixed (one-hour data, 15-minutes data). Harmonised methodologies and technical tools must support the verification process.

User experience. There will be many new players participating in the energy market – aggregators and distributed resource owners. For them the market access needs to be seamless. This includes user friendly tools – APIs, user interfaces, intuitive usage. As an example, on New Resource creation form, it would be good to have information ("i") icons next to field titles which open tooltips with additional descriptions. For example, a user might want to better understand what "Actual Up Regulation Power [MW]" means and what input is required.

Also, user experience can be improved by visualising relevant data even more, e.g.:

- FSP could see the list of all their bids that they have created and that have been received by the IEGSA (not just the ones that get activated).
- Activated quantity direction (up/down) could additionally be shown near activated quantity in trades list view / detailed view (Figure 17).

- In resources list view, beside existing resources' normal power values, also their flexible power values could be displayed as this is important value from FSP's point of view (up- and downregulation power).

Figure 17 Activated Quantity information in Trades form

Another aspect of user experience is to lessen the efforts required from FSPs when using IEGSA. A support to duplicate a resource or create multiple similar resources at once could be introduced, to lessen needed manual work. Second example relates to new resource creation – modal fields are nullified when user clicks in non-modal area and modal is closed. Already inserted data is deleted so it is not possible to continue from the previous state. It could be handled in a way that already inserted (possibly important) data is stored in cache and this way avoid extra manual work.

Privacy. Engaging end-consumers in the flexibility market means handling of personal data (e.g., meter readings, bids). Proper consent management mechanisms need to be in place for personal data, but also for commercial private data. It would be good to have a possibility to attach FSP client contract data and consent data to IEGSA. This way FSP could avoid extra manual work that had to be done separately between FSP and TSO.

4.2. mFRR Latvia

The mFRR demonstration in Latvia utilized the real information of the TSO grid and the Latvian part of the Baltic balancing market. Unfortunately, no real information of the DSO grid was used under mFRR process, therefore only system resources connected to the TSO grid were involved in the testing and demonstration.

The aim was to demonstrate all IEGSA mFRR related processes by using real data input from the TSO and the MO. Both the TSO and the MO were represented by AST, the Latvian TSO. Insight of real data provision is provided under Latvian internal developments section, see Subchapter 3.4.3.

The following subchapters describe demonstration scenarios and their results, as well as provide main conclusions from the mFRR demonstration.

4.2.1. Preparatory stage

Preparatory stage includes the necessary processes that must be carried out before proceeding with partial to full test case scenarios. Under mFRR demonstration the following preparatory stages are realized:

- New user registration. Administrator of the IEGSA platform created new TSO, DSO, MO and FSP role representatives to utilize and benefit from the IEGSA platform.
- TSO and DSO network data provision. The TSO provided network data based on subsection 3.4.3.1. and no information was provided for the DSO.
- MO defines market product. MO defines mFRR product for balancing market.

- FSP resource and resource group creation. In FSP profile resource and resource group profiles are created reflecting real market participant resources. For process simplification, consent service was not used in this demonstration.
- FSP resource and resource group qualification. The IEGSA platform automatically performs grid and product qualification based on SO provided network data and MO defined market product attributes. Additionally, MO manually confirms product qualification.

Preparatory stage processes are not modified under mFRR demonstration and reflect the close to the actual balancing market situation. However, test scenarios for some of the preparatory processes are included under CM product test scenarios, see Subchapter 4.4.

4.2.2. Test scenarios

The test scenarios for mFRR demonstration in Latvia were limited in versatility as scenarios reflect close to the real scenarios that occur between the FSP, MO and SO. Considering many processes are same for mFRR and CM, more versatile scenarios were tested under the CM product using simulated data, see Subchapter 4.1.1.

The test scenarios used real market participant data based on a bilateral agreement, allowing all necessary data to carry out IEGSA mFRR demonstration to be used and forwarded by AST on behalf of the market participant (i.e., an FSP). Overall, four test scenarios of interest are collected in the Table 8 with given general description and the scenario goal. Scenarios 1-3 are specific scenarios with a narrow objective and goal but reflect the actual market processes occurring daily. Scenario 4 is a repeating daily scenario with a goal to test IEGSA flexibility platform operation reliability and to highlight found operational nuances that might not classify as separate scenario. The test scenario results are presented in the following section.

Table 8 Test scenarios of mFRR Latvia implementation

No.	Scenario description	Scenario goal
1	SO partial bid volume or delivery interval activations.	Partial bid activation.
2	SO alters bid activation after initial bid activation.	Bid activation modification.
3	FSP delivers the product using another resource group in its portfolio. Similar outcome to not delivering the product.	Non-delivery settlement.
4	Daily full IEGSA mFRR process, excluding preparatory stage.	Stable and consistent operation.

The full demonstration process is represented in Figure 18, where the mFRR demonstration process flow is depicted under figure sections – Trading and Settlement.

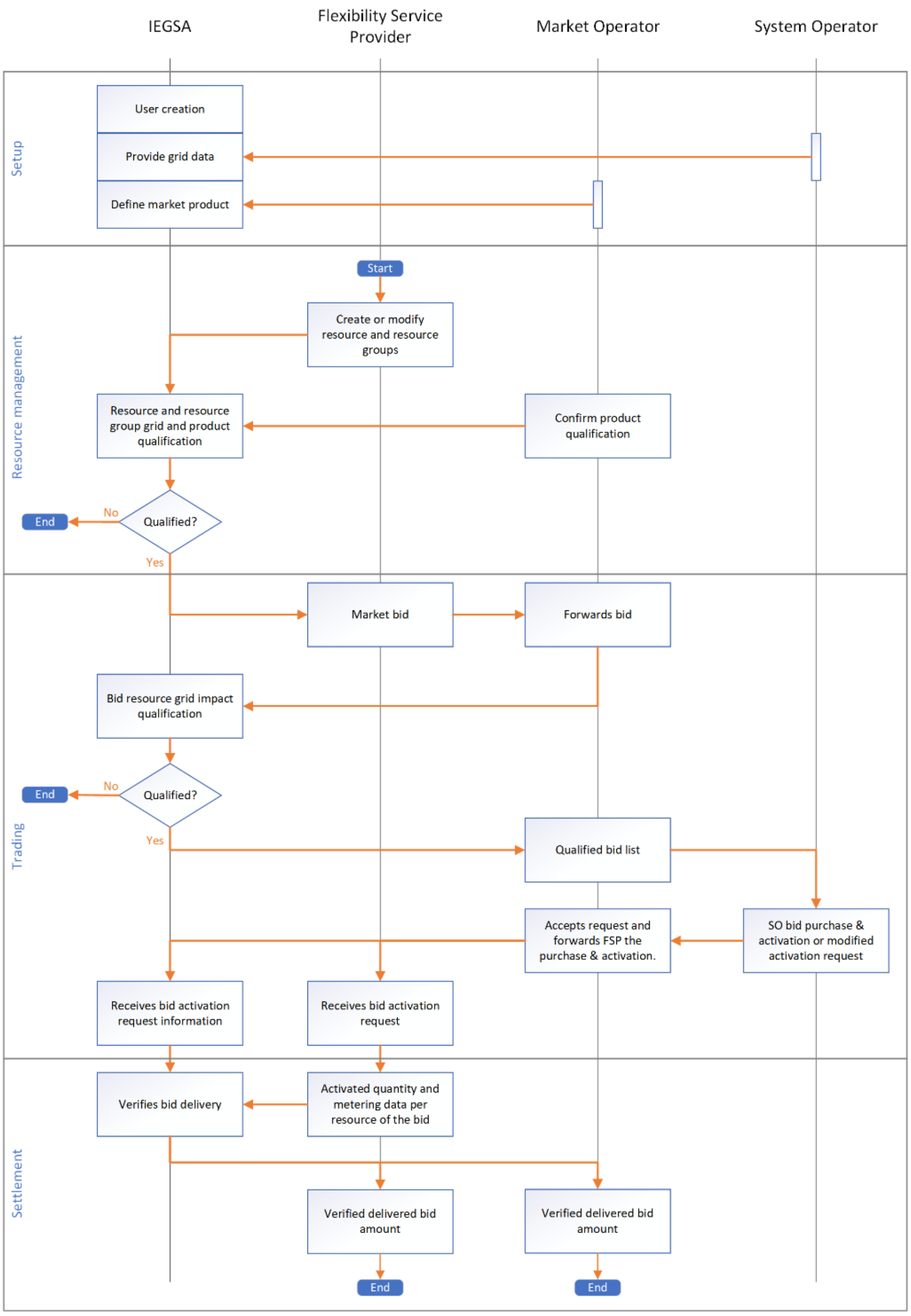


Figure 18 Demonstration process flow

The mFRR demonstration process includes trading process and settlement process. Trading process contains the process from FSP bid creation till FSP bid resource activation, where IEGSA`s main function is to examine FSP bid delivery involved resource impact on the SO grid and to keeping track on MO market bid activations. The settlement process is short but very important, it includes FSP provision of bid delivery related data to IEGSA and IEGSA bid delivery verification. The IEGSA bid delivery verification process determines how accurate FSP has delivered activated bid. The settlement process section ends with verified delivery amounts available for the FSP and MO.

4.2.3. Test scenario results

Scenario 1 – SO partial bid activations by volume or activation period. Accommodating divisible and non-divisible bids and providing SO bid activation flexibility, the individual market bids can be activated with specific definition of delivery volume or activation period. In Latvia primary choice is specifying activation period rather than volume, therefore it is important that such functionality is possible in the IEGSA flexibility platform.

Scenario results:

- Utilization of bid activation with specific delivery volume and keeping delivery period length 60 min, representing the MTU, provides correct bid delivery results in the settlement process. Functionality is accommodated in the IEGSA platform.
- Utilization of bid activation with specific time period within the MTU, shorter than 60 min (MTU), and keeping delivery volume maximum or altered, provides incorrect bid delivery results in the settlement process. Issue occurs because IEGSA platform algorithm used in the settlement process does not support activation periods under 60 min. Analysis of relevant bid settlements shows that most deliveries are completed as activation requested. Furthermore, analysis of bid activation orders from SO shows that from Latvia most of the bid activation durations are under 60 min. Considering the occurrence, the IEGSA flexibility platform should accommodate this functionality.

Scenario 2 – SO bid activation altering after initial activation request. Occasionally the balancing need prediction changes till bid activation starts or while it is ongoing. Therefore, SO can update the bid activation by activation request modification to suite the most up-to-date system situation.

Scenario results:

- During the demonstration period it was possible to successfully modify activation orders. This functionality is supported by the IEGSA flexibility platform.

Scenario 3 – FSP delivers the market bid with a different resource group in its portfolio. Accommodating various changes in FSP resource operation, the FSP might not be able to deliver market bid with the resources initially offered. There might be various reason such as resource availability forecast issues, resource utilization impact due to resource recent activities or operational patterns.

Scenario results:

- In the situation that FSP has offered the market bid with a specific resource group, but delivers the bid with another resource group, the bid settlement result should show that the bid was not delivered. In this case the settlement process worked correctly and showed that the bid was not delivered. This result is the same as for simple non-delivery because the meter data provided by the FSP show no fluctuation. Furthermore, in the situation when FSP resource availability changes, the IEGSA platform allows resource modification, but this modification does not impact bids that had been already bought in the market. In case bid has been bought in the market, the FSP cannot change the resources providing the bid and must bear the consequences for non-delivery.

Scenario 4 – Daily full IEGSA mFRR process testing platform reliability and consistency. Considering AST demonstration process automation setup, described in Subchapter 3.4.3, it was possible to perform full mFRR process multiple times in one day. Full process in mFRR demonstration starts from FSP bid submission and ends with settlement, see Figure 18.

Table 9 and Table 10 contain summarized results of the full IEGSA mFRR process demonstration during April 2022. Results provide better understanding about the IEGSA platform possibilities and limitations.

Table 9 Bid summary – month of April

	Bids	Bids activated	Bids settled	Bids not settled
Total	3431	396	361	35
Daily average	114	13	12	1
Daily minimum	65	0	0	0
Daily maximum	136	35	32	7

Table 10 Non-settled bids per type

	Periodic issue (23:00 – 24:00)	Unknown issue	Cancelled activation	Total
Number of issues	18	16	1	35
Issues per type, %	51%	46%	3%	100%

Table 9 shows IEGSA platform capability to ensure large bid pool processing as per daily processed bid average of 114 and maximum daily processed bids of 136. However, comparing activated bid and settled bid results has shown some unreliability of the IEGSA platform. From 396 bids activated 361 (91%) had been successfully settled using IEGSA platform settlement process, the other 35 (9%) had not been settled for one or another reason.

Table 10 contains the 35 (9%) non-settled bid analysis results. The analysis shows that 51% of the unsettled bids are due to issue with time period 23:00 – 24:00 as bids of this time period always were unsettled. 3% of the unsettled bids are due to activation cancellation and the 46% of the unsettled bids have an unknown issue. Not settled bids resulting from the specific time period (51%) and due to activation cancellation (3%) show the need for IEGSA platform further improvement, but the cause is understandable. However, the rest of not settled bids (46%) have an unknown cause of why the settlement process was not concluded. The issue seems to be on the IEGSA platform side as per communication logs it was deducted that the necessary data input for the settlement process had been provided to IEGSA and IEGSA had returned an answer that the provided information is correct.

4.2.4. Conclusions

The IEGSA platform provides an array of beneficial functionalities to accommodate future FSP role and its integration in the balancing and other markets. Part of this beneficial process from new platform user creation till initial FSP resource and resource group qualification was demonstrated only once during the mFRR demonstration process as no user, product or resource and their group changes were needed. However, the mFRR demonstration process covered trading and settlement part of the process tree, starting from market bid evaluation and concluding with settlement results.

In Latvian demonstration of IEGSA mFRR process, real market data was used, and it was provided to IEGSA platform by automated data exchange, simulating close to real life market process. During the demonstration four scenarios were selected to test the specific market function support as well as IEGSA platform reliability in everyday operation.

Demonstration had concluded that one necessary market functionality is not supported by the IEGSA platform and is to be considered as future improvement, such as market bid activations under MTU (60 min). Furthermore, daily testing of the operational reliability of IEGSA platform has shown not only IEGSA platform potential but also need for improvement. The operational reliability test results show that in a month of April 9% of the full mFRR process flow was not completed of which 54% of the tested cases have a correlating reason to be addressed in further IEGSA platform improvement, but 46% of the tested cases have an unknown cause of failure. This shows that IEGSA would require some improvements if used in real market situation and this should be considered as future improvement. However, looking at the full process success rate, 91% of April`s test cases had been process as expected by the IEGSA flexibility platform. Considering the high success rate, the current IEGSA provides high operational reliability and consistency.

The IEGSA flexibility platform provides valuable functionalities addressing future and current needs in Latvia, as well as show high operational reliability. Some further IEGSA improvements to accommodate current market functions and increase operational reliability were identified.

4.3. Operational CM Estonia

4.3.1. Test scenario

Congestion management scenario was similar to mFRR, same messages were used for operational CM product as for mFRR product (Table 7). This was intentional as the ultimate goal is to use the same product for different purposes – balancing and congestion management. Also, the products and technical tools were elaborated keeping this goal in mind.

The main and only difference was the inclusion of DSO grid data. Especially for CM one needs to know where exactly in the grid the congestion issue is located and where exactly are the available flexible resources, in order to select "right" flexibilities. Grid information is also needed for avoiding the creation of additional congestions if "wrong" flexibilities would be activated (i.e., resource qualification and bid qualification processes). Such grid data may include topologies, node limitations, energy flow estimates, PTDFs, etc., depending on the specific design preference.

Therefore, the attention was given to appropriate grid data uploading in this scenario. Based on the example of a major town in Estonia the scenario considers a case whereby voltage issues may occur if the reconstruction of an existing substation or investments into new infrastructure would be postponed and if this was not replaced by adequate flexibility measures.

Current situation is depicted in Figure 19 (the names of substations are artificial!). The peak load of the Juhani substation is 9 MW and it can be backed up on the basis of the existing network, but the consumption of the area is increasing, and therefor N-1 will be not ensured anymore. Up to 9 MW of capacity can be backed up with the existing 35 kV network. Long-term load forecasts show an increase in the total load in this area, which is why today's 35 kV network does not meet the future needs.

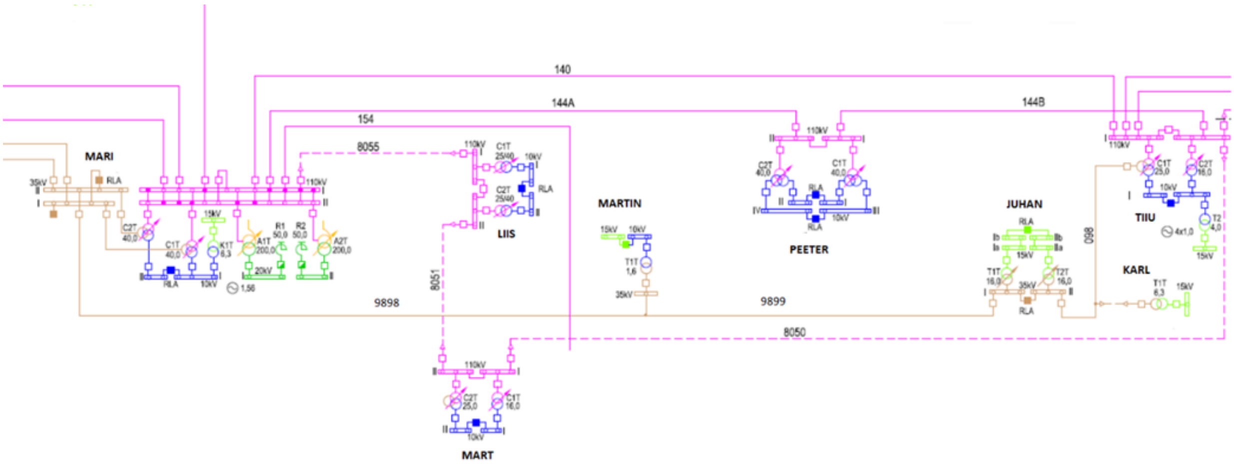


Figure 19 Activated Quantity information in Trades form

Therefore, if the entire 35 kV distribution network has to be switched to power supply from one direction only (e.g., in case of network maintenance or some interruptions), there will be problems in ensuring proper voltage in Mari and Juhani substations' areas. For ensuring proper voltage for customers (i.e., avoiding undervoltage), there is a need in 35 kV network to start purchasing flexibility from FSPs, in order to reduce the load on 35 kV lines.

In business-as-usual case, Juhani substation's 35 kV switchgear and power lines between Tiiu–Juhani and Mari–Juhani substations would be upgraded (the network capacity would be increased). With this, the power lines of Juhani substation and related 35 kV lines will be upgraded from 35 kV to 110 kV.

Test scenario intended to consider the case whereby the 35 kV line between Mari and Juhani substations is under maintenance. Customers who are powered by Juhani substation would face voltage problems because the 35 kV line between Juhani and Mari substations is under maintenance and customers of Martini substation would need to be supplied through Juhani substation using the medium voltage network. In order to ensure the required voltage, it is necessary to limit the consumption of substations supplied by Tiiu substation 35 kV network. Flexibility must be found behind Juhani or Karli substations amounting to approximately 1,5 MW.

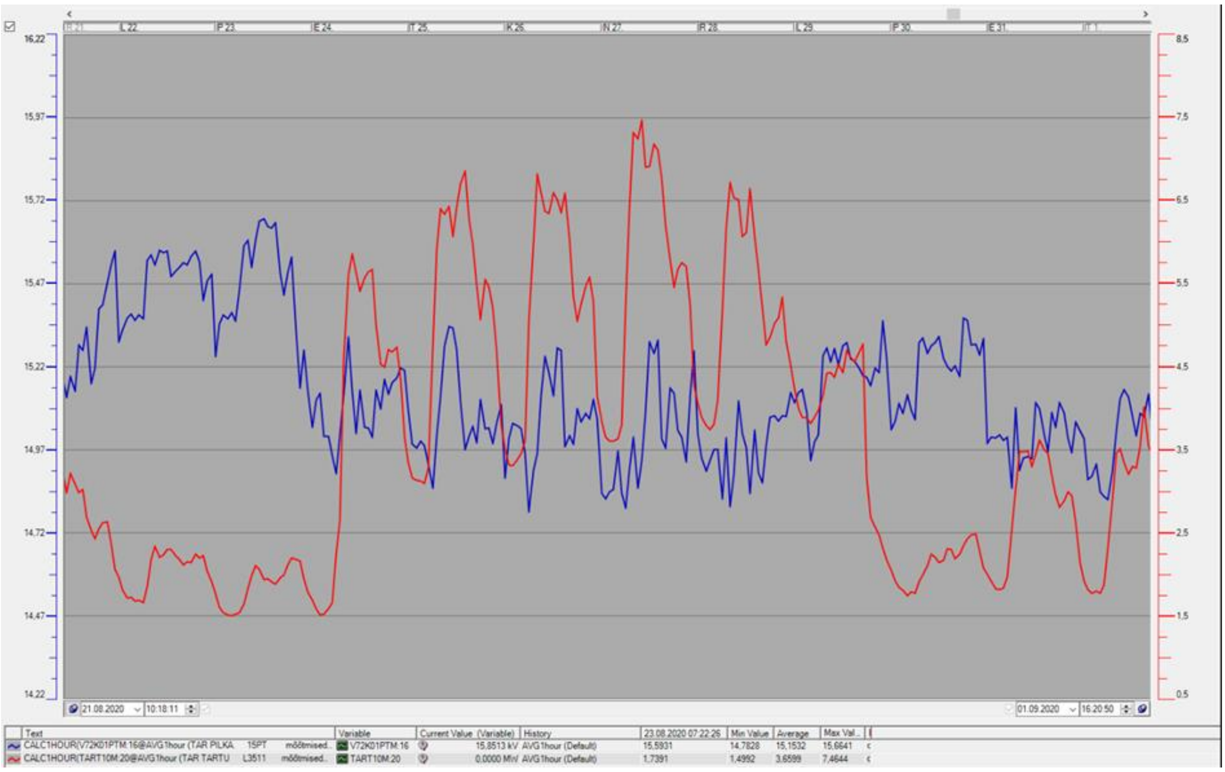


Figure 20 Mari substation 35 kV power capacity (red line, right scale, MW), Karli substation voltage (blue line, left scale, kV)

4.3.2. Test scenario results

During the test the grid data described in test scenario was successfully uploaded to IEGSA. All the other data exchanges for CM product basically mirror the respective exchanges of mFRR product and were therefore tested only partly. The actual activation of flexibilities was not in the scope, because only the theoretical congestion could be tested and also because no actual flexibilities were available in this area.

While testing the data exchanges few observations specific to CM were made:

- In case of bid data (A37), MOL data (A43) and activation order data (A40) custom codes for business type and process type had to be used to have capability for the CM product.
- The partial activation for the CM products proved to be problematic under CIM current format due to reference to resource group but not individual resources.
- Due to the issue with partial activation a resource schedule (A14) has been used to be able to divide the resource groups into topological sections. Proportions for the individual resources was used.
- Reserve confirmation (A14) – due to the limitations from activation message the individual resources activation amounts for resources were given with additional message to the activation order.

4.3.3. Conclusions

Using the same product for balancing and congestion management enables to increase liquidity in the market and provide easier access to the market for FSPs. Both cross-service and cross-border integrations would be enabled. Facilitating factors are harmonised market processes (including product definitions), technical tools (like algorithms, software) and standards for interoperability.

Regarding the market processes and specific improvements to technical tools some conclusions made in case of mFRR product (Chapter 4.1.3) are as relevant for CM product. It is worthwhile to add that the availability and proper usage of grid data is especially important for congestion management. Definitely, for congestion management the location of both congestion and flexibilities must be known. This enables resource/bid qualification and bid selection processes.

In practice the DSO grid data will be similarly needed for mFRR – once more and more resources located in medium and low voltage will be available for balancing services, the system needs to ensure that the activation of such resources would not cause congestions in the grid. Using same resources simultaneously for different needs (such as balancing and congestion management) will increase the complexity even further. For this, novel optimisation algorithms will be required, e.g., based on PTDF approach.

Another observation made relates to data interoperability. Future standardisation with CIM expert group is proposed for congestion management product related data exchanges to support interoperability.

4.4. Operational CM Latvia

The operational CM demonstration in Latvia was carried out mostly using test data as only the TSO network information represented the real grid. The test information regarding the DSO network and the CM market was created by AST. This data was provided through manual input see subsection 3.4.3.1. for more details.

The aim was to demonstrate IEGSA CM related processes to understand the CM potential of the CM product and test in detail IEGSA platform user, resource, and resource group management, which was excluded under Latvian mFRR demonstration.

The following subsections describe the demonstration scenarios and their results, as well as the main conclusions from the CM demonstration.

4.4.1. Test scenarios

The test scenarios for CM demonstration in Latvia cover IEGSA flexibility platform processes from platform user creation till settlement. The settlement process is not the focus of this demonstration as exact process occurs for mFRR product and this was sufficiently covered under mFRR demonstration. During all the testing scenarios test data was used, except for TSO network information.

In **Error! Not a valid bookmark self-reference.**, list of CM demonstration test scenarios is available. The scenarios 1-3 test IEGSA platform user and resource management and scenarios 4-6 test the market activity support. The selected test scenarios complement the previously examined Latvian mFRR demonstration scenarios in Subchapter 4.2 as both CM and mFRR product processes are quite similar in the platform.

Table 11 Test scenarios of CM Latvia implementation

Nr.	Scenario description	Scenario goal
1	Register multiple IEGSA platform users.	Large user support.
2	Register multiple FSP resource and resource groups. Within grid limitation and product specification bounds.	Large resource portfolio support.
3	FSP resource and resource group modification. Respecting product specification, but exceeding grid limitation bounds.	Resource management.
4	FSP market bid creation within product specification bounds, but exceeding grid limitations.	System stability.
5	FSP resource and resource group modification after same resource bid offer publication in the market.	Market bid update.
6	SO activation of multiple bids and causing network congestion.	TSO-DSO market coordination.

The CM demonstration process covers the process sections from Setup up till Settlement, see Figure 18 Demonstration process flow. Settlement is not extensively tested under CM demonstration because settlement process for mFRR and CM products is the same. Testing under CM demonstration covers system resource impact on the grid and congestion mitigation.

4.4.2. Test scenario results

Scenario 1 – Registration of multiple IEGSA platform users. Testing scalability, the platform must handle a large number of users. Considering SO and MO users are limited, the test was made with creating multiple FSP users.

Scenario results:

- Testing of large number of FSP user creation was successful. In the test, 20 additional FSP users were created as well as flexibility resources added under their profile to further simulate user intended activities. IEGSA can accommodate a large number of registered users.

Scenario 2 – Registration of multiple FSP resources and resource groups while respecting the boundaries of the grid limitations and product specification. Continuation of scenario 1, under each new FSP user multiple resources and a resource group were added to test IEGSA platform's FSP resource management.

Scenario results:

- The IEGSA platform does successfully meet FSP resource management needs. During the testing, under each new FSP profile 20 resources and a resource group were created simulating FSP with larger resources such as industrial system resources in the DSO level.
- The testing also highlighted future drawback under resource group creation. The current resource group creation process allows to scroll a list of individual FSP owned resources and select them one by one to be added in a new resource group. This type of resource browsing and selection process is acceptable while FSP has small number of individual resources, but this does not accommodate the potential FSP with non-industrial resources with 1000 or more individual resources. To accommodate FSP with a large resource portfolio a search bar using resource name, network connection ID or other locational parameter should be added, as well as option to select all search results could provide additional benefit.

Scenario 3 – FSP resource and resource group modification, including modification outside of grid limitations but respecting product specifications. Continuation of scenario 2, IEGSA platform should support FSP resource and resource group modification, which includes modification and deletion in order to provide FSP resource management flexibility.

Scenario results:

- The IEGSA flexibility platform does support flexible modification of FSP owned individual resource and resource groups. Moreover, IEGSA keeps track of the individual resource and resource group change history through an archived version of pre-modified versions. However, altering individual resource or resource group name is not possible, this is not an issue as FSP can always create a new group easily, but could improve resource management flexibility.
- Testing also highlighted implemented methodology drawback with resource group qualification information that is available for the FSP, where grid qualification result might show that individual resource group is restricted due to network limitations. This situation occurs when many individual resources have been registered in IEGSA with similar grid element impact, meaning in theory if these resources would be activated together, they could cause congestion for the TSO or the DSO. The problem is twofold, 1) the information provided per congesting resource is very vague, see Figure 21, FSP cannot clearly understand how much of the resource power is allowed to be used; 2) cross-FSP resource grid congestion results should not appear for FSPs, rather FSP should see its own individual resource group grid congestion results only.

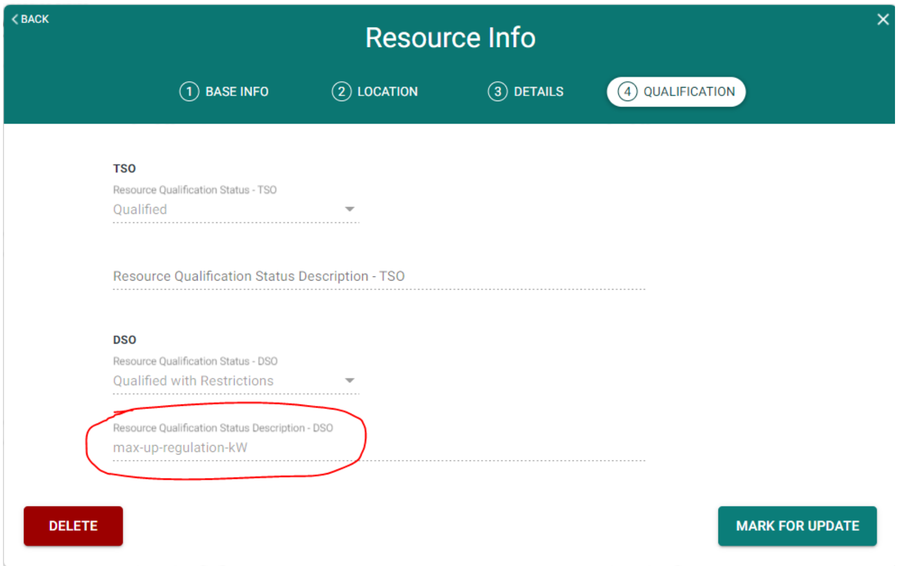


Figure 21 Resource with operational restriction

- Another drawback the testing highlighted was lack of warning message for unsaved change for updating of modified resources. As stated before, the FSP can quite flexibly modify its own flexibility resource data in the platform, but once necessary changes are input, then FSP must press the "Update Resources" button in order to accept the made changes. The issue is the lack of pop-up window asking the FSP to save or not save changes before moving to another IEGSA tab as currently FSP can freely change tabs and lose unsaved modifications.

Scenario 4 – FSP creates market bid which by itself exceeds SO network limits. In the IEGSA platform SO network limits are in two timeframes – long-term and short-term. The long-term network limits are used for resource and resource group qualification and are less restricting. It means that in long-term the network dynamics is not considered, in order not to exclude the resources in early phase just because they might cause congestions in very few hours only. However, short-term network limits are used as more up-to-date network limit information for market bid qualification and are more restricting than long-term. This means that FSP in the IEGSA platform might see that resource and resource group is qualified without restrictions, but this might not reflect the current network limitation perspective as during the market bid qualification process more accurate network limitation is used.

Scenario results:

- The IEGSA platform successfully provided the expected outcome and did not allow network congesting market bid to be included in the market. During the scenario test the resource group representing the FSP market bid offer was not restricted based on FSP IEGSA platform view, but for the bid valid time period short-term network limits were reduced so that the FSP market bid offer would cause congesting by itself. The IEGSA platform did not allow this market bid to be offered in the market.
- This test highlighted drawback that FSP lacks feedback from such situation outcome. The IEGSA platform market bid evaluation feedback should be received by the MO as two bid lists where one list is used in the market and second one contains the rejected bids with clear reasoning. Furthermore, the reasoning should not be limited to only network constraints as the reasoning might also be issue in the bid message format, unknown EIC or resource group ID etc. Implementing a rejected bid feedback functionality in IEGSA platform would provide means for MO to clearly inform FSP of the market bid rejection and the reasoning behind it.

  Scenario 5 – FSP resource or resource group modification after offering same resource market bid to the market. The FSP must honour market bid and resources selected to deliver offered bid. However, FSP resources or resource groups that already have been offered as market bid can change due to new resource additions, or existing resource changes or removal. After FSP has modified their resources, it is their responsibility to cancel any upcoming MTU market bids, but IEGSA platform offers support by cancelling these bids automatically.

Scenario results:

- The IEGSA platform in this test scenario performs as expected, after the resource modification, the impacted market bids are removed from the market bid list.

Scenario 6 – SO activates multiple market bids and causes congestion. This scenario might occur as between TSO and DSO there is no network congestion information exchange after grid qualification in IEGSA platform. This means that, e.g., TSO to solve its congestion issues can cause congestions in DSO network by activating individual bids that by themselves do not cause congestion but together overwhelm the DSO network.

Scenario results:

- The IEGSA platform unfortunately does not limit activations considering congestions between TSO and DSO, therefore congestions due to multiple individual bid activations can occur. However, this is not IEGSA platform issue as activations will be happening in the market which is hosted by the respective MO and IEGSA platform is only informed about the activation request from the MO, therefore congestion control of multiple bids must be done on the MO side and not the IEGSA platform side.

The CM demonstration test scenarios in Latvia cover CM specific as well as complementing scenarios excluded from mFRR demonstration. The six scenarios show IEGSA platform potential and need for further development.

4.4.3. Conclusions

The IEGSA platform offers processes needed in the close future, which at the moment have no alternative in Latvia. Highly valued are processes related to FSP portfolio management and TSO-DSO coordination.

During the CM demonstration, the FSP portfolio management was tested under scenarios 2 and 3. The tested scenarios showed that the IEGSA platform offered ease of use and management support for the FSP. The FSP within the platform was able to create new resources, modify and delete old resources as well as keep track of changes made through resource historical version archiving. However, future development had also been indicated during testing. During resource group creation or modification there should be a resource search bar available for filtering of available resources to support FSP with large flexibility resource pool. Moreover, after FSP has modified registered resources before switching to other IEGSA platform section a pop-up window is needed informing about unsaved changes to minimize repeated inputs from unsaved resource modifications.

Regarding TSO-DSO coordination, during CM demonstration this was tested under scenarios 2-4. The coordination between the networks is cleverly imbedded in platforms grid qualification process that repeats when creating or modifying resource and resource group and when resource group pre-registered on platform submits a market bid. This process to some extent ensures operational stability between TSO and DSO network levels by evaluating the FSP resources using network information directly from TSO and DSO. However, future developments had also been indicated during testing. Scenario 3 results highlighted the need to redesign FSP resource grid qualification result depiction by providing numerical limitation value rather than vague text if the resource causes congestion and, moreover, for FSP the resource group grid qualification process should only consider resource group impact on the grid and not all registered resources on the IEGSA platform, because overpopulated grids will show all resources with overlapping grid impact as restricted and cause unnecessary confusion on FSP side. Furthermore, scenario 4 showed the need to provide information to the MO not only about the qualified market bids, but also disqualified bids along with disqualification reason, as currently MO does not have such information and in result FSP is not provided with a reason why its market bid is rejected. To improve process transparency rejected market bids and their individual rejection reasons should be provided to the MO to further inform FSP. Lastly, scenario 6 shows that after IEGSA platform TSO-DSO coordination, there still is a chance to cause network stability issues, thereby it is needed to extend the TSO-DSO coordination till market bid activation.

The IEGSA platform has a large potential but requires further development to accommodate solution shortcomings to reliably support network flexibility from resource provider, market, and system side.

4.5. Operational CM Finland

The operational CM demonstration in Finland was based on connecting IEGSA with the Finnish BMS operated by Fingrid. In the Finnish context the Operational CM can be regarded as using locational information on the mFRR market to provide bids to not only balancing use but also to CM. These bids were available in IEGSA for TSO and DSOs.

The aim of the demonstration was to conduct end-to-end pilots following the IEGSA processes in scenarios that are based on real-world flexibility needs of the DSO and the TSO. To conduct the full end-to-end process flow, the demonstration required an external party to provide flexibility offers and conduct activations. Such an external party was found through the cascade funding scheme of the INTERRFACE project, which resulted in a contract with a Finnish FSP.

The following chapters describe the different scenarios planned for the demonstration, a summary of results, and the main conclusions and lessons learned through the pilots.

4.5.1. Test scenarios

The Finnish demonstration partners defined a set of technical and practical scenarios which on one hand reflect different real-world flexibility needs of the SOs and on the other hand test different aspects of the IEGSA functionalities. Table 12 summarizes the end-to-end test scenarios containing real flexibility bid activations. In addition to these, the demonstration contained several tests that did not result in bid activations. These included, for example, tests where FSP creates a resource group but product qualification fails, and tests where bids were automatically re2jected due to congestion in either TSO or DSO network.

Table 12 End-to-end test scenarios of CM Finland implementation

Scenario	Scenario story	Scenario goal
1	SO activates a flexibility bid through the IEGSA user interface but only part of the flexibility is supplied by the FSP.	Settlement of partial activation
2	SO activates a flexibility bid for a period shorter than one hour.	Settlement of short activation
3	TSO activates flexibility to maintain operational security during planned outage by procuring upregulation.	Cleared congestion
4	Planned maintenance is causing a short-term need for the use of a backup connection, which is congested. DSO procures upregulation (load reduction) from the flexibility market to solve the congestion.	Cleared congestion
5	Planned maintenance is causing a long-term need for the use of backup connection, which gets congested during the daily peak hour. DSO procures upregulation (load reduction) from the flexibility market to clip the peak and solve the congestion.	Cleared congestion
6	Battery storage system is used to secure MV branch electricity supply during a fault. DSO procures upregulation (load reduction) from the flexibility market to extend the islanding time.	Extended islanding
7	Excessive solar generation is forecasted to cause distribution transformer overloading. DSO procures downregulation (load increase) from the flexibility market to clip the peak caused by solar generation.	Cleared congestion

As described in the above table, all the scenarios were based on different use-cases. All the end-to-end scenarios comprise of the same base process flow which was altered to validate the desired outcome of the case in question.

Test scenario runs consisted basically of two parts:

1. Preparatory measures
2. Trading process flow (Figure 22)

Preparatory measures covered, among other things

- Modelling of FSP resources to be activated (only first time) or at least updating their available up- and downregulation capacities based on the actual situation. This was done by the FSP.
- Grouping of resources to be referenced from bids placed by the FSP. Two different groups of resources were used in operational CM test scenarios.
- Uploading grid topology and either power limit tables or PTDF matrices for the period for which the test scenario was to be conducted. This was done separately by a TSO and a DSO taking care that grid models of both were glued together with the help of commonly identified single node or multiple nodes.

After the preparatory measures had been taken, the trading process flow started with FSP placing a bid. The bid went through Fingrid's BMS system and reached IEGSA. If the bid was successfully qualified against the grid model and its capacities, then it appeared on the MOL list 40 minutes before the start of the delivery hour. If the bid did not qualify due to insufficient capacity, it never appeared on the MOL list and thus was not available for the purchase.

While the bid was on the MOL list it could be purchased by any of the SOs. As a default, the activation time is for the whole delivery hour and the quantity is the available maximum for the node in question but the purchasing SO has a possibility to set them freely as follows:

- Activation time: 1–60 minutes within delivery hour in 1 minute resolution
- Activation volume: Between zero and available maximum

Once the bid is purchased then IEGSA forwards the related bid activation request through the BMS system to the FSP. The FSP in turn activates the resources according to a schedule set in the activation request.

The final step in the operational CM trading process flow is settlement. In order to run the settlement, IEGSA needs input data from the FSP covering activated volumes per metering point and secondly, measurement values for each metering point in one minute resolution for the period covering both the activation period and the hour before. Settlement is to be run by IEGSA once a day every morning for all activations taken place the day before giving enough time for the FSP to collect all measurements and validate the input data for settlement. Settlement results are available both on the IEGSA UI and through the API request.

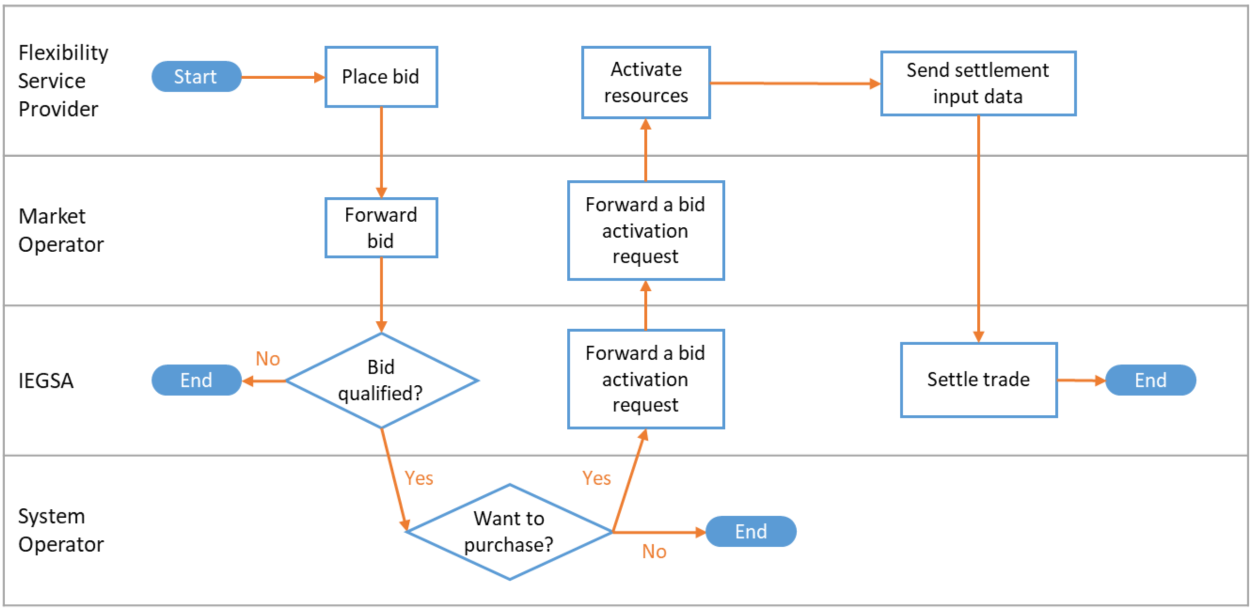


Figure 22 Operational CM trading process flow

The demonstration cases included activations using real flexibility resources. These resources were controlled by a company funded by the cascading funding scheme of the INTERRFACE project, namely Kapacity.io Solutions Oy. The controlled resources comprised of a variety of heat pumps located in Finland. Most of the heat pumps were used in residential apartment buildings, and one larger unit was located in a leisure centre including sports halls and other buildings. Kapacity.io developed the capability to offer them to the flexibility market following the IEGSA processes and conducted activations accordingly by using an automated system that reacts to activation requests from the market. Kapacity.io communicated with the BMS using ENTSO-E's ECP platform and message, which are already currently used on the marketplace. Table 13 presents the resource pool used in the demonstration. The buildings located in Pirkkala and Kuortane were connected to Elenia's network, which supported well the undertakings of the project and enabled the use of Elenia's measurements for analysing the behaviour of the resources.

Table 13 List of the flexible resources used in the demonstration

	Location	Nominal capacity (kW)	Building type	Heat pump model used	Floor area (m^2)
1	Pirkkala	23	Residential	Nibe F	1 730
2	Pirkkala	27	Residential	Nibe F	1 868
3	Pirkkala	16	Residential	Nibe F	1 172
4	Pirkkala	25	Residential	Thermia Mega	1 264
5	Pirkkala	25	Residential	Thermia Mega	1 614
6	Helsinki	65	Residential	Thermia Mega	2 861
7	Kuortane	550	Leisure centre, mixed	Thermia Mega	47 000

For demonstration purposes, the resources were connected to a fictional distribution network model that was modifiable and allowed us to run simulations on different scenarios where flexibility procurement might be beneficial for DSO or where the DSO network congestion prevents resource or bid qualification. As Figure 23 shows, the demonstration network contains three different voltage levels. The residential resources are connected to the low voltage network and the leisure centre is connected to the medium voltage network, as it is in real-life. An Octave model of the network was used when running the scenario simulations and a network model in the form of topology, PTDF and NVSF matrices, loading and node voltage forecasts, and a power limit table was sent to IEGSA. In addition to the network shown in Figure 23, smaller distribution networks were used in scenario 3 that required several TSO-DSO connections. The distribution networks were connected to transmission network with commonly identified TSO-DSO connection points.

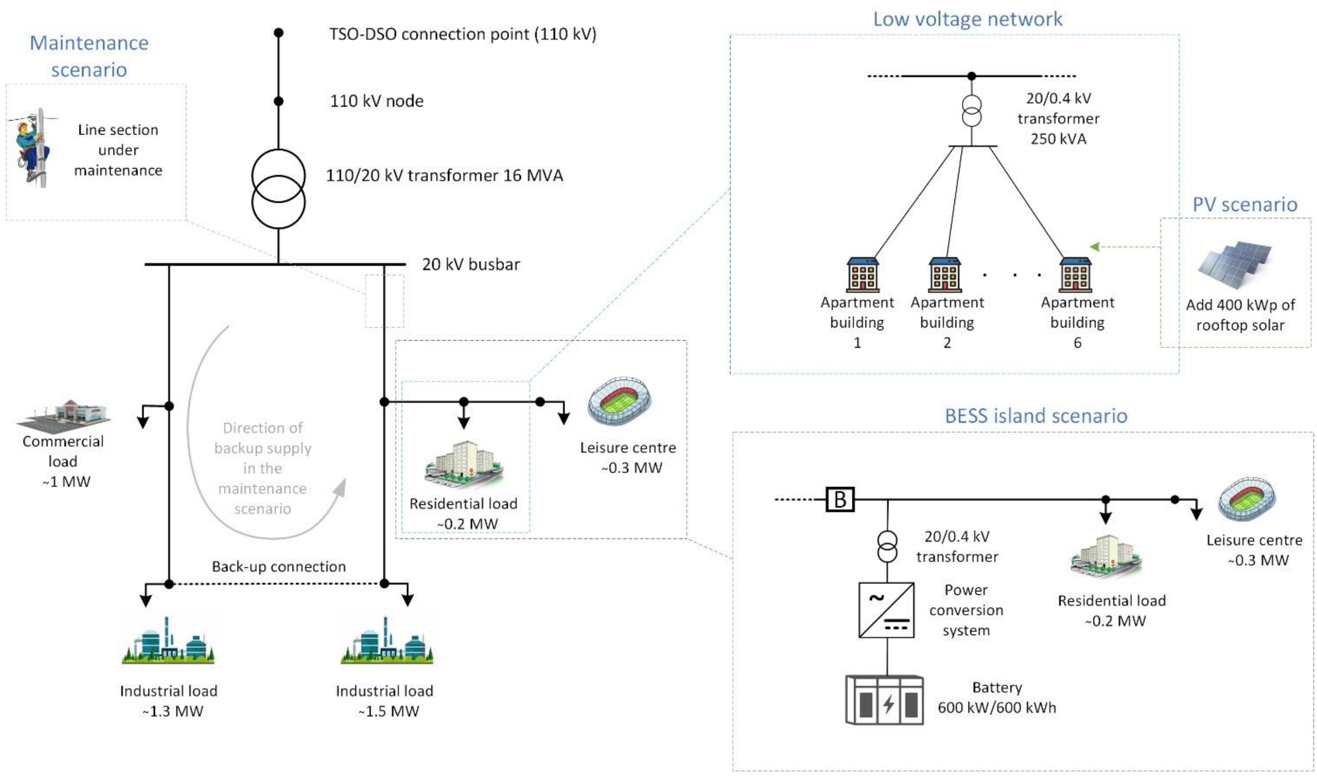
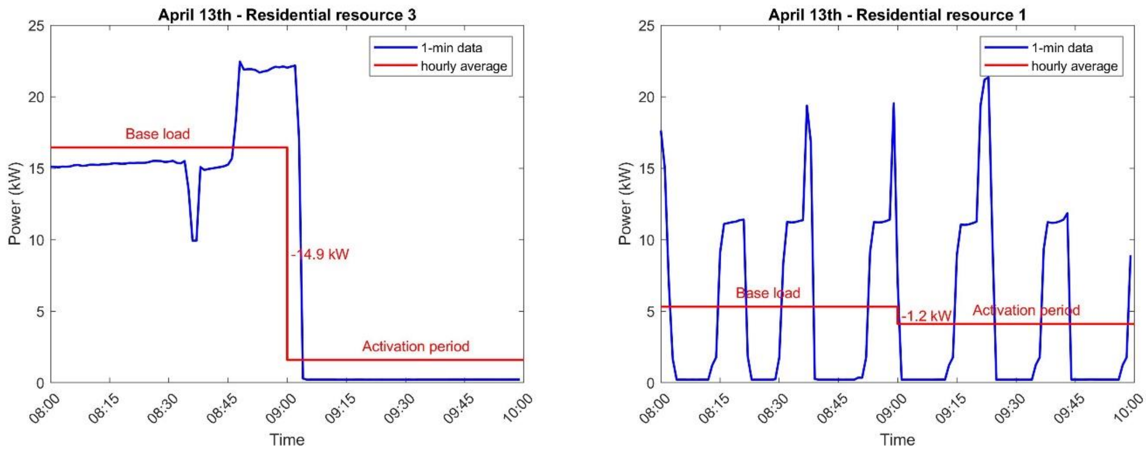


Figure 23 Distribution network used in the demonstration

The transmission network was modelled as separate points representing the DSO network model connections to the TSO network. The approach chosen was influenced in particular by the fact that the implemented model was not able to handle meshed but only radial networks. And thus, from the TSO perspective, increasing radially connected points to the model would not have been given any added value as the TSO network is practically completely meshed.

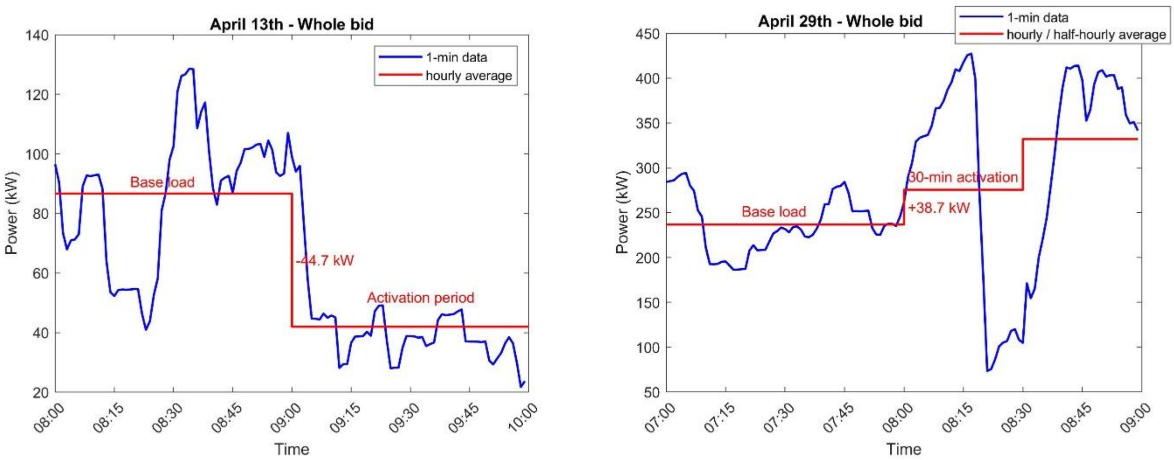
4.5.2. Test scenario results

Following the planned scenarios presented above in Table 12, the FSP placed flexibility bids to market and SOs activated them through the IEGSA user interface on eleven separate days. The realised responses were analysed, and real-life activations were combined with simulated bottleneck situations or other situations where flexibility activation might benefit the SOs. On individual level, the flexibility resources responded to control actions in many ways. In some cases, the responses were clear and expected, as is shown if Figure 24a. Whereas in some cases, the resources did not respond as expected. Figure 24b shows a resource with no clear response to an upregulation request, the heat pump continues to cycle on-off despite the activation. On aggregated level, the variation was smoothed and responses were clearer, as is shown in Figure 25a. In some cases, the aggregated responses did not satisfy the buyer's needs. Figure 25b shows a situation where the response is delayed and the average load change on the requested 30-minute activation period is in wrong direction. This result was analysed in scenario 2. A summary of the scenario results is given in Table 14.



a) b)

Figure 24 Individual resource responses to activations (upregulation)



a) b)

Figure 25 Aggregated resource group responses to activations, a) 1 h upregulation and b) 30 min upregulation

Table 14 Summary of scenarios built around the real-life activations done during the demonstration

Scenario	Summary of scenario results
1	TSO procured 50 kW of upregulation from the market to the TSO-DSO connection point, but the FSP supplied only 31 kW. All resources, that were activated in the scenario, were located in the DSO network. The volume activated in the scenario was not enough for a real-life TSO case, but the applied architecture and process model are fully scalable for larger resources.
2	TSO procured 100 kW of upregulation for a period of 30 minutes to the TSO-DSO connection point. In this particular case, flexibility resources responded to the upregulation request with a 20-minute delay. This delay, together with a badly timed stochastic load peak, led to 39 kW increase in average load during the 30-minute activation period. All resources, that were activated in the scenario, were located in the DSO network. The volume activated in the scenario was not enough for a real-life TSO case but the applied architecture and process model are fully scalable for larger resources. The settlement process was not able to handle the behaviour of resources to wrong direction as the implemented settlement model considers only those metering points that have delivered flexibility to the same direction as the original activation request was.
3	TSO procured 10 MW of upregulation for the whole hour to maintain operational security in the area during a planned outage. The settlement gave as a result that only about 4,5 MW of flexibility was delivered which would not meet the need of a real-life TSO case. Due to the limitation in the volume of flexible resources to be activated, it was decided to use the factor of 100 everywhere except the physical resources itself to make the scenario more realistic for TSO. This meant practically that characteristics of resources as well as network limits were updated in order to support the run of the scenario.
4	DSO procured upregulation (load reduction) for one hour from a resource located at the end of the feeder to solve a simulated short-term voltage violation issue arising from a short-term use of a backup connection. Without flexibility, the voltage was forecasted to drop down to 0.9835 p.u., which is below the 0.985 minimum voltage limit in Elenia's MV network. The leisure centre responded to the upregulation request by cutting consumption on average 180 kW compared to forecasted consumption (111 kW compared to baseline). This raised the MV network minimum voltage to 0.9878 p.u. (hourly average), assuming all other loads behaved as

	forecasted. Considering the hourly load forecast variances, 225 kW of additional load reduction, evenly distributed along the feeder, would have been needed to achieve 95 % confidence that the minimum voltage limit is not violated. The load rebound was not considered in this scenario, because the network was assumed to return to a normal non-congested state before the end of the activation.
5	Similarly to scenario 4, DSO procured upregulation to solve a one-hour long voltage violation issue but in this case the need to use a backup connection was long-term. This meant that the flexibility resource's rebound on the next hour was also relevant. The flexibility activation solved the one-hour long congestion but caused another congestion on the following hour. The 180-kW consumption decrease was followed by a 128-kW consumption increase on the following hour. On 1-minute level, the rebound peak was 437 kW higher than the forecasted hourly consumption, and this caused a significant voltage dip below the minimum voltage limit.
6	An unexpected fault situation, where a battery storage system secures MV branch electricity supply, was simulated. It was assumed that the MV branch switches automatically into islanding mode and DSO procures upregulation from the market as quickly as possible. The real-life activation combined with this scenario simulation reduced load in the islanded area by 47 kW, which meant that the battery storage system was able to maintain the island 8 minutes (15 %) longer than it would have had without the flexibility procurement.
7	In this simulated scenario, excessive solar generation was forecasted to cause distribution transformer overloading. DSO procured downregulation from the market and FSP activated flexibility resources. Consumption in the congested area increased by 10 kW during the first activation hour and by 11 kW during the second activation hour. Congestion would have been avoided, if PV production had not exceeded the forecasted production. About ¾ of the procured flexibility was activated outside the congestion area and the resources (heat pumps) used in this demonstration were able to provide flexibility for only two consecutive hours. Typically, in this kind of scenario, downregulation for at least four hours is needed.

The scenario studies that combined real flexibility activations with historical consumption data and simulated network model revealed many interesting aspects about flexibility use. One important lesson learnt was the effect of consumption and production forecast uncertainties. In scenario 7, the flexibility activation would have solved the congestion if the PV production had realised as forecasted but the actual production was higher than forecasted and congestion remained. In scenario 4, congestion was avoided but taking into account the consumption variability, a lot more flexibility would have been needed to make sure that congestion can be removed repeatedly and with the necessary confidence level. Another important factor to consider is load rebound after activation. In scenario 5, congestion on the activation hour was solved but the load rebound caused another congestion on the following hour. Figure 26 shows how the overall consumption of the leisure centre responded to the upregulation request. A notable load reduction was achieved during the activation period, but the rebound was also significant. The large rebound spike had a clear effect on the simulated demonstration network minimum voltage, which dipped well below the minimum voltage limit, as is shown in Figure 27.

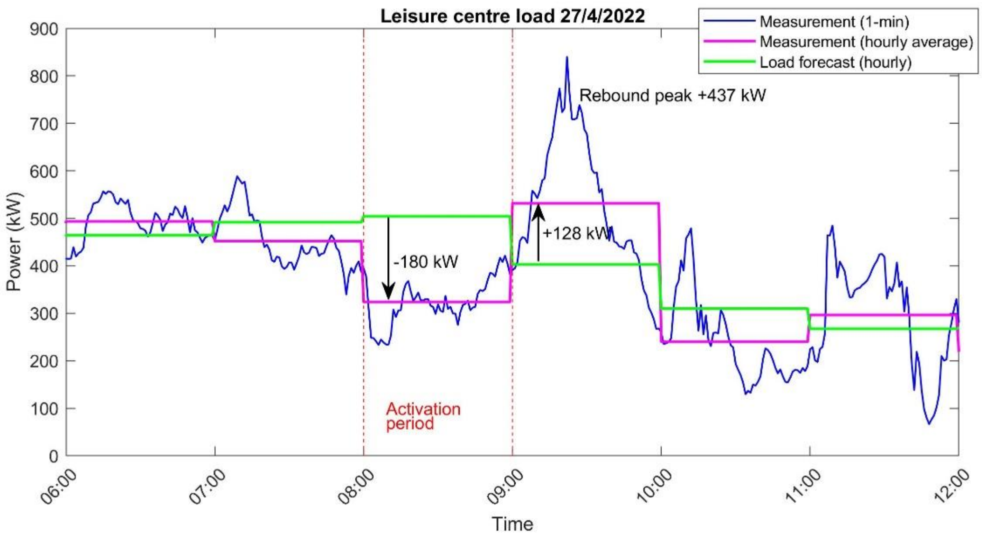


Figure 26 Leisure centre's response to activation and rebound in scenario 5

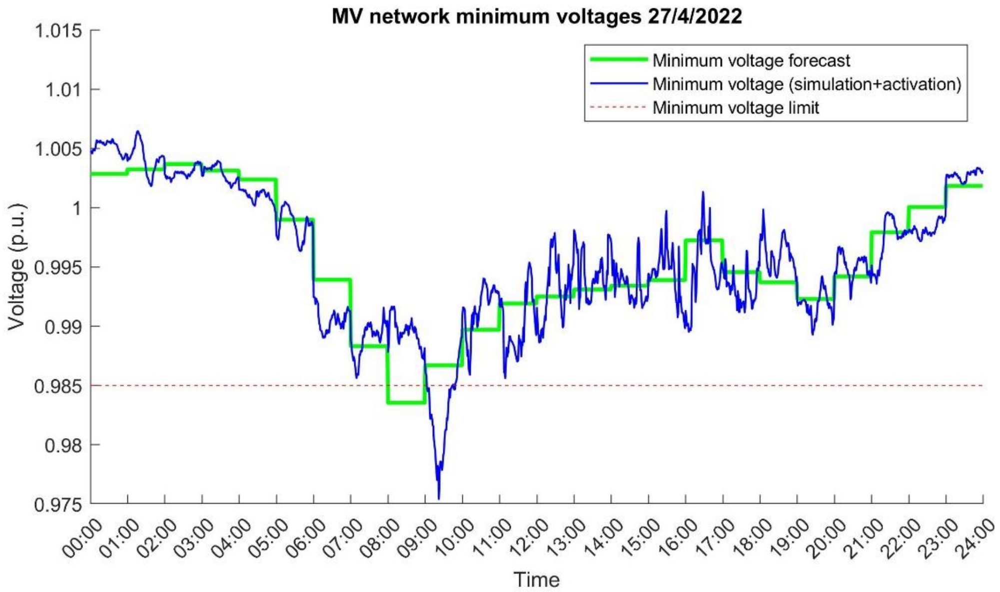


Figure 27 MV network minimum voltage in scenario 5

4.5.3. Conclusions

The Finnish operational CM demonstration was successful in piloting the end-to-end IEGSA process in the planned scenarios to validate its functioning in different situations. The IEGSA solution provided the FSPs a possibility to manage their resources, offer them to markets through the connected MO, and get activation request from the respective marketplace. For the SOs, the solution introduced a possibility to procure flexibility in a coordinated manner based on the location of the resources. IEGSA performed resource-, product- and bid qualifications as planned, which worked as a prerequisite for the realization of flexibility trades. Finally, the settlement functionality determined the amount of delivered flexibility.

The IEGSA platform provided novel functionality related to TSO-DSO coordination of flexibility bids and functioned mostly as expected with the given inputs. The IEGSA content was developed during the project, but some development needs can be identified based on the results of the operational CM demonstration.

Regarding the grid representation on the IEGSA platform, one of the major shortcomings was the lack of support for meshed networks. This implied, that only radial network topologies could be used, although the developed grid qualification model using PTDF matrices would have been capable of managing more complex meshed systems. Radial topologies are often sufficient for the DSO, but on TSO side the networks are operated as meshed systems.

The concept and implementation of breaking down the original bid into child bids based on the network node model was very interesting. For SOs it offered the possibility to purchase flexibility exactly on the location where the need was located and thus avoiding unnecessary activation of resources even causing unwanted situation in some other parts of the network. Then again, from the perspective of FSPs, this approach may present some challenges as the reliability requirement of a single resource increases significantly leading to a situation where the fulfilment of a child bid activation request is harder than for the original bid comprising of a pool of resources. Even though the UI of IEGSA MOL supports the activation of child bids on any node level it has clear development needs. The most important thing to develop is the hierarchical structure of network nodes or at least a sorted order of the node list rows as they are now presented in random order.

The settlement is the final part of the IEGSA trading process. In the implementation of the settlement logic, the first priority was put to a method where the actual flexibility is calculated from the average measurements between the activation period and the previous hour. It turned out to be too straightforward method and posed insurmountable challenges in situations where behaviour of a resource in the previous hour was not even close to normal. This is the case, for example, when activation takes place during two consecutive hours. Therefore, implementation of a more advanced baseline method would have been the preferred way to go.

However, the biggest shortcoming in the implementation of settlement was the assumption that all resources activated based on the request of an SO would deliver flexibility to the direction of the request. But regarding flexibility, due to local conditions, there is always unforeseen behaviour as the resources activated in the test scenarios were in the kilowatt class. Because of this those resources that responded to a wrong direction were disregarded in the calculation. The correct way would be to account the possibility that resources can respond to wrong direction and use the net sum of up- and downregulation in the settlement. Settlement results in the CIM document format were available both through the API and downloadable from the UI. This should have been improved by providing the essential information extracted from the CIM documents in the IEGSA UI as currently only very advanced users are able to interpret the available documents.

The scope defined for the demonstration did not include financial settlement. The demonstrated process ended after the delivered flexibility amount was determined. The following development would have been to continue the process to invoicing and reporting the traded bids to imbalance settlement and delivered amounts in some cases.

The model chosen for IEGSA architecture to connect multiple market platforms to a single TDCP was proved to work well as a whole and help to enable the increase of liquidity on the market. The flexible resources operated by the FSP performed real activations based on the activation requests generated in the IEGSA system and forwarded through the BMS.

The functionality to activate flexibility bids on IEGSA was also presenting some behaviour that would require further development. The functionality in the tested system allowed activation of bids also to the past during the hour. This should be something to be prohibited by the system. Another important addition would be to include the use of “full activation time” of a product. This would, for example, allow the activation to end no earlier than defined full activation time counted from the time point in question during the operating hour. Still the possibility to activate during the operational hour was seen essential. For example, in fault situations it is important to be able to do the activation without the need to wait until the beginning of the next hour.

The performance of the FSP delivering the agreed flexibility by activating real resource demonstrated varying results regarding the behaviour of the resources. It should be noted, that studying the behaviour of single flexible resources was not in the scope of the project, but it showed some of the challenges of using demand response in operating the power system.

It was proven that flexibility offered by the IEGSA architecture and distributed flexible resources can be used to manage local congestions. Still, it is evident that when using distributed resources, sufficient safety margins need to be applied. Also, more information on the availability of the flexibility is needed in some cases to ensure that enough capacity is available for SOs and the FSP has an incentive to provide the capacity.

4.6. Short-term CM Finland

Delivery model for Short-term CM in Finland was implemented by integrating the Nord Pool's current intraday marketplace and IEGSA. Intraday pilot was part of task 5.3 Single Flexibility Platform demonstrator and it was carried out by the Finnish INTERRFACE piloting partners (Fingrid, Elenia, Enerim) in a tight co-operation with Nord Pool as an external partner.

This setup enables SOs to purchase flexibility (for CM) directly using IEGSA and for FSPs to place bids directly to Intraday marketplace. Intraday marketplace is the most liquid and commonly used marketplace for intraday trading (mainly for balance management purposes). The sequence diagram of the process is presented in Figure 28.

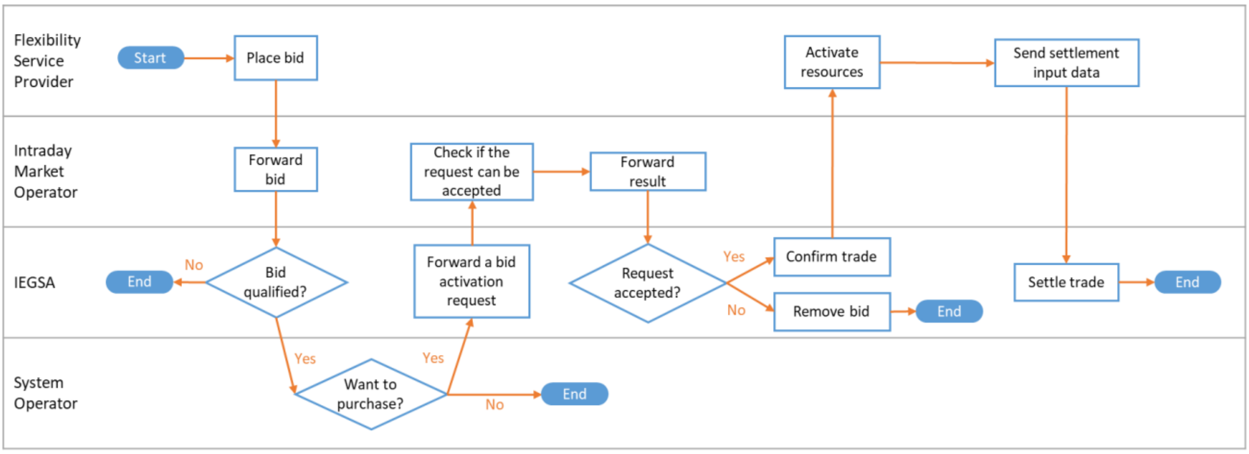


Figure 28 Short-term CM trading process

Main requirements for the practical setup are reliable & real time integration between IEGSA & Intraday marketplace and well built & simple FR in IEGSA.

4.6.1. Test scenarios and results

In this pilot the fully functional integration was done using the API provided by IEGSA. Nord Pool had to develop its own IT systems to enable the integration. Description of Nord Pool integrations is presented in Figure 29 below.

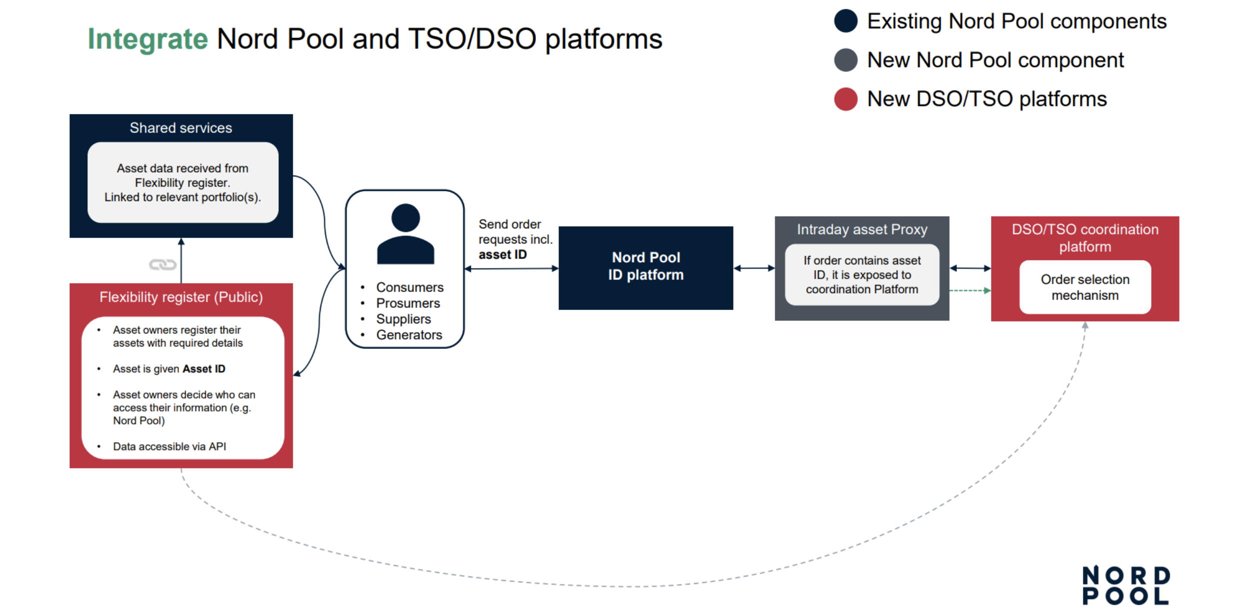


Figure 29 Nord Pool integrations

The FR was implemented and pilot proved that no necessary functions or contents were missing. The FR (example in Figure 30) includes detailed network node level information from every resource object and resource objects are composed into resource groups where the individual locational intraday bids are allocated to.

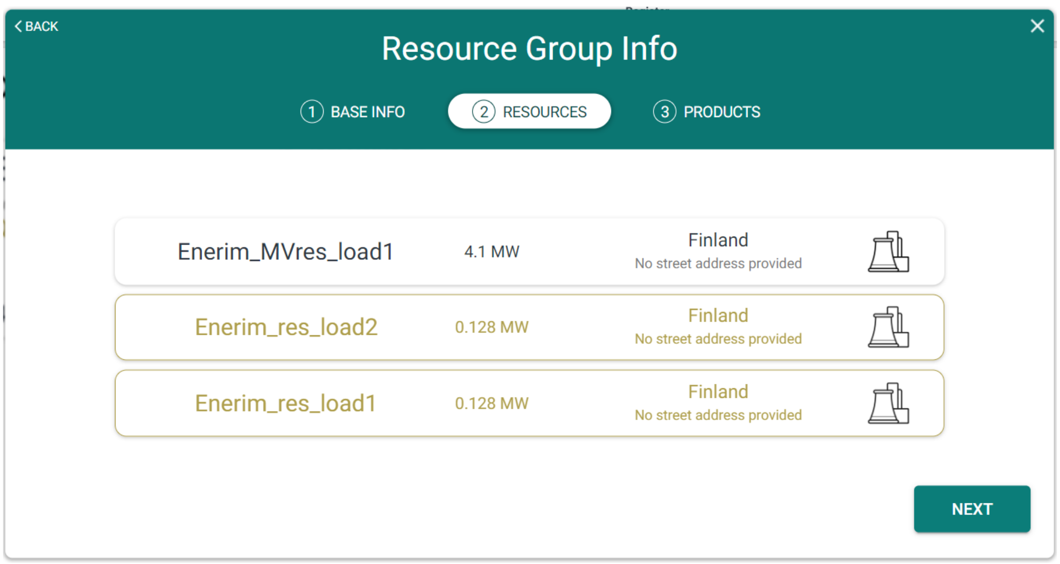
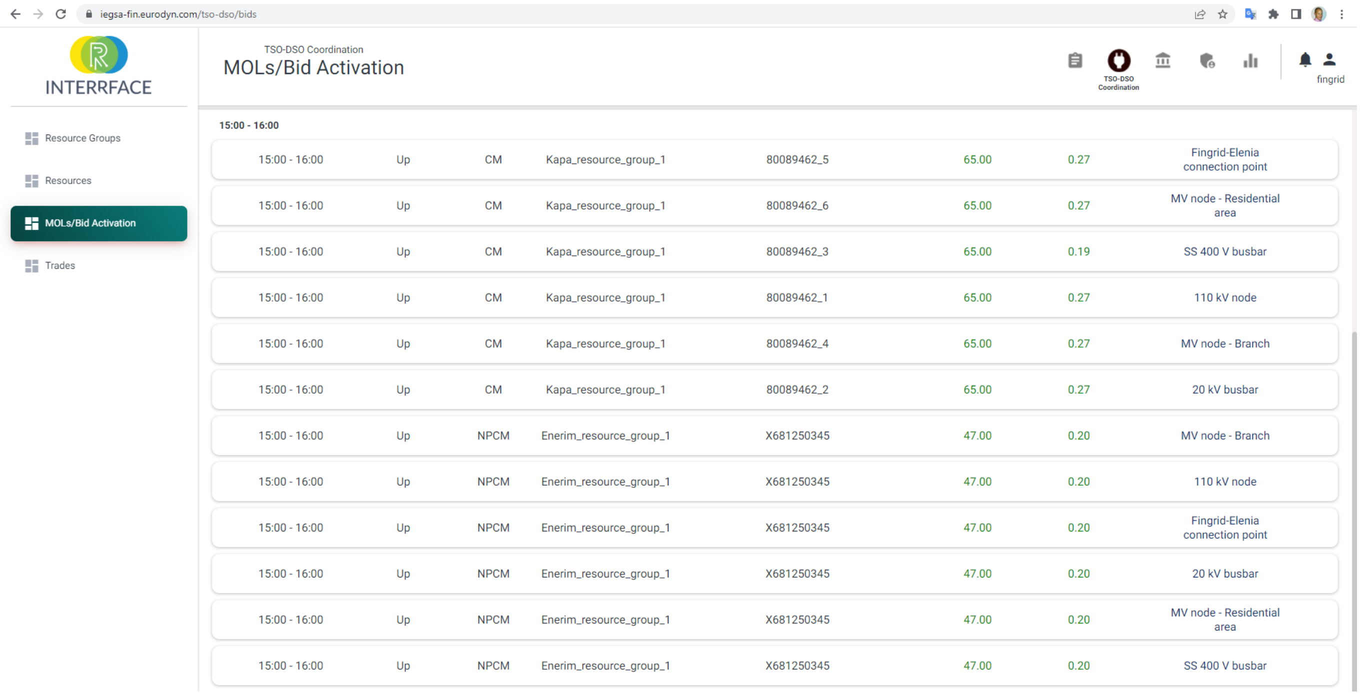


Figure 30 Resource group example in IEGSA

Offering flexibility to regional intraday market only slightly differs from offering to the regular intraday market. Only major difference is that bid must include an Asset ID that refers to the resource group defined in IEGSA and each individual resource in a resource group has location information in a form of identified grid connection point. The IEGSA connects the bid connection point to the SOs' network topology to assess and present flexibility impact to the SOs

All intraday bids that include the Asset ID are automatically forwarded to IEGSA using the API and SOs can buy the flexibility directly from IEGSA. Gate Closure Time in IEGSA is 40 minutes before the start of the delivery period and bids are not anymore accepted after that.



15:00 - 16:00	Up	CM	Kapa_resource_group_1	80089462_5	65.00	0.27	Fingrid-Elenia connection point
15:00 - 16:00	Up	CM	Kapa_resource_group_1	80089462_6	65.00	0.27	MV node - Residential area
15:00 - 16:00	Up	CM	Kapa_resource_group_1	80089462_3	65.00	0.19	SS 400 V busbar
15:00 - 16:00	Up	CM	Kapa_resource_group_1	80089462_1	65.00	0.27	110 kV node
15:00 - 16:00	Up	CM	Kapa_resource_group_1	80089462_4	65.00	0.27	MV node - Branch
15:00 - 16:00	Up	CM	Kapa_resource_group_1	80089462_2	65.00	0.27	20 kV busbar
15:00 - 16:00	Up	NPCM	Enerim_resource_group_1	X681250345	47.00	0.20	MV node - Branch
15:00 - 16:00	Up	NPCM	Enerim_resource_group_1	X681250345	47.00	0.20	110 kV node
15:00 - 16:00	Up	NPCM	Enerim_resource_group_1	X681250345	47.00	0.20	Fingrid-Elenia connection point
15:00 - 16:00	Up	NPCM	Enerim_resource_group_1	X681250345	47.00	0.20	20 kV busbar
15:00 - 16:00	Up	NPCM	Enerim_resource_group_1	X681250345	47.00	0.20	MV node - Residential area
15:00 - 16:00	Up	NPCM	Enerim_resource_group_1	X681250345	47.00	0.20	SS 400 V busbar

Figure 31 MOL for CM (including mFRR and Intraday markets)

MOL list in IEGSA is automatically updated via API and it includes both Intraday and mFRR bids. MOL updating and activation was tested during the pilot and all functionalities (API towards Nord Pool, bid sending from intraday market and bid activation functionality) were verified.

After the SO purchases the bid meeting the need and enters preferred activation time and quantity, the bid activation request is sent to Nord Pool to verify if the bid is still available. At the same time, the bid is tentatively marked as traded (green rectangle in Figure 32) so that no one else can purchase it anymore on the IEGSA side.

15:00 - 16:00	Up	NPCM	Enerim_resource_group_1	X681250345	47.00	0.20	SS 400 V busbar
15:00 - 16:00	Up	NPCM	Enerim_resource_group_1	X681250345	47.00	0.20	MV node - Branch
15:00 - 16:00	Up	NPCM	Enerim_resource_group_1	X681250345	47.00	0.20	110 kV node
15:00 - 16:00	Up	NPCM	Enerim_resource_group_1	X681250345	47.00	0.20	Fingrid-Elenia connection point
15:00 - 16:00	Up	NPCM	Enerim_resource_group_1	X681250345	47.00	0.20	20 kV busbar
15:00 - 16:00	Up	NPCM	Enerim_resource_group_1	X681250345	47.00	0.20	MV node - Residential area

Figure 32 Traded ID bids in IEGSA

If the bid is still available in Nord Pool's Intraday market and the activation request could be accepted, Nord Pool calls the API provided by IEGSA and updates the status as MATCHED.

If the activation request could not be accepted, the API is called with a status of REJECTED. As result the trade is not confirmed and the related bid is removed from the MOL list.

The settlement process is run daily for all new trades and as an input it needs, e.g., measurement data of resources that have been activated as a result of those trades. FSP can see the results and download needed reports straight from IEGSA (Figure 33).

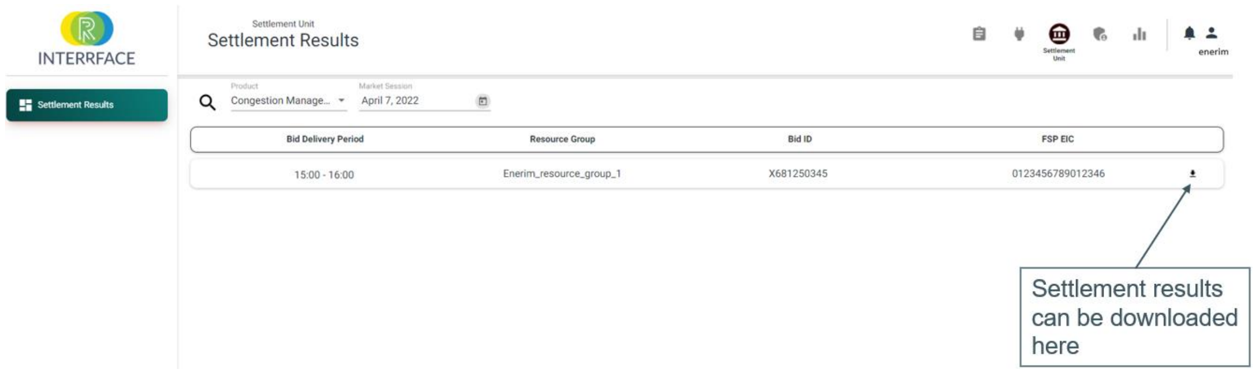


Figure 33 Settlement reporting in IEGSA

4.6.2. Conclusions

Intraday pilot case proved that CM can be part of international and liquid intraday market with relatively small system level exceptions and modifications. This makes it possible for all SOs, FSPs, and independent service providers to participate into regional intraday based flexibility market without any major updates to systems or operative processes.

4.7. aFRR and FCR

Initially the plan of the demonstrator was to test the aFRR and FCR products as a part of the demonstration. In early phase of the demo planning, focus was put to the most prominent products for CM. mFRR is used for transmission level CM in many countries and additionally it was seen as the most interesting product for independent aggregation in some. Also, one criterion for the products to be focused on was the usability from DSO perspective.

The aFRR and FCR are frequency and balance management products, and of the three demo countries they are used only in Finland. The used products are capacity products procured by the TSO. The FCR product is activated based on frequency and the aFRR based on an activation signal sent by the TSO directly to the control systems of the contracted devices. These aspects make the products less interesting from the Single Flexibility Platform demonstrator point of view.

FSP participation in aFRR and FCR will be of great importance in Latvia and Estonia from 2025 onward, especially due to current concerns regarding the sufficiency of future balancing reserves after desynchronization. However, as currently those markets are not yet there, IEGSA end-to-end mFRR testing, in principle, is sufficient for the future development of aFRR and FCR in the Baltics, since indeed a lot of the functionality IEGSA already has (and which has been validated during mFRR piloting) will be similarly needed for those products.

The possible most interesting use cases that the IEGSA could offer regarding these products are the three different qualification processes. Resource qualification could check the resources' impact to the grid in the initial phase. Also, similarly to other products, the product qualification could be run for the resources to first make sure that the technical characteristics meet the product requirements and afterwards the TSO conducts activation tests, after which the resource group gets qualification to these products in the FR. In the daily auction for capacity for these products, the bid qualification could theoretically be run to find bids that have negative effects to the grid. As said, these products were left out of the final scope of the demo, since the products can be regarded as "single purpose" compared to for example mFRR, and the products are used only by the TSO as a single buyer to buy capacity services.

4.8. Flexible grid contracts Estonia

4.8.1. Test scenario

The scenario was to test the conversion, forwarding and activation of the national specific flexible grid connection agreements at Elering. During the test case the existing flexible grid connection agreements were converted into hourly short term flexible contracts and shared to IEGSA for common MOL.

Elering has existing flexible grid connection agreements that regulate the grid connection customers and give them a possibility to define their fixed capacity and flexible capacity. At any time during the planning or operational phase TSO has the right to limit the capacity in the amount of flexible capacity by notifying the connecting customer beforehand (at least X hours). Currently Elering has two agreements with flexible capacity defined (Figure 34).

Date | Y-0 - 01.01.2021 00:00 - 01.01.2022 00:00 (EET) | Suund | Up

TIMESTAMP	PAINDLIK LIITUJA				
	STAATUS	EIC	NIMI	FIRM	FLEX
02.01.2021 00:00 - 03.01.2027 00	1	EIC1	[redacted]	38	2
02.01.2021 00:00 - 03.01.2027 00	1	EIC2	[redacted]	2	7.125

Figure 34 List of active flexible grid connection agreements

In order to have the flexible grid connection agreements visible and comparable with the other short- and long-term flexible contracts, Elering system is generating the short-term flexible contracts with prices as agreed between the customer and TSO (currently no price is paid for the flexible contracts, meaning 0 price is used – Figure 35).

TIMESTAMP	PAKKUMISE KOGUS DOWN			PAKKUMISE KOGUS UP		
	KOGUS (MW)			KOGUS (MW)		
04.12.2021 00:00 - 01:00				2,0000	0	ELERING
04.12.2021 00:00 - 01:00				7,1250	0	ELERING
04.12.2021 01:00 - 02:00				2,0000	0	ELERING
04.12.2021 01:00 - 02:00				7,1250	0	ELERING
04.12.2021 02:00 - 03:00				2,0000	0	ELERING
04.12.2021 02:00 - 03:00				7,1250	0	ELERING
04.12.2021 03:00 - 04:00				2,0000	0	ELERING
04.12.2021 03:00 - 04:00				7,1250	0	ELERING
04.12.2021 04:00 - 05:00				2,0000	0	ELERING
04.12.2021 04:00 - 05:00				7,1250	0	ELERING

Figure 35 List of generated bids based on Flexible grid contracts

The bids are generated with the meta-information shown in Figure 36 and are stored in local MO system.

Kogus (MW) data - 470354703					
LOODUD (EET)	**PRE VALUE**	**VALUE**	**LOCKED**	**KASUTAJA**	**KOMMENTAAR**
03.12.2021 10:26	0.0000	2.0000	-		

Metadata - 28546304	
METAKEY	**METAVALUE**
acquiring_area	10Y1001A1001A39I
business_type	C33
connecting_area	10Y1001A1001A39I
coordinated	
direction	A01
divisible	A02
domain	10Y1001A1001A94A
identification	ID_[redacted]2T 110_2021-12-03 22:00:00.000000
message_type	A37
receiver_identification	10X1001A1001A39W
receiver_role	A04
reserve_object	[redacted]
resourceprovider	10X1001A1001A39W
sender_identification	10X1001A1001A39W
sender_role	A27

Figure 36 Meta-information for the generated Flexible grid contracts

Generated bids are used for activation in specific grid limitation situations defined in the current grid connection agreements. The bids are also forwarded to IEGSA in order to store them in the same MOL with other flexible contracts. However, the activation of those bids can be made only in the Elering system due to contractual limitations set in the flexible grid connection agreements.

During the test case the following tests were run:

1. Adding the flexible grid agreements into local MO system.
2. Generation of the flexible contact bids for each hour of the MTU.
3. Sending the bids to the IEGSA system for visualisation of the common MOL.
4. No activation tests were held due to contractual limitations of the activation set in the flexible grid connection agreements.

The issues identified during the implementation were fixed during the development. As the testing was only held inside Elering and no other party was involved, there were no major errors to be reported.

4.8.2. Conclusions

During test case 1 and 2 the tests ran successfully and the flexible contract bids were generated. Bids were set as flexible contracts and were stored together with the other flexible short-term contracts.

From the testing it can be concluded that the existing principle of flexible grid contracts could be used in the flexibility services provision, however the contractual rights and obligations are generating some constraints in the business processes and activation conditions that limit the full implementation and testing of the solution.

The principle of 0-priced bids might create uneven involvement in the market and the process of setting the price for the contracts should be analysed in more detail. Furthermore, the active overview of the amounts available under the flexible grid connection agreements would need real time measurements in order to understand the amounts available at any given MTU.

Due to contractual conditions no activation was possible to be made as there were no specified power restrictions foreseen in the flexible grid contracts. The role of the aggregator for the flexible grid contracts is not defined and subsequent responsibilities of the notification and imbalance settlement for the regulating energy is not set in the current agreements. That means that any activation that would have been made would be considered a power restriction as defined in the grid connection agreement and the following imbalance generated would not be reimbursed to the flexibility provider for the regulating power.

This means that the role and responsibilities of the aggregator should be defined in the context of the flexible grid connection agreements in order to merge and align the business processes between the flexibility products (primarily related to CM) and flexible grid connection products. Possible options for assigning the responsibility could be:

1. Party connected to the grid;
2. Involving third party aggregator in the process;
3. SO taking the role of “technical” aggregator.

Also, the contracts should be reviewed from the activation condition perspective in order to make them accessible to other participants in the flexibility market. Removing the specific conditions would allow the contracts to be activated by other market participants.

4.9. Testing PTDF matrix-based grid qualification

4.9.1. Testing environment

The grid qualification service made by Cybernetica was tested by Elenia. The testing concentrated on confirming that the implementation of the qualification service corresponded to the specifications, worked in different kinds of situations that could happen during the live demonstration, and provided accurate qualification results. In order to test the qualification service, one must have access to the Swagger API. The authorization details (username and password) were acquired from Cybernetica.

The following steps needed to be taken in right order:

1) Log in to Swagger.
2) Upload topologies for both resource and bid qualification (use example template: Request with conducting-equipment). A new topology upload always replaces the old topology. Partial/incremental topology uploads are not possible.
    a. For simplified testing, identical topologies for both resource and bid qualification were uploaded during this test.
3) Upload sensitivity matrices. Uploading a sensitivity matrix with the same ID replaces the existing matrix with the same ID.
    a. PTDF matrix

    b. NVSF matrix
4) Upload forecasts (without flexibility) for conducting-equipment power flows and node voltages. Several intersecting forecasts can be uploaded, only the latest forecast for the studied time interval will be used.
5) Qualify resources or bids by uploading:
    a. Resource qualification request
    b. Bid qualification request.

Elenia's 19-bus test network shown in Figure 37 was used to test the PTDF matrix – based resource and bid qualification. The network contains examples of typical distribution network nodes and components ranging from TSO-DSO connection point all the way to metering points in LV network. Since only a small fraction of real distribution network metering points is present in this simplified network model and the upper-level components would otherwise be in a very light load, load injections representing the missing loads are added to the intermediary nodes. The total base load, before flexibility activation, is 12.790 MW (13.043 MVA) and Table 15 shows how this load is distributed to different nodes. All loads in the test network are assumed to have a power factor close to 0.98_{ind}.

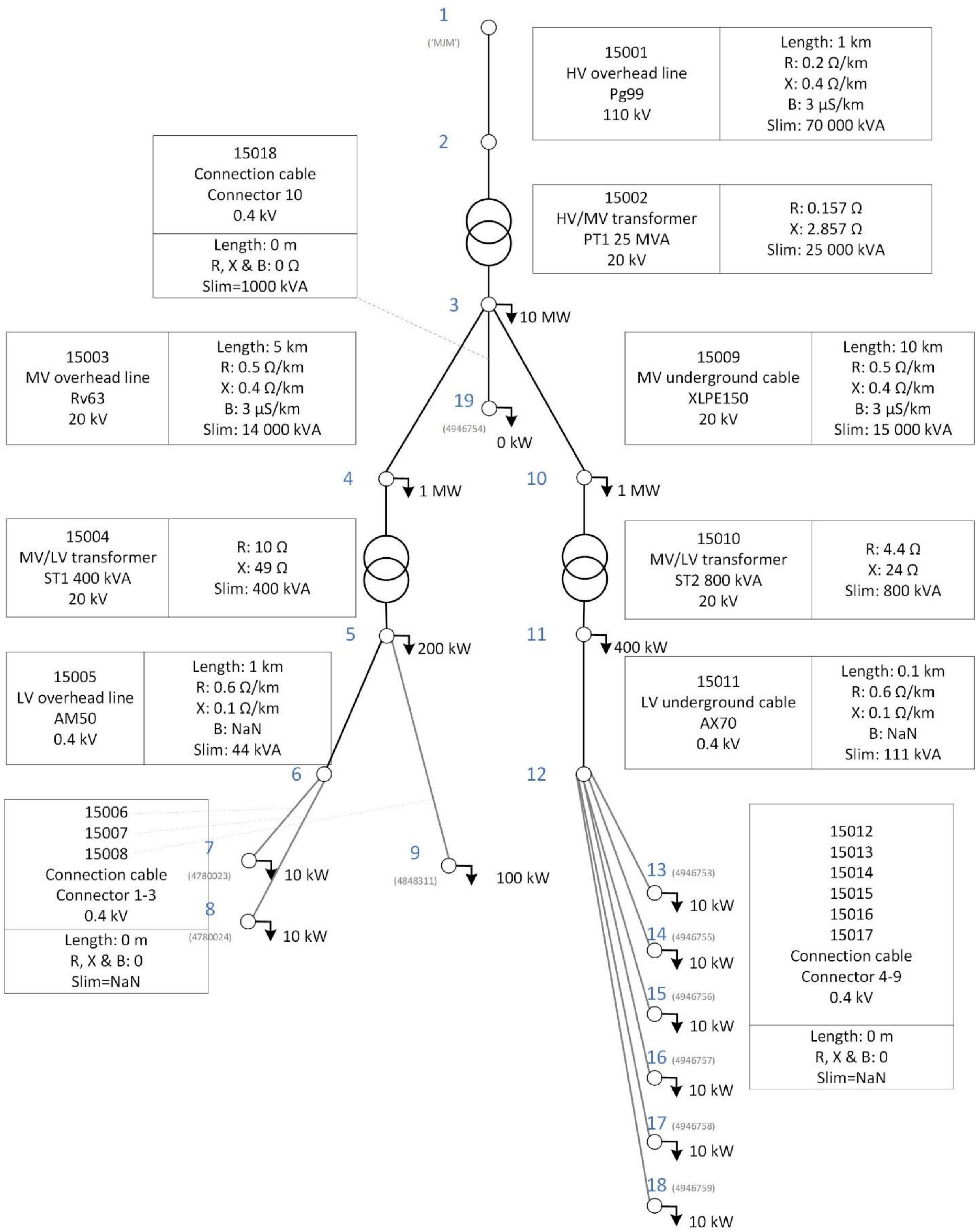


Figure 37 The 19-bus network used in testing

Table 15 Example network base loads

Node	Load kW	Load kVAr
1	-	-
2	-	-
3	10 000	2 000
4	1 000	200
5	200	40
6	-	-
7	10	2
8	10	2
9	100	20
10	1 000	200
11	400	80
12	10	2
13	10	2
14	10	2
15	10	2
16	10	2
17	10	2
18	10	2
19	-	-

Table 16 shows the network node and Table 17 the conducting equipment details. All other nodes and conducting equipment are fictional except the Marjamäki primary substation. The network is connected to TSO network through node "MJM" which is included into the predetermined list of available TSO-DSO connection points.

Table 16 Example network nodes

Node	Node ID	Node type	Node name
1	MJM	TSO_DSO_CONNECTION_POINT	Marjamäki
2	580001	HIGH_VOLTAGE_NODE	Marjamäki PT1 primary
3	580002	MEDIUM_VOLTAGE_NODE	Marjamäki PT1 secondary
4	580003	MEDIUM_VOLTAGE_NODE	400 kVA transformer primary
5	580004	LOW_VOLTAGE_NODE	400 kVA transformer secondary
6	580005	LOW_VOLTAGE_NODE	Connection point 2
7	4780023	LOW_VOLTAGE_NODE	Metering point 1
8	4780024	LOW_VOLTAGE_NODE	Metering point 2
9	4848311	LOW_VOLTAGE_NODE	Metering point 3
10	580006	MEDIUM_VOLTAGE_NODE	800 kVA transformer primary
11	580007	LOW_VOLTAGE_NODE	800 kVA transformer secondary
12	580008	LOW_VOLTAGE_NODE	Connection point 2
13	4946753	LOW_VOLTAGE_NODE	Metering point 4
14	4946755	LOW_VOLTAGE_NODE	Metering point 5
15	4946756	LOW_VOLTAGE_NODE	Metering point 6
16	4946757	LOW_VOLTAGE_NODE	Metering point 7
17	4946758	LOW_VOLTAGE_NODE	Metering point 8
18	4946759	LOW_VOLTAGE_NODE	Metering point 9
19	4946754	MEDIUM_VOLTAGE_NODE	Metering point 10 (MV)

Table 17 Example network conducting equipment

CE* ID	CE* type	CE* name
15001	HV overhead line	Pg99
15002	HV/MV transformer	PT1 25 MVA
15003	HV overhead line	Rv63
15009	MV underground cable	XLEP150
15018	Connection cable	Connector 10 (MV)
15004	MV/LV transformer	ST1 400 kVA
15005	LV overhead line	AM50
15008	Connection cable	Connector 3
15006	Connection cable	Connector 1
15007	Connection cable	Connector 2
15010	MV/LV transformer	ST2 800 kVA
15011	LV underground cable	AX70
15012	Connection cable	Connector 4
15013	Connection cable	Connector 5
15014	Connection cable	Connector 6
15015	Connection cable	Connector 7
15016	Connection cable	Connector 8
15017	Connection cable	Connector 9

*CE – conducting equipment

Table 18 Example network maximum and minimum node voltages

Node	Nominal voltage (kV)	Maximum voltage (kV)	Minimum voltage (kV)
1	110	121	99
2	110	121	99
3	20	21.1	19.7
4	20	21.1	19.7
5	0.4	0.44	0.36
6	0.4	0.44	0.36
7	0.4	0.44	0.36
8	0.4	0.44	0.36
9	0.4	0.44	0.36
10	20	21.1	19.7
11	0.4	0.44	0.36
12	0.4	0.44	0.36
13	0.4	0.44	0.36
14	0.4	0.44	0.36
15	0.4	0.44	0.36
16	0.4	0.44	0.36
17	0.4	0.44	0.36
18	0.4	0.44	0.36
19	20	21.1	19.7

The test network contains nodes with 110 kV, 20 kV and 0.4 kV nominal voltage. The maximum and minimum voltages of each node are listed in Table 18. In 20 kV network, Elenia aims to keep the node voltages between 19.7 and 21.1 kilovolts and in low voltage network the maximum and minimum limits come from the standard SFS-EN 50160 that allows ±10 % deviations from the nominal voltage (95 % of the time). In the following calculations, the voltage of the TSO-DSO connection point is assumed to be constant 1.055 p.u. (116.05 kV) and all transformers are assumed to operate in their nominal transforming ratio (all taps are in position ±0 %).

The conducting equipment impedances and thermal power flow limits (Slim) are shown in Figure 37. The node numbering in Figure 37 has been simplified so that the nodes range from 1 to 19. The actual node IDs used in the uploaded network topology files are shown in Table 16 and in case of metering points also in Figure 37 (below the simplified number).

In this test network, all connection cables are assumed to have zero impedance and infinite thermal maximum load. The connection cables connecting the electricity meters to connection points are not DSO property and are thus not modelled in the network information system. However, in cases where several metering points are connected to a single connection point, connection cables are necessary in the selected topology format.

The maximum amount of additional down- or upregulation each node can individually host before the network is congested due to power flow or node voltage constraints are shown in Table 19. Nodes 4, 6, 7, 8 and 10 are first constrained by the node voltage limit. In all other cases the power flow limits are limiting how much additional load or production can be added. The values in Table 19 are based on load flow calculation done with Power System toolbox (Matlab/Octave). The accuracy is such that these values (kW) do not cause congestion, but the next decimal value will cause congestion. The power limit, dictated by the minimum of power flow and node voltage limits, is shown in red.

Table 19 Limits for up- and downregulation based on load flow calculation

Node	Downregulation		Upregulation	
	Power flow limit	Node voltage limit	Power flow limit	Node voltage limit
1	-	-	-	-
2	56 960.5	980 069.4	82 859.3	1 537 279.2
3	11 161.9	12 930.4	37 228.0	54 820.9
4	10 035.2	2 338.9	16 419.4	5047.0
5	65.5	421.2	716.8	4 342.9
6	16.48	4.32	70.8	48.3
7	16.48	4.32	70.8	48.3
8	16.48	4.32	70.8	48.3
9	65.5	421.2	716.8	4 342.9
10	10 298.2	5 766.3	17 495.6	5738.6
11	321.2	2 906.9	1 257.6	7 811.6
12	45.7	195.1	174.7	305.5
13	45.7	195.1	174.7	305.5
14	45.7	195.1	174.7	305.5
15	45.7	195.1	174.7	305.5
16	45.7	195.1	174.7	305.5
17	45.7	195.1	174.7	305.5
18	45.7	195.1	174.7	305.5
19	1 000.0	12 930.4	1000.0	54 820.8

Table 20 shows the down- and upregulation limits achieved with custom made PTDF-based Octave calculation scripts. These values are later compared with the outputs of the qualification service. The results in Table 20 differ somewhat from the results in Table 19. Differences of this magnitude were expected. In case of upregulation, the errors are to "correct direction", meaning that less upregulation is accepted than the network can actually handle (safety margin). In some downregulation cases, the allowed downregulation is more than the network can handle. The reason for this has to be studied, so that sufficient safety margin can be guaranteed. This is however not the purpose of this document, here the goal is to test that Cybernetica's qualification service works as expected.

Table 20 Limits for up- and downregulation based on the PTDF matrix-based calculation in Octave

Node	Downregulation		Upregulation	
	Power flow limit	Node voltage limit	Power flow limit	Node voltage limit
1	-	-	-	-
2	57 042.4	Inf	82 792.4	Inf
3	11 764.3	8045.7	37 228.6	22 401.5
4	11 547.3	2681.9	15 046.7	4 547.3
5	66.5	447.0	702.2	2 391.3
6	17.6	4.25	52.9	38.0
7	17.6	4.25	52.9	38.0
8	17.6	4.25	52.9	38.0
9	66.6	447.0	703.5	2 391.3
10	11 569.7	6152.2	16 198.0	5 229.8
11	325.3	4424.6	1241.9	4399.3
12	46.3	213.2	162.8	268.6
13	46.3	213.2	162.8	268.6
14	46.3	213.2	162.8	268.6
15	46.3	213.2	162.8	268.6
16	46.3	213.2	162.8	268.6
17	46.3	213.2	162.8	268.6
18	46.3	213.2	162.8	268.6
19	999.9	8045.7	999.9	22 401.5

4.9.2. Resource qualification tests

Resource qualification (of one or more resources) is done by sending a request to endpoint, example of the request:


```
[
  {
    "metering-point": {
      "node-id": 4946754,
      "system-operator": "55X-00000000074F"
    },
    "capacity": {
      "max-down-regulation-kW": 1500,
      "max-up-regulation-kW": 0
    }
  }
]
```


The resource qualification request contains the sum of resource maximum regulation capacities of resources connected to a certain node. The maximum up- and downregulation values in the resource qualification request can be given simultaneously but in the following tests these are given separately, so that the results can be analysed in more detail. If both maximum up- and downregulation values are given simultaneously and the qualification of this resource fails, it's impossible to know from the response if the failure was caused by the upregulation, downregulation, or both. Below is an example of the response given by the qualification service. The information on failed nodes is later combined with resources in IEGSA and the qualification statuses of these resources are set to "Qualified with restrictions". The response message shows qualification results from TSO point-of-view, DSO point-of-view, and their aggregate:

```
{
 "transmission-system-operator-results": [],
 "distribution-system-operator-results": [
  {
   "passed-nodes": [],
   "failed-nodes": [
    {
     "node": {
      "node-id": "4946754",
      "system-operator": "55X-00000000074F"
     },
     "reasons": [
      "Power flow congestion on CONNECTION_CABLE connector 10 (MV)"
     ]
    }
   ],
   "system-operator": "55X-00000000074F"
  }
 ],
 "aggregated-results": {
  "passed-nodes": [],
  "failed-nodes": [
   {
    "node": {
     "node-id": "4946754",
     "system-operator": "55X-00000000074F"
    },
    "reasons": [
     "Power flow congestion on CONNECTION_CABLE connector 10 (MV)"
    ]
   }
  ]
 }
}
```


Test network nodes 7, 9, 18, and 19 were selected for detailed testing. Maximum downregulation capacity on these nodes was gradually increased, until the node failed the resource qualification. The reason for failure, either power flow congestion or voltage constraint, was read from the response. Then the capacity was gradually increased even more, until also the other reason for failure emerged. Table 21 shows what are the maximum values that pass the power flow and node voltage qualification individually on each node. The results are given with 1 kW accuracy, because the qualification service seems to omit all decimal values i.e. uses only integers.

Table 21 Maximum downregulation capacities that pass the PTDF matrix-based resource qualification

Node	Node ID	Limiting factor		Difference (kW) to table 6
		Power flow limit (kW)	Node voltage limit (kW)	
7	4780023	17	4	0 / 0
9	4848311	66	447	0 / 0
18	4946759	46	213	0 / 0
19	4946754	1000	8050	0 / +4

In all cases except one the results were exactly the same as the theoretical results calculated with Octave. In case of node 19 there was a 0.05 % error in node voltage limit based maximum capacity. This error was most likely caused by the rounding of the sensitivity factors sent to the qualification service. The node 7 correctly reached the node voltage limit before the power flow limit. It can be concluded, that in this case the qualification service works as expected.

Nodes 13–18 are connected to the same connection point with a zero-impedance connection cable, therefore maximum for the sum of downregulation capacity in these nodes is the same 46 kW (power flow limit) and 213 kW (node voltage limit) than in the case of individual node 18. Several different combinations for dividing the downregulation capacity to nodes 13-18 were tested, and whenever their sum exceed 46 kW or 213 kW, all nodes 13–18 with downregulation capacity failed due to power flow congestion or voltage constraint. In this respect, the qualification service worked as expected.

There is LV overhead line between nodes 7 and 9 but also in this case the qualification worked as expected. For example, if node 9 had a maximum downregulation capacity of 64 kW, only 2 kW of downregulation capacity could be added to node 7 without overloading the feeding MW/LV transformer. If node 9 had a maximum downregulation capacity of 50 kW, only 3 kW of downregulation capacity could be added to node 7 without causing voltage limit violations to nodes 6, 7 and 8 – these nodes are all connected with zero impedance connection cables and thus they all have the same voltage.

Table 22 shows results for the maximum upregulation values that pass the power flow and node voltage qualification individually on each tested node. The results are once again, extremely close to the expected values.

Table 22 Maximum upregulation capacities that pass the PTDF matrix-based resource qualification

Node	Node ID	Limiting factor		Difference (kW) to table 6
		Power flow limit (kW)	Node voltage limit (kW)	
7	4780023	52	38	0 / 0
9	4848311	703	2391	0 / 0
18	4946759	162	268	0 / 0
19	4946754	1000	22 400	0 / -1

Simultaneous qualification of several nodes worked similarly as in the case of downregulation. If the sum of maximum upregulation capacities exceeded the available free network capacity of some upstream conducting equipment, the qualification service correctly disqualified these nodes. The node voltage limits were also taken into account correctly. Table 23 contains some examples. Table 23 contains some examples.

Table 23 Combined upregulation capacities that pass the PTDF matrix-based resource qualification

Nodes	Combined limit (kW)	First limiting factor
7 & 8	38	Maximum voltage limit in nodes 6, 7 & 8
13-18	162	Power flow limit on underground LV cable between nodes 11 & 12
7 & 9	38-703	Depends on how the upregulation is divided between nodes 7 & 9 If division is e.g. 35 kW + 350 kW, the limiting factor is the maximum voltage in nodes 6, 7 & 8. If division is e.g. 20 kW + 700 kW, the limiting factor is power flow on the 400 kVA MV/LV transformer ST1.

4.9.3. Bid qualification tests

The bid qualification requests (without already qualified bids) sent to the qualification service follow the following format:


```
{
  "qualified-bids": [],
  "new-bids": [
    {
      "bid-id": "test-bid-1",
      "resource-group-id": "resource-group-1",
      "time-interval": "2021-10-13T14:00Z/2021-10-13T15:00Z",
      "quantity": 10,
      "direction": "A02",
      "product-type": "MFRR",
      "resources": [
        {
          "resource-id": "resource-in-node-9",
          "metering-point": {
            "node-id": "4848311",
            "system-operator": "55X-00000000074F"
          },
          "capacity": {
            "max-down-regulation-kW": 20,
            "max-up-regulation-kW": 20,
            "actual-up-regulation-kW": 20,
            "actual-down-regulation-kW": 20
          }
        }
      ],
      "energy-price-euro-kWh": 20.34
```

```
    }
  ]
}
```

For testing purposes, the strings “bid-ID”, “resource-group-id”, and “resource-id” can be any string. If bid contains several resources, the resource IDs must be unique. If the same resource ID is used for several resources, the CM qualification results are incorrect. Quantity is given in kilowatts. Direction “A01” means upregulation and “A02” means downregulation. The product type must be either “CM” or “MFRR”. Max-down/up-regulation-kW is used when qualifying mFRR bids. Actual-down/up-regulation-kW is used when qualifying CM bids. If either maximum or actual regulation capacity exceeds the bids total quantity, the maximum or actual regulation capacity value is replaced with the bid quantity.

If product type is mFRR, the response message from the qualification service is very simple. For qualified bids, it contains only the bid ID and time interval. The response messages for CM bids contains a lot more information since qualified and rejected bids are broken down into partial "child bids”. In practice this seems to mean that bid capacity per each node is given in the response message.

For example, bid’s total quantity 250 kW is provided by resources 9 and 19 that have actual capacities of 50 kW and 200 kW, respectively. Below nodes 1, 2 and 3 there is 250 kW of downregulation, and below nodes 4 and 5 there is 50 kW of downregulation. This information is later used in IEGSA to show to the CM buyer where the flexibility is located and how much flexibility is available on each network level. This helps SOs identify specific bids that could relieve congestions in the network.

The amounts of up- or downregulation that can be qualified without exceeding any power flow or node voltage limits were observed to be exactly the same as in the case of resource qualification – as they should be in this case – and therefore similar up- and downregulation tests were not repeated here. Instead, the following tests concentrated to functionalities specific to bid qualification. In case the CM bid is rejected, only the child bid that is responsible for the rejection is shown in the response message.

Summary of the already qualified bids is added to the beginning of the bid qualification request (see the example below). The already qualified bids must be summed to node level. Since these bids are already qualified, they cannot be rejected and are not shown in the response message. Only new bids can be rejected.

```
"qualified-bids": [
    {
      "metering-point": {
        "node-id": "4848311",
        "system-operator": "55X-00000000074F"
      },
      "capacities": [
        {
          "time-interval": "2021-10-13T18:00Z/2021-10-13T19:00Z",
          "capacity": {
            "max-down-regulation-kW": 10,
            "max-up-regulation-kW": 10
          }
        }
      ]
    }
  ],
```

Qualification with already qualified bids was tested and the qualification service was observed to work correctly. For example, when already qualified 20 kW downregulation bid existed at node 17, any new bid larger than 26 kW in node 18 was rejected due to power flow congestion. This is correct, because from resource qualification we remember that the sum of downregulation in nodes 13–18 should not exceed 46 kW. The time interval of the already qualified bid must overlap with the new bids, otherwise the already qualified bid doesn’t have any effect to the qualification of new bids.

If the combined effect of several bids causes network congestion, bids are rejected starting from the most expensive bids. Table 24 shows four different test cases. In these test cases, congestion occurs if the total downregulation exceeds 46 kW. In test cases 1–3 the qualification service rejects the bids in correct order.

Test case 4 is a bit more challenging since three bids have exactly the same price and only one of them can be qualified. No rules have been set how to do the bid selection in this kind of situation and therefore the qualification service does the selection between nodes 16, 17, and 18 quite randomly. The order in which the bids appear in the bid qualification request seems to have some effect which of these three bids gets qualified.

Table 24 mFRR downregulation bid rejection based on price

Test Case	Node	max-down-regulation-kW	energy-price-euro-kWh	Qualification status
1	15	30	15	Qualified
	16	60	20	Rejected
2	15	30	15	Qualified
	16	10	20	Qualified
	17	10	25	Rejected
3	15	30	15	Qualified
	16	30	20	Rejected
	17	30	25	Rejected
4	15	5	15	Qualified
	16	20	25	Rejected
	17	30	25	Rejected
	18	40	25	Qualified

Even if the bid qualification request contains both mFRR and CM bids, the qualification service handles them correctly and rejects the most expensive ones if the combined effect of mFRR and CM bids would otherwise cause congestions. For example, when qualification is requested for overlapping downregulation bids (30 kW mFRR bid priced at 15 €/kWh and supplied by resource in node 13; 20 kW CM bid priced at 25 €/kWh and supplied by resource in node 17), then the more expensive CM bid is rejected.

The maximum or actual regulation capacities of resources are used to determine whether or not the mFRR and CM bids, respectively, are qualified or rejected. However, in the case of CM bids the quantities of the child bids are limited so that they never exceed the quantity of the original bid. As an example, the following bid was studied:

- Quantity: 50 (kW)
- Direction: downregulation
- Resource in node 9
    - Max-down-regulation-kW: 100 (used in mFRR bid qualification)
    - Actual-down-regulation-kW: 100 (used in CM bid qualification)

The test network node 9 can handle only 66 kW of downregulation, and therefore this bid will be rejected whether or not it is mFRR or CM bid. This is a somewhat controversial result, since the bid quantity is only 50 kW and would not cause congestion if the resource is correctly controlled.

Arguments in favour of such implementation:

- In worst case situation, the 100-kW resource used in the example above can be controlled only on or off. Meaning that the FSP has to activate the whole 100 kW even if the bid quantity is only 50 kW. In this case, the selected procedure protects the network from congestions by using the correct capacity in the bid qualification.
- If the actual capacity of the resource is uncertain, and the penalties for non-delivery are very high, the FSP might want to bid less than 100 kW to be sure that the bid flexibility can be supplied.

Argument against such implementation:

- It is not economical for the FSP to make a 50-kW bid with a fixed 100 kW resource. If the resource output cannot be controlled continuously or in steps, the straightforward solution would be to make only 100 kW bids.

Since the child bids are limited to the quantity of the original bid, the amounts of flexibility the SO sees at different network locations is in theory correct, although the actual reliability of the delivery might be lower than what the FSP designed for the whole bid.

4.9.4. Test with 2-part distribution network

Topologically DSO networks are typically divided into several subnetworks connected to the TSO network. One DSO substation may be connected to one TSO-DSO connection point and another substation may be connected to another TSO-DSO connection point. Since these are, from DSO perspective, completely separated from each other's, two separate PTDF matrices can be given for these two networks. Working of the qualification service in this kind of a situation was tested with two extremely simplified test networks shown in
Figure 38. Each of these subnetworks had only two nodes and one conducting equipment.

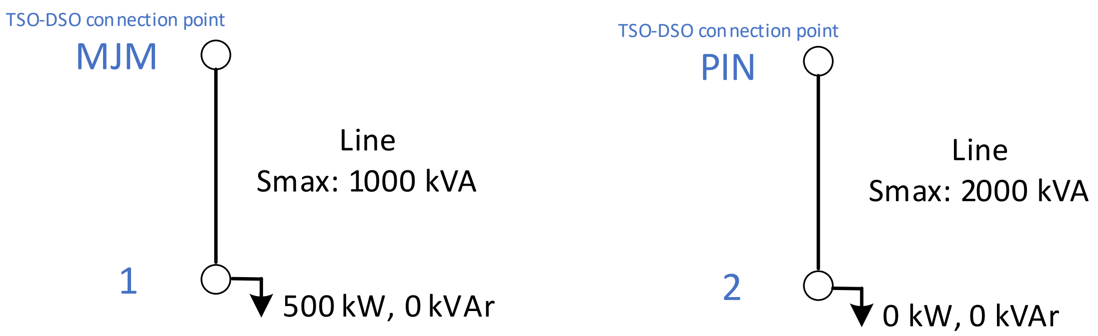


Figure 38 Very simple 2-part distribution network used in testing

The qualification service worked correctly also with the test networks shown in
Figure 38. For example, resources or bids in node 1 were rejected if their capacity exceeded 500 kW and resources or bids in node 2 were rejected if their capacity exceeded 2000 kW.

4.9.5. Combining TSO and DSO networks

As a TSO, Fingrid has uploaded a network topology that contains the TSO-DSO connection points and Elenia must connect the distribution networks to these points. The network topology uploaded by the DSO should not contain the TSO-DSO connection point as node, instead the distribution network is connected to the transmission network with a conducting equipment that connects the TSO-DSO connection point to the uppermost node in distribution network. To do this, the DSO must know the EIC code of the TSO it is connecting to. In Figure 37, the node “MJM” (node 1) is the TSO-DSO connection point and the first conducting equipment is defined as follows:

```
"conducting-equipment": [
```

```
{
  "connected-from-node": {
    "node-id": "MJM",
    "system-operator": "90X8002B1001B364"
  },
  "connected-to-node-id": "580001",
  "conducting-equipment-id": "15001",
  "conducting-equipment-type": "HV overhead line",
  "conducting-equipment-name": "Pg99",
  "max-apparent-power-flow-kVA": "70000"
},
```


TSO’s EIC

For rest of the conducting equipment, DSO’s own EIC code is used. If the TSO and DSO networks have been combined correctly, the response messages from resource and bid qualification show qualification results separately for both transmission and distribution networks.

5. Conclusions and lessons learned

Flexibility markets and TSO-DSO coordination have many novel aspects that were encountered and developed further during the INTERRFACE project. For most of these aspects, there were no previous references from other projects and initiatives on the level that is required for conceiving a functioning flexibility market with TSO-DSO coordination. Many pilot projects have tackled parts of the process, creating, for example, standalone flexibility markets for a single buyer. But when the coordination aspects are brought to the picture, a variety of new questions arise. The INTERRFACE project also contributed to the definition of new roles, including those not included in Harmonised Electricity Market Role Model yet. This work clarifies the different tasks of emerging flexibility markets and helps in assigning responsibilities in future implementations.

The Single Flexibility Platform demonstrator embarked on a task to bring together SOs procuring the same flexibility from multiple market platforms. An important enabler for this was a common flexibility resource register including prequalification information, and shared network information from all the involved grids. This adds a new level of complexity that the IEGSA platform needed to handle. The Finnish-Baltic demonstrator piloted this entirety successfully to validate its functioning. During the journey a lot of experience was gained, and future development needs identified.

The concept of TSO-DSO coordination, or flexibility coordination, has many different aspects to be considered. Firstly, it is in the SOs' common interest to coordinate the use of flexibility so that more harm is not caused when one problem is solved. This was the starting point for the grid qualification functionality of IEGSA system. Another aspect for TSO-DSO coordination is the ability to jointly procure flexibility which benefits more than a single grid operator. This part of coordination was left to future undertakings.

Another aspect of coordination can also be identified. When multiple actors utilize the same flexibility, coordination is needed to secure the integrity of the flexibility market. This starts from managing sufficient information about the market parties, or FSPs, and their resources. One side of coordination is also the arrangement of different markets and products that might overlap or offer bids to the common procurement of a service by the SOs. In this sense, it is crucial to have sufficient coordination in place to maintain liquidity of the markets without fragmenting them.

The coordination was one reason to connect existing and liquid marketplaces to the IEGSA in the demonstrator. In the Finnish-Baltic demo, CM was separated to two distinct products: operational CM and short-term CM. What came up when working with these two products was that they started to merge, since the timescales are overlapping while the service procured through them was the same. In the Finnish demonstration this materialized by the decision to combine the MOLs of the bids provided by the BMS and intraday platform. This again, demonstrates the benefit of gaining more supply on the market, when they are integrated and act as a whole.

The need for coordinating the SOs' use of flexibility is evident, but when looking at the situation in the demonstrator countries, it's easy to see that the actual need is not materializing in the near term. When the DSOs step into the flexibility market scene and start to use the flexibility in scale, the need emerges, and it is crucial to have the plans and structures how to handle the situation.

While the IEGSA platform is an important enabler for the TSO-DSO coordination process, it still requires significant development from the SOs to be able to utilize the functionalities. Firstly, the SOs need to be able to collect the needed grid information from various systems, process it, and supply it in the agreed format. Secondly, the SOs need to develop their forecasting capabilities and uncertainty management, so that they can procure flexibility at the right time and enough to solve the congestions with sufficient level of confidence.

The FSP perspective is equally important. The concept and tools developed within INTERRFACE provide a sufficiently streamlined solution especially for smaller FSPs to enter and participate in the market. Using the same product for balancing and congestion management enables to increase liquidity in the market and provide easier access to the market for FSPs. Both cross-service and cross-border integrations would be enabled. Facilitating factors are harmonised market processes (including product definitions), technical tools (like algorithms, software) and standards for interoperability.

The concept clearly enables not only the participation of FSPs of any size and technology, but also the participation of third-party Market Operators (whereas for mFRR it is currently TSO). Last-but-not-least, most obviously for mFRR product the cross-border harmonisation is increasingly required – commonly defined technical tools can support this. Also, future standardisation is proposed for congestion management product related data exchanges to support interoperability.

When the term 'flexibility service' is used, it is often referring to distributed flexibility for solving "local" issues which must consider the spatial aspect. While other use cases can also be regarded as flexibility services, such as balancing or BRP's portfolio management, the locational aspect brings whole new requirements for managing the flexibility market. This need was solved in the IEGSA processes by having a common register (Flexibility Register) for the flexible resources which again were connected to the grid models of the SOs. Without this information the processes would not work. Also, linking this information to the metering data collected from the resources, the verification of flexibility activations could be performed on the level of detail required to sufficiently reflect the spatial dimension reaching all the way to specific metering points.

Several lessons learned were gained also regarding the management of resources and resource groups in the Flexibility Register. Since all the bids refer to the resources registered in the register, the system must be able to handle the modification to the resources at any point of the process. The resources can be changed while there's a bid submitted to the market, or while it has been already accepted for activation, or after the activation when the bid is pending for settlement. For this reason, the IEGSA manages the changes to the resources and resource groups by assigning new identification numbers to each revision so that the process always refers to the correct version of the resources.

In the demonstrator, the concept of using highly granular information about the flexible resources and their location was investigated. In order to use flexibility for CM and perform grid prequalification, it is required to have exact information about resources and their location. From the market's perspective this aspect differs from other products. For example, in the demonstration countries also in the mFRR product portfolio bidding is applied. The child-bid concept tested by the demonstrator enabled the SOs to procure flexibility by the accuracy of single resources, which were broken down from the bids submitted by the FSPs. This allows the SOs to procure only the resources they need to resolve a local congestion. From the FSP's perspective this is an important aspect to be considered while bidding on the market.

For the DSOs the available flexible resources are often smaller distributed resources, e.g., electrical boilers, for which the behaviour is harder to forecast. This poses a risk to the FSP of not being able to deliver the promised flexibility, if they must use a specific resource instead of a pool. The conclusion regarding these aspects is that the FSPs need to knowingly make the decision when they are willing to make bids that are broken down to single units. Also, the tools for the SOs need to be developed further to enable fit for purpose size of the used resource pool for the need of both DSOs and TSOs. The IEGSA MOL provided the SOs with a view of bids in locations on different grid levels. This functionality has still room for improvement in order to manage the location more easily and prepare the system for a situation where there might be large number of bids, which need to be efficiently managed and displayed.

An important topic that was discussed among the demonstration partners was the exploitability and possible future options to take such flexibility enabling platforms into operational use. The first encountered barrier for the deployment of flexibility platforms is the current lack of flexibility need and the difficulty to estimate when it might appear on a scale which would require dedicated flexibility platforms, like the one tested in the INTERRFACE project.

On the other hand, the modular architecture developed in the project makes the threshold lower, because the deployment and ownership of different components can be shared in different ways and the deployment doesn’t require a massive go-live of a single system. Instead, some components can be developed with a faster pace while others follow later. One of the major barriers is still the uncertainty of the evolution of the regulatory model to incentivize the use of flexibility by the SOs. In all the demo countries, discussions were held with the regulators and officials to share the understanding on regulatory development and the possibilities offered by flexibility markets.

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