2020

System integration design for the Trade Permission System

DREM – DSO ROLE IN ELECTRICITY MARKET

D5.1 REPORT

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Introduction and objective

The objective for WP5.1 is to outline communication in detail and implement communication in IT systems.

The scope of this document

The scope of this document is firstly to develop a communication plan to Aggregator (AGR) and Transmission System Operator (TSO) to signal local grid congestion and thus the allowed trading for the radial in question, which places the DSO organizational in a controlling and market facilitating position. Furthermore, implementation of the communication plan and demonstrating the communication flow between the TSO, DSO, AGR and FLEXIBILITY ASSET. Similarly, the post-delivery service verification procedures and coordination will be tested. Time and resources spend on the actual trading is outside the scope of the project.

This WP is the practical layout of communication and implementation in IT system as a result of the conclusions in WP3 and requires that practical data communication between FLEXIBILITY ASSET, AGR and TSO is working.

Basic design

The basic design for communication system in DREM is as shown in figure 1 below.

The red lines are ICT information exchange between the **actors** (grey boxes) and the **systems** (blue boxes).

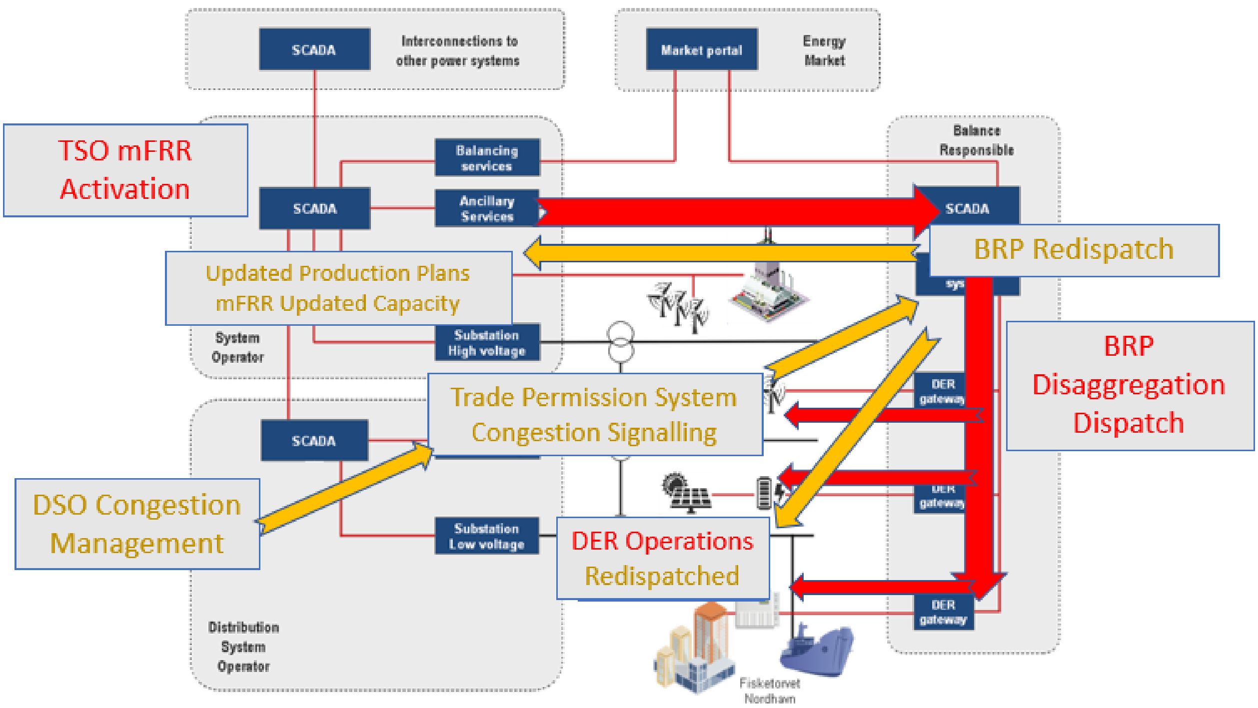

Figure 1 Basic ICT architecture

Responsibility and roles of the stakeholders

Here, a short description of the market actors and the proposed roles for each actor in the new market setup presented in figure 1, which also includes congestion management on DSO-level.

- **DSO**

  Distribution system operators (DSO) are the operating managers and owners of energy distribution grid. The voltage in DSO grid is from 0,4kV to 60kV.
  Participation in the system market, will ensure less congestion situations in the DSO grid, due to trading in the system market.
  With the DSO in the communication loop, the limitation of the grid is known by Aggregator. DSO customers will thereby know limitations day ahead and react to this.

- **AGR/BRP**

  Balance Responsible Parties (BRP) are responsible for balance between production and consumption in the grid. The Aggregator (AGR) has direct contact with FLEXIBILITY ASSET and trades in different system markets for these. In principle, the BRP could do both, or an independent AGR could trade for the FLEXIBILITY ASSET on its own or in cooperation with a BRP.

  Here, the BRP/AGR has information from the DSO, regarding limitations in the grid. This information will be handled by the AGR/BRP and will be implemented in the overall system market plan.

- **TSO**

  Transmission System Operator (TSO) fulfils the task of balancing the electricity grid at the system level. TSO buys the necessary energy hourly in the system market as well as other ancillary-, and non-ancillary services in other markets.

- **FLEXIBILITY ASSET**

  The flexibility asset can participate in the TSO-markets as well as DSO-markets. Here, the flexibility asset will due to the DSO planned limitations, participate in the TSO market with respect for DSO limitations. The overall result is that no customer will be disconnected from the grid due to trading in the TSO market.

Sequence diagrams

The Trade Permission System is designed to handle two separate cases, depending on whether a grid capacity problem is the result of a planned action such as e.g. scheduled maintenance ("foreseen"), or whether the problem arises on short notice, such as e.g. due to equipment failure or a mismatched load forecast ("unforeseen").

These two cases result in two different patterns of information exchange between actors and are therefore discussed separately throughout this document.

Foreseen Capacity Issues

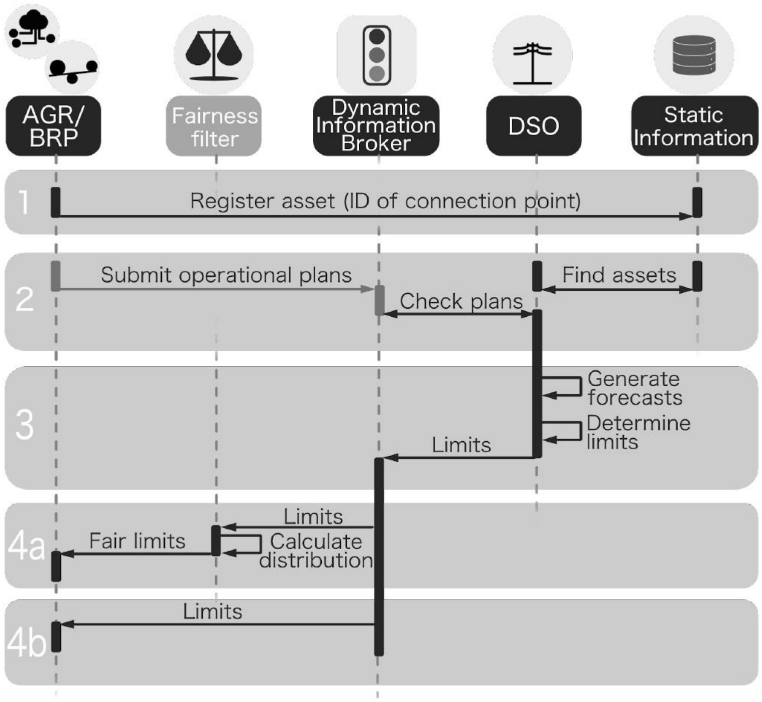

Figure 2 Communication of Foreseen Capacity Issues

As illustrated in 'Figure 2 Communication of Foreseen Capacity Issues', the information exchange due to foreseen capacity issues involves two independent communication sequences executed at two different points in time: A continuous but irregular update of the flexibility asset register (static information system), and a time-triggered and regular interaction between AGR/BRP and DSO.

Flexibility asset register update

Step 1: This update should happen whenever flexibility assets are connected to or disconnected from the power grid, or if a flexibility asset gets reassigned to a different operator. The AGR/BRP updates the static Information system with information about the flexibility assets that they operate. The information includes the point of grid connection of the flexibility asset, its operating range and an anonymized hash code indicating which AGR/BRP operates the flexibility asset.

AGR-DSO interaction

Step 2: On a regularly basis (e.g. daily), the DSO will query the static information system for a list of flexibility assets with connection points within its network.

Likewise, on a regular basis, AGRs/BRPs voluntarily submit operational plans for individual flexibility asset to the Dynamic Information Broker. These plans reflect the production and/or consumption planned for the flexibility assets. The DSO periodically retrieves these operational plans from the broker.
While submitting operation plans is not mandatory, regular and accurate submission is in the AGRs/BRPs self-interest. It will greatly help the DSO when determining capacity issues. Without any operational plans, the estimations must include a greater safety margin, causing the DSO to allow less operational flexibility due to the increased uncertainty.

Step 3: Based on knowledge about scheduled maintenance of the distribution grid, historical power flows in the grid and the operational plans submitted by the AGRs/BRPs, the DSO estimates the expected power flows in the grid and determines limits to available grid capacity on a per-feeder or per-flexibility asset basis These limits are then submitted to the Dynamic Information Broker. Limits may be imposed directly for individual flexibility asset, or on a list of flexibility assets, e.g. for all flexibility assets on an entire feeder.

Step 4: The Dynamic Information Broker de-anonymizes the mapping of flexibility asset to AGRs/BRPs and communicates the capacity limits to the respective AGR/BRPs. In cases where there are flexibility assets from multiple AGRs/BRPs affected by the same limit, the Trade Permission System (TPS) should ensure a fair distribution of the burden, at least on average and over time **(variant 4a)**. A sub-module of the TPS called a "fairness filter" is used to distribute flexibility limitations between all AGR/BRPs having flexibility asset e.g. on a network feeder. The DREM project considers the exact definition of "fairness" to be a regulatory matter and therefore to be out of scope for the project. The proof-of-concept implementation only provides a simple sharing mechanism to demonstrate feasibility, based on the ratios of total flexible capacity between all AGRs/BRPs in the affected section of the grid.
If all resources in a section belong to the same AGR/BRP, or if a regulator decides that strict fairness is not required, the fairness filter can be removed **(variant 4b).**

Unforeseen Capacity Issues

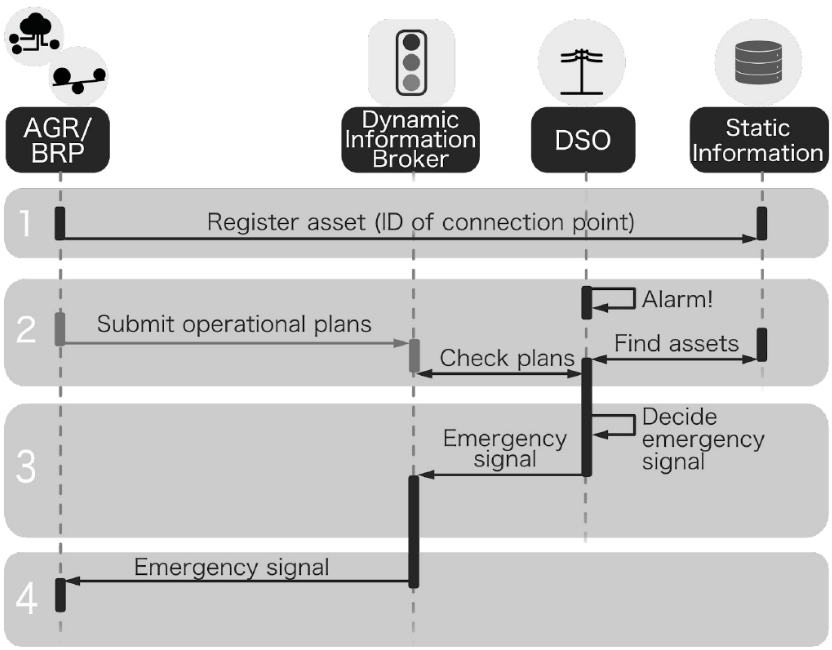

Figure 3 Communication of Unforeseen Capacity Issues

The response to an unforeseen capacity issue is simpler than the foreseen case, as figure 3 illustrates. However, unlike in the foreseen case, three independent communication sequences are involved: A continuous but irregular update of the flexibility asset register (static information system), a time-triggered and regular submission of operational plans by the AGR and an event-triggered and irregular interaction between DSO and AGR.

Flexibility asset register update

Step 1: As in the foreseen scenario, the AGR or BRP updates the Static Information system with information about the flexibility asset that they operate. Ideally, this happens every time flexibility assets are connected to or disconnected from the power grid, or if flexibility assets get reassigned to a different operator. The information includes the point of grid connection of the flexibility asset, its operating range and an anonymized hash code indicating which AGR/BRP operates the flexibility asset.

Update of operational plans

Step 2: Meanwhile, and on a different but regular schedule, AGRs/BRPs voluntarily submit operational plans for individual flexibility assets to the Dynamic Information Broker. These plans reflect the production and/or consumption planned for the flexibility assets.

Response to unforeseen event

Step 2 (continued): The DSO detects an abnormal event in the power grid which could result in a severe situation, if not mitigated promptly.
The DSO requests a list of flexibility assets connected to the affected feeder. For the sake of speed, this information may have been previously fetched and processed by the DSO as part of a regular (e.g. hourly) schedule, such that the list would already be available in a system local to the DSO.
The DSO then requests the operational plans for the listed flexibility assets by querying the Dynamic Information Broker. Alternatively, this information could also be a regularly updated and cached regardless of any existing events, in order to speed up the response time.

Step 3: Based on the operational plans and type of affected flexibility assets, the DSO determines one of several possible mandated actions for each flexibility asset or group of flexibility assets. Potential actions include to hold production or consumption constant, to increase or decrease the power level, or to start or stop units. This action list is sent to the Dynamic Information Broker.

Step 4: The Dynamic Information Broker de-anonymizes the mapping of flexibility assets to AGRs/BRPs and distributes the emergency signal to the AGR/BRPs on a per-flexibility asset basis. As response speed is essential in this case, the unforeseen response will not be passing through a "fairness filter". Instead, the DSO decides directly which flexibility asset should respond in which way.

Requirements for DREM data communication

The DREM data communication use cases are being tested and validated using a proof-of-concept (PoC) implementation of a communication platform.

The requirements to the platform are collected in two groups: functional and non-functional.

Functional requirements are the main features that users would expect from the system, i.e. what the system should do. For example, if the system is an online to-do list application, it should be possible to create a new list, add an item to a list, remove an item from a list, etc.

Non-functional requirements are not straight forward requirement of the system. In some way they are related to the usability of the system. With the example of an online application a major non-functional requirement would be availability, e.g. the application should be available 24/7 with no down time.

The requirements reflect the solutions proposed by the "D2.2 Workshop Report Final" document:

Solution acronym	Solution name
R-1	Registration of FLEXIBILITY ASSET on the Datahub
R-2	Redefining the DSOs installed capacity obligation
R-3	Aggregators must be attached to a BRP
R-4	DSOs are not required to reimburse for trade interruptions
R-5	DSOs are not responsible for redispatch impact
M-1	Use of flexibility markets for DSO services
M-2	Redefinition of services to include rebound
C-1	Establishing a dynamic information broker for allowing the DSO to communicate limits to BRP/AGR
C-2	AGR/BRPs submit operational schedules

Table 1

Functional requirements

F1 - Standardised communication

Communication within the platform SHALL be according to the international standard IEC 62351-503 (MADES Market Data Exchange Standard).

The platform SHALL provide an ECP Component Directory, an ECP Broker and three ECP Endpoints (one per backend as specified in requirement 'NF1 - Grouping of functionality').

The messages communicated SHALL be using XML documents as specified in 'IEC 62325-451 Framework for energy market communications. As the documents have been designed to exchange power grid related information between Transmission System Operators (TSO), it MAY be necessary to extend the documents with additional information. If such extensions are necessary, they SHALL follow the rules of extensions as specified in the IEC 62325 documents.

Messages SHALL only be communicated indirectly between AGR/BRP and DSO modules (i.e. with the platform as mediator; communication SHALL NOT take place between the AGR/BRP and DSO modules directly.

F2 - Web service interfaces

The AGR/BRP and DSO backend implementation SHALL provide a REST/HTTP based interface that simplifies the sending and receiving of the standardised messages. The interfaces SHALL be specified using the RESTful API Modelling Language (RAML).

The AGR/BRP interface SHALL include the following functionality:

- ping: for checking if the interface is available, SHALL respond with pong

- set, update, get and delete the configuration of a flexibility asset (ref. 'F4 - Registration of flexibility assets' for details)
- set, update and cancel operational plans for a flexibility asset (ref.: 'F8 – Sending operational schedules' for details)
- get relevant capacity limit plans (ref.: 'F7 – Retrieving capacity limits' for details)

The DSO interface SHALL include the following functionality:

- ping: for checking if the interface is available, SHALL respond with pong
- get list of flexibility assets (ref.: 'F5 – List available flexibility assets' for details)
- set, update and cancel capacity limits (ref.: 'F6 – Sending capacity limit' for details)
- get operational plans (ref.: 'F9 – Receiving operational schedules' for details)

F3 - Web based graphical user interface

The DREM-TPS backend SHALL provide a graphical web interface that can be used for demonstration purposes.

It SHALL provide a display of:

- operational plans sent by a selected AGR/BRP
- capacity restrictions sent by a selected DSO
- possible implications between operational plans and capacity restrictions

F4 - Registration of flexibility assets

This requirement is described in the D2.2 Workshop Report as" R-1 Registration of flexibility units on the Datahub"

The DSOs has to know which flexibility assets are connected to the power grid and where in the grid the flexibility assets are connected. This information is provided by the AGR/BRPs which operate the flexibility assets.

For the DSOs to be able to only receive information about flexibility assets connected to the power grid that the DSO operates, the DSO needs to provide information about the electrical connection points in their respective grid.

Flexibility asset registration message

The message communicated SHALL include the following information:

- the ID of the flexibility asset
- who operates the flexibility asset
- the ID of the electrical connection point of the flexibility asset
- the capabilities of the flexibility asset; whether the flexibility asset is producing and/or consuming, and the maximum power it can produce or consume

The content and structure of the message SHALL be as specified in IEC 62325-451-N Ref_MarketDocument.

The message SHALL be communicated as specified in requirement'F1 - Standardised communication'.

Electrical Connection Point registration message

In order to allow a DSO to get a list of flexibility assets connected to their power grid, the DSOs need to register electrical connection points with the platform. Such a message SHALL include the following information:

- the ID of the DSO
- the IDs of electrical connection points in their grid

The content and structure of the message SHALL be as specified in IEC 62325-451-N Ref_MarketDocument.

The message SHALL be communicated as specified in requirement'F1 - Standardised communication'.

F4a – DREM-TPS backend

The DREM-TPS backend SHALL be able to receive and process the messages specified in requirement'F4 - Registration of flexibility assets'.

F4b – AGR/BRP backend

The AGR/BRP backend SHALL provide a REST interface for sending flexibility asset information messages to the DREM-TPS backend, as specified in the requirement 'F4 - Registration of flexibility assets - Flexibility asset registration message'.

The REST interface SHALL implement endpoints to provide the following functionality:

- set the information about a flexibility asset
  - SHALL allow setting one or more flexibility assets in a single endpoint call
- get information about a flexibility asset
  - SHALL allow listing one or more flexibility assets in a single endpoint call
- update the information about a flexibility asset
  - SHALL allow setting one or more flexibility assets in a single endpoint call
- remove information about a flexibility asset
  - SHALL allow removing one or more flexibility assets in a single endpoint call

F4c – DSO backend

The DSO backend SHALL provide a REST interface for sending electrical connection point registration messages to the DREM-TPS backend, as specified in the requirement 'F4 - Registration of flexibility assets - Electrical Connection Point registration message'.

The REST interface SHALL implement endpoints to provide the following functionality:

- set the information about a connection point
  - SHALL allow setting one or more connection points in a single endpoint call
- get information about a connection point
  - SHALL allow listing one or more connection points in a single endpoint call
- update the information about a connection point
  - SHALL allow setting one or more connection points in a single endpoint call

- remove information about a connection point
    - SHALL allow removing one or more connection points in a single endpoint call

F5 – List available flexibility assets

This requirement is described in the D2.2 Workshop Report as" C-1 Establishing a dynamic information broker for allowing the DSO to communicate limits to BRP/AGR"

In order for the DSO to communicate limits to the AGR/BRP, the DSO need knowledge about flexibility assets connected to the power grid.

Get flexibility asset list message

The message for requesting a list of available flexibility assets SHALL include the following information:

- the ID of the DSO

The structure of this message is specified in IEC 62325-451-5 StatusRequest_MarketDocument.

Flexibility asset list message

The message that provides a list of available flexibility assets SHALL include the following information:

- the ID of the DSO that operates the power grid that the listed flexibility assets are electrically connected to
- a list of flexibility assets, where each flexibility asset SHALL be described by
    - the ID of the flexibility asset
    - the ID of the electrical connection point

The message SHALL NOT include details on the operator of the flexibility asset.

The structure of this message is specified in IEC 62351-451-N Ref_MarketDocument.

The messages SHALL be communicated as specified in requirement 'F1 - Standardised communication'.

F5a – DREM-TPS backend

The DREM-TPS backend SHALL be able to receive and process the message specified in requirement 'F5 – List available flexibility assets - Get flexibility asset list message'.

The DREM-TPS backend SHALL be able to generate and send the message specified in requirement 'F5 – List available flexibility assets - Flexibility asset list message'.

F5b – DSO backend

The DSO backend SHALL provide a REST interface for listing available flexibility assets, as specified in the requirement 'F5 – List available flexibility assets'.

The REST interface SHALL implement endpoints to provide the following functionality:

- get the current list of flexibility assets
    - SHALL return all flexibility assets connected to power grid that the DSO operates
- get changes when the list is updated
    - SHALL return with an empty list after a while if the list has not changed since the request was made
    - SHALL return with a list only including new or changed flexibility assets, when the list has been changed

F6 – Sending capacity limit

This requirement is described in the D2.2 Workshop Report as" C-1 Establishing a dynamic information broker for allowing the DSO to communicate limits to BRP/AGR"

It allows a DSO to indirectly notify an AGR/BRP about limitation in available capacity in the power grid.

This requirement deals with two scenarios:

1) Foreseen: scheduled maintenance of a substation will result in the station being disconnected from the grid, hence limiting the available capacity in a section of the power grid
2) Unforeseen: an unscheduled event, e.g. an internal component of a substation forces a power line disconnect

The foreseen message SHALL include the following details:

- flexibility assets affected by the incident
- the capacity available for use by these flexibility assets
- the time period when the capacity is limited

The unforeseen message SHALL include the following details:

- flexibility assets affected by the incident
- the action required by these flexibility assets; the action SHALL indicate either start, stop or hold
- date/time when the incident is expected to be dealt with, hence the power grid returning to normal operation

The structure of the message is specified in IEC 62325-451-6 Unavailability Market Document

The messages SHALL be communicated as specified in requirement'F1 - Standardised communication'.

F6a – DREM-TPS backend

The DREM-TPS backend SHALL be able to receive and process the messages described in requirement'F6 – Sending capacity limit'.

Based on the listed flexibility assets in the message sent by the DSO, the DREM-TPS backend SHALL forward the message to any AGR/BRP that controls one or more of these flexibility assets. Capacity limits SHALL be fairly divided between flexibility assets.

F6b – DSO backend

The DSO backend SHALL be able to generate and send the messages described in requirement' F6 – Sending capacity limit'

The DSO backend SHALL provide a REST interface for sending foreseen and unforeseen capacity limit plans to the DREM-TPS backend, as specified in the requirement'F6 – Sending capacity limit'

The REST interface SHALL implement endpoints that provides the following functionality:

- sending a foreseen capacity limit message
- sending an unforeseen capacity limit message
- sending an update to a foreseen capacity limit message
- sending an update to an unforeseen capacity limit message
- cancelling/deleting a foreseen capacity limit message
- cancelling/deleting an unforeseen capacity limit message

Parameters for the messages to be send are described in requirement'F6 – Sending capacity limit'.

F7 – Retrieving capacity limits

This requirement is described in the D2.2 Workshop Report as" C-1 Establishing a dynamic information broker for allowing the DSO to communicate limits to BRP/AGR"

It provides an AGR/BRP with knowledge about limitations in the power grid that may affect the operation of connected flexibility assets.

The content and structure of the messages SHALL be as defined by requirement'F6 – Sending capacity limit'

The message SHALL be communicated as specified in requirement'F1 - Standardised communication'.

F7a – AGR/BRP backend

The AGR/BRP backend SHALL be able to receive and parse the messages described in requirement'F7 – Retrieving capacity limits'

The AGR/BRP backend SHALL provide a REST interface for requesting foreseen and unforeseen capacity limit plans, as specified in the requirement'F7 – Retrieving capacity limits'

The AGR/BRP backend SHALL implement REST endpoints for the following functionality:

- get capacity limit schedules limited by time
    - SHALL return all schedules received by the platform within a specified period of time
    - SHALL only return schedules relevant for the AGR/BRP
- get capacity limit schedules that are currently active
    - SHALL return all non-expired schedules
    - SHALL only return schedules relevant for the AGR/BRP
- wait for new capacity limit schedules that are currently active
    - SHALL block until timeout or a new schedule is available
    - SHALL return all non-expired schedules that has been received by the AGR/BRP backend since the last time this endpoint was addressed
    - SHALL only return schedules relevant for the AGR/BRP

F8 – Sending operational schedules

This requirement is described in the D2.2 Workshop Report as" C-2 AGR/BRPs submit operational schedules"

It allows an AGR/BRP to inform DSOs about planned energy production and consumption, which can help the DSO to more precisely estimate if capacity issues will arise in their power grid.

The message SHALL include the following information:

- the ID of the AGR/BRP
- list of flexibility assets; for each flexibility asset, the following information SHALL be provided:
  - ID of the flexibility asset
  - a schedule, where positive values is 'production' and negative values is 'consumption'

The content and structure of the message SHALL be as specified in IEC 62325-451-6 GL_MarketDocument.

The message SHALL be communicated as specified in requirement'F1 - Standardised communication'.

F8a – DREM-TPS backend

The DREM-TPS backend SHALL be able to receive and process the messages described in requirement'F8 – Sending operational schedules'.

Based on the listed flexibility assets in the message sent by the AGR/BRP, the DREM-TPS backend SHALL reorganize the message into a message per DSO and send these messages to the respective DSO.

F8b – AGR/BRP backend

The AGR/BRP backend SHALL be able to generate and send the message described in requirement'F8 – Sending operational schedules'

The AGR/BRP backend SHALL provide a REST interface for sending operational plans messages, as specified in the requirement'F8 – Sending operational schedules'

The AGR/BRP backend SHALL implement REST endpoints for the following functionality:

- sending an operational schedules message for one or more flexibility assets
- sending an update to an operational schedules message for one or more flexibility assets
- cancelling/deleting an operational schedules message for one or more flexibility assets

F9 – Receiving operational schedules

This requirement is described in the D2.2 Workshop Report as" C-2 AGR/BRPs submit operational schedules"

It provides a DSO with knowledge about planned energy flows, that will help the DSO in estimating if issues could arise in their power grid.

The DSO can get the schedules using two methods:

1. by sending a request to the platform
2. by waiting for an AGR/BRP to send new schedules

Message request

The message for requesting operational plans from the platform, SHALL include the following information:

- the ID of the DSO

The content and structure of the message SHALL be as specified by IEC 62325-451-5 StatusRequest_MarketDocument.

The message SHALL be communicated as specified in requirement'F1 - Standardised communication'.

Schedules message

The message for receiving operational plans, SHALL include the following information:

- the ID of the DSO
- a list of flexibility assets; for each flexibility asset, the following information SHALL be provided
  - the ID of the flexibility asset
  - a schedule, where positive values indicates feeding energy to the grid and negative values indicates removing energy from the grid

The message SHALL NOT include information about who operate the flexibility assets

The content and structure of the message SHALL be as specified by IEC 62325-451-6 GL_MarketDocument.

The message SHALL be communicated as specified in requirement'F1 - Standardised communication'.

F9a – DREM-TPS backend

The DREM-TPS backend SHALL be able to receive and parse the message described in requirement'F9 – Receiving operational schedules : Message request'.

It SHALL respond with a message as described in requirement'F9 – Receiving operational schedules : Schedules message'.

F9b – DSO backend

The DSO backend SHALL be able to receive and parse the message described in requirement'F9 – Receiving operational schedules : Schedules message'.

The DSO backend SHALL provide a REST interface for requesting and waiting for operational plans, as specified in the requirement'F9 – Receiving operational schedules : Message request'.

The DSO backend SHALL implement REST endpoints for the following functionality:

- get operational schedules for one or more flexibility assets
  - SHALL only return schedules for flexibility assets connected to the DSOs grid
- Waits for new operation Schedules
  - SHALL block until timeout or a new schedule is available
  - SHALL return all schedules that has been received by the DSO backend since the last time this endpoint was addressed

- SHALL only return schedules for flexibility assets connected to the DSOs grid

Non-functional requirements

NF1 - Grouping of functionality

The PoC SHALL consist of three main groups of functionalities:

- An AGR/BRP backend, that an AGR or BRP can use to communicate with the platform
- A DSO backend, that a DSO can use to communicate with the platform
- A DREM-TPS backend, that implements the Static Information and Dynamic Information Broker functionality.

NF2 - Platform architecture

All modules of the platform SHALL be deployed in Docker or Kubernetes.

NF3 – Platform privacy

The platform SHALL prevent an actor from getting information that belongs to another actor. E.g. AGR#1 SHALL NOT be allowed to retrieve information provided by AGR#2.

Expected results

In delivery 7a, a series of prefeasibility tests are presented. These tests were performed in ELN as part of a use-case as HOFOR and Radius cooperated for congestion management in the outskirts of Nordhavn. The same partners are working in the DREM project, but with additional aid from the university (DTU Elektro), a BRP (Markedskraft) and a Software developer (EURISCO). These results form the foundation for further field-testing in DREM.

Expected results and technical challenges

The tests in ELN were performed manually – i.e. cooperation between HOFOR and Radius for when to enable flexibility from a flexibility asset to perform congestion management. This was performed in a foreseen and unforeseen scenario.

In the foreseen scenario, HOFOR prepared the facility for increased electricity consumption by Radius indicating 24-hours ahead when flexibility was needed. Here, full flexibility from the storage tank, the DH grid and the consumers could be utilized.

In the unforeseen scenario, HOFOR did nothing prior to the activation from Radius, and at a specific time, Radius would call HOFOR to ask for flexibility, and HOFOR would provide the flexibility, which were possible at the time.

The tests did show some interesting phenomena, but the setup was too rigid for utilizing in practice. Hence, the communication structure and concepts developed in DREM are paramount to ensure technical feasibility of controlling flexibility assets intelligently to the benefit of DSO's. This is valid for communication from the DSO, communication with the BRP, and automatic control of the flexibility asset. Here, standardization of the communication is also paramount to ensure that different heat pumps – and flexibility asset in general, can be utilized with the same standardized communication of data.

Expected results and economical challenges

The financial consequences are outlined in d7a. The main findings are represented in the following figure:

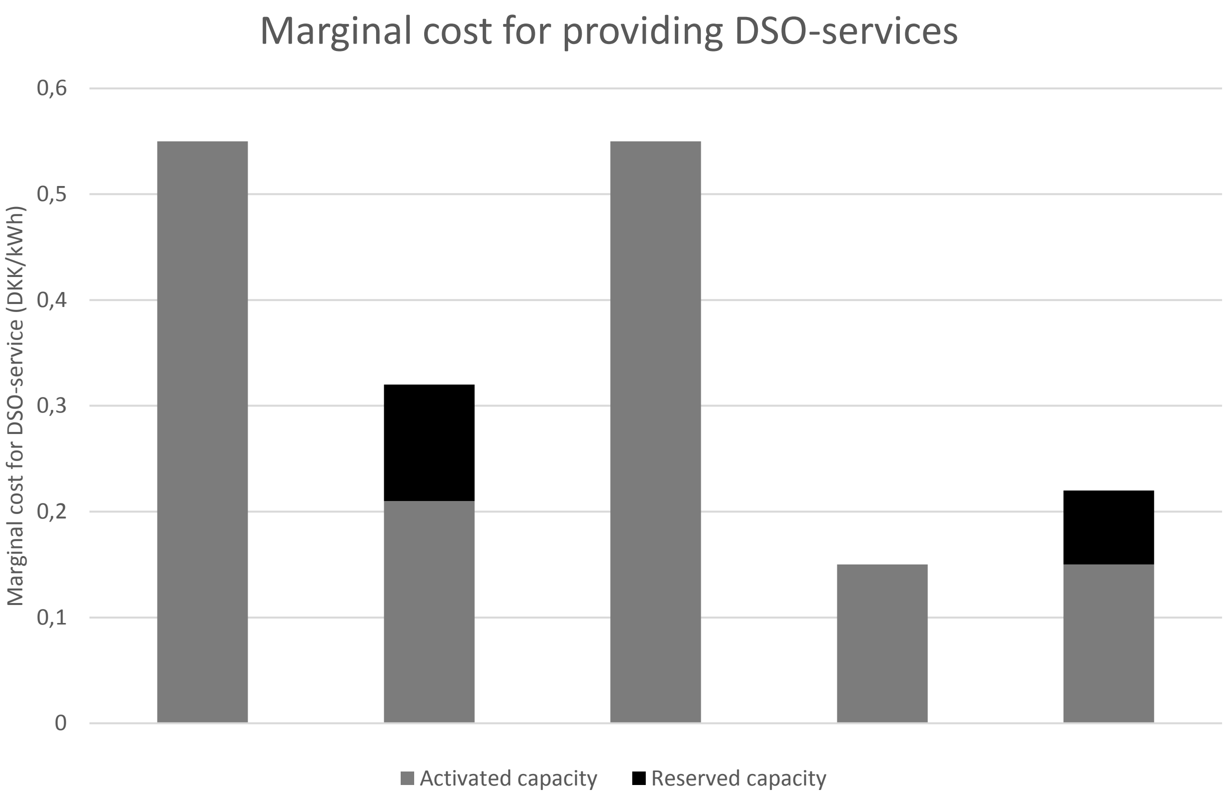

Figure 4: Prefeasibility study for economic consequences from performing upwards- and downwards regulation to the DSO from a FLEXIBILITY ASSET.

Figure 4 shows the economic consequences for generalized examples for upwards regulation and downwards regulation. Here, the quantity and quality of supply for downwards regulation are deeply linked with reservation of capacity, as the only option to provide flexibility of the storage tank is fully charged is electric boiler boost – hence making it increasingly expensive.

For upwards regulation, interruption of the facility would, in worst case, result in manual starting of oil-fired boilers, making it very expensive.

The main takeaways from the prefeasibility study are that if DSO-services from a FLEXIBILITY ASSET is procured beforehand, risk for excessive costs can be mitigated and quality of supply can be more easily ensured.

Plan for testing DREM Trade Permission Concept

Overall description

The Trade Permission System requirements include generic requirements as well as specific functional ICT systems requirements for TPS core components: the dynamic broker and flexibility asset database.

The overall requirements are listed in Table 2.

#Req.	Requirement Title	Addressed by Test / assessment
R-1	Registration of flexibility units on the Datahub	*Conceptually validated in RISØ demo and simulation.*
R-2	Redefining the DSOs installed capacity obligation	*Simulation to quantify impacts*
R-3	Aggregators must be attached to a BRP	*[Markedskraft fulfils both roles]*
R-4	DSOs are not required to reimburse for trade interruptions	*Open Discussion - Simulation assessment to quantify impacts*
R-5	DSOs are not responsible for redispatch impact	*Open Discussion – N-1 Simulation assessment to quantify impacts*
M-1	Use of flexibility markets for DSO services	*-- / out of scope: hypothetical market functions*
M-2	Redefinition of services to include rebound	*-- / out of scope: applies to market services*
C-1	Establishing a dynamic information broker for allowing the DSO to communicate limits to BRP/AGR	*TPS system, validated in Risø Demo, and concept verified in long-term simulation.*
C-2	AGR/BRPs submit operational schedules	*Risø demo; End-to-end Test*

Table 2

To evaluate the proposed solution, DREM has planned a number of different tests and simulations. The outcome of these evaluations is aimed to qualify different aspects of the proposes solutions:

1. Can the proposed system be realized, are the available stakeholder systems ready to interface with DREM, and can the TPS required system interfaces implemented with available standards and technology?
2. What are the impacts of Trade-permission activations on long-term operation? How frequent would such activations be? Where is the trade-off between increased grid capacity and limiting Flexibility assets under N-1 conditions?
3. Given the validation of TPS core components, how do the actual business systems of a BRP (Markedskraft) and a Flexibility Asset (here: HOFOR FlexHeat) need to be interfaced to realistically respond to the designed TPS signals (foreseen and unforeseen)

Integrated system validation

In this testing configuration, the test system is distributed geographically across three locations: Several flexible loads are in the SYSLAB laboratory at DTUs Risø campus, the Trade Permission System is located on EURISCOs premises in Odense, and the MKPlanner aggregator platform is operated from Markedskrafts offices in Aarhus. A software client running at DTU campus is used to emulate a DSO, announcing capacity limits. These four entities are connected over the internet through interfaces specified in WP6, such that

- MKPlanner can control the power setpoints of the flexibility asset in SYSLAB
- the DSO emulator can commit capacity limit requests to the Trade Permission System
- the Trade Permission system can distribute the capacity limit requests to MKPlanner

The test objective is to validate the correct flow of information between these four entities. The scope is limited to the interaction with the Dynamic Information Broker (steps 2-4 in the sequence diagrams), i.e. not including the Static Information System. It is assumed that the DSO "already knows" the flexibility asset it is requesting capacity limitations for. For the purpose of this test, the control loop remains open at the

DSO side, i.e. there is no link between the flexibility asset setpoints, and the capacity limits requested by the DSO emulator.

The following tests should be executed:

- Test whether the power consumption/generation of the flexibility asset follows the setpoints issued by the aggregator (MKPlanner). A schedule containing several step responses is generated and executed by the aggregator while the power flow across the unit terminals is logged at an enough time resolution. Schedule and measurements are compared afterwards. Success criteria are a response time which is consistently below a maximum threshold (e.g. 10s), and a maximum setpoint deviation which is consistently below another threshold (e.g. twice the unit accuracy).
- Test whether capacity limits submitted by the DSO emulator are correctly and consistently represented in the Trade Permission System. A set of both foreseen and unforeseen capacity limit requests is generated, including some that overlap in time or between sets of units, or both. The requests are submitted one at a time, and the set of active limits is read from the Trade Permission System after each request. The sequential TPS readouts are then compared to the set of active limits expected from the set of input requests submitted at that point in time. The sole success criterium is a complete match for all readouts.

Tests for capacity limits submitted by the DSO will cause flexibility asset production/consumption to rise or fall as expected. A constant schedule is generated and executed by the AGR for all flexibility assets, such that the combined power flow exceeds a certain threshold value X by a margin dX. The DSO emulator will then execute a limit request for a maximum power level of X. After the request has been processed by the Trade Permission System and the AGR, the combined output of the flexibility asset should reduce by dX. This should be conducted with both foreseen and unforeseen capacity limits. Success criteria are a response time which is consistently below a maximum threshold (e.g. 1min), and a maximum deviation of the reduction from dX which is consistently below another threshold (e.g. twice the sum of unit accuracies).

Scenario based validation

The testing configuration for the scenario-based validation is identical to the integrated system validation, with the addition of a power grid to which the flexibility asset is now connected. The grid topology is chosen to emulate an urban distribution feeder which can be supplied from transformers at both ends and is equipped with a disconnector at about half its length. This enables the feeder to be operated in its normal configuration as two independent half feeders with the disconnector open, each supplied through its own transformer. In case of e.g. a transformer fault at one end, the disconnector can be closed, enabling all customers to be supplied from the other (unaffected) end. In this configuration, the capacity of the feeder will be reduced and may require DSO intervention.

For this test, the software client emulating the DSO is extended to measure power flows across different locations on the feeder, and to indicate if the capacity of the feeder is exceeded.

The test objective is to validate the ability of the Trade Permission System to mitigate a capacity issue in a concrete scenario. Like in the integrated system validation, the scope is limited to the interaction with the Dynamic Information Broker (steps 2-4 in the sequence diagrams), i.e. not including the Static Information System. It is assumed that the DSO "already knows" the FLEXIBILITY ASSET it is requesting capacity limitations for. In this test, the control loop is closed at the DSO side.

The following tests should be executed:

- Test whether the Trade Permission System mitigates a foreseen capacity issue. Two types of schedules are generated and executed by the aggregator: One set of flexibility asset S1 will follow a generic load profile while the other set of flexibility assets S2 will execute an upward step at a time where the generic load profile generates high loading of the feeder. The magnitudes used for the schedules should be chosen such that the maximum power flow caused by S1+S2 is within the capacity of the divided feeder, but above the capacity of the single-fed feeder. Furthermore, the power flow caused by S1 alone should be within the capacity of the single-fed feeder, such that a reduction of S2 to zero will free enough capacity to move the single-fed feeder from an overloaded to a normal state. The test will be run with the feeder in the normal (divided) configuration. The DSO will then submit a foreseen capacity limit for a specified time interval, according to the maximum capacity of the single-fed feeder. As a response, the AGR should generate a new schedule for the units in S2 such that the total power flow drops below the capacity limit at the specified time. Success criteria are a time deviation of the power flow reduction from the time requested by the DSO which is consistently below a maximum threshold (e.g. 10s), and a maximum upwards deviation of the power flow from the requested capacity limit which is consistently below another threshold (e.g. twice the unit accuracy).
- Test whether the Trade Permission System mitigates an unforeseen capacity issue. The test is executed with the same sets of units S1 and S2 and load profiles identical to the previous tests. The test will be started with the feeder in the normal (divided) configuration. After the flexibility assets in set S2 have increased their power according to schedule, the feeder topology is changed to the single-fed configuration in order to respond to a simulated fault at one end. The DSO will then submit an unforeseen capacity limit, according to the indicated amount of feeder overload. As a response, the AGR should immediately generate a new schedule for the units in S2 such that the total power flow drops below the capacity limit. The sole success criterion is a maximum upwards deviation of the post-intervention power flow from the requested capacity limit which is consistently below another threshold (e.g. twice the unit accuracy).

Simulation-based scenario assessment

The system configuration for this assessment is like the “scenario-based validation” with a loop consisting of two 10 kV distribution feeders. The configuration includes a DSO, an aggregator and a flexibility asset. The flexibility asset is modelled on HOFOR’s FlexHeat system, with a two-level control system to represent both physical dynamics and predictive optimization. The feeder model is based on an actual network in Nordhavn where FlexHeat is connected, with load profiles based on metered data from 2017 and 2018. In order to emulate random faults locations, the model includes the individual cable segments in the feeder.

DSO requests are generated automatically based on expected congestions. The TPS messaging functionality is implemented such that the aggregator (predictive optimization) receives DSO restrictions either on a day-ahead basis (foreseen capacity issue) or immediately (unforeseen capacity issue). Scheduled setpoints are exchanged with the local controller. In line with the overall project scope, the design of aggregator solutions for multiple household level flexibility assets has been excluded. Multiple FlexHeat units could however be simulated.

The main objective of this simulation-based assessment is to anticipate the overall impact of a TPS mechanism on flexibility asset operation as well as on distribution network operations, as opposed to scenarios where a TPS is not available. This objective is derived from stakeholder questions at the DREM workshops: How often would a TPS be used to impose restrictions on flexibility assets? What are the expected costs incurred by the AGRs/BRP/FLEXIBILITY ASSET due to a TPS activation? And how much would a DSO be relieved from congestion caused by increasing coincidence factors?

In addition to these key metrics, the assessment observes the impacts on heat loads being served or under-supplied and whether the available interventions were enough to relieve congestion situations.

To reduce the computational burden, the assessment is carried out only for systematically selected “representative days” which cover the typical load patterns in the considered distribution feeders.

The simulation-based assessment shall contribute to informing the following identified requirements:

- R-1 : the registered static information about flexibility assets meets the minimal information requirements for the DSO decision process.
- R-2: The capacity adjustments performed by the DSO are quantitatively compared to the impacts on flexibility asset operation.
- R-4 and R-5: Future discussions about regulatory measures concerning compensation are supported by quantifying the cost of impact on operational schedules.
- C-1 : The reimplementation of TPS within the simulation framework serves as an independent validation of the TPS specifications.

The results of the simulation-based assessment are reported in deliverable D7b.

End to end test with FlexHeat

The field-test on FlexHeat are ensured by communication between the actors in real-time and based on plans. More elaborate descriptions are found in d7a and d6.3. The important takeaways are the data-streams:

- Communication of plans between the BRP and facility
- **IEC 61850** for real-time data exchange towards the facility
- **IEC 62325** for market-based data exchange towards the BRP

Here, a set of standardized communication set-points were defined to ensure that it would be applicable for any flexibility asset. For heat pumps, this also indicated that the standardized communication of data would allow any heat pump to be remotely controlled even if the contractor of the heat pump has different methodology of setting a capacity on the heat pump depending on the technology. This is important as we see now that the control of the FlexHeat facility is different from the control of the newest heat pump addition to HOFOR, SVAF. This heat pump is a 5 MW seawater and/or sewage water heat pump, which has a different methodology of implement an electricity consumption. The standardized interface would thus handle both situations.

FlexHeat activation in a foreseen scenario

A field-test scenario were executed on site, and further economic optimization and extensions were performed afterwards to illustrate a more general perspective on the scenarios. These scenarios were considered only with day-ahead markets, indicating conflict case 5 and 8, and also scenarios with ancillary services indicating conflict case 4.

The foreseen scenario was handled in two-stages:

1- Exchange of plans
2- Real-time data communication

In the first stage, figure 5 explains the flows:

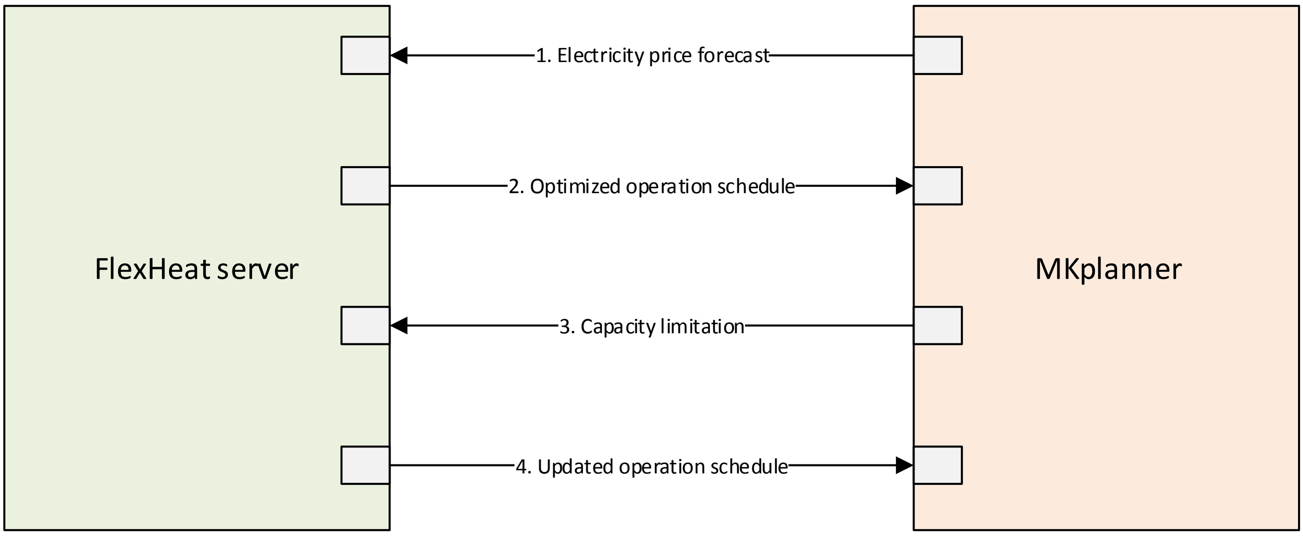

Figure 5: Planning of the foreseen scenario between the FLEXIBILITY ASSET and BRP.

Here, the following points are valid:

1. Firstly, electricity price forecast is delivered to HOFOR for the next 48 hours. An additional option could also be to deliver FCR-N price forecasts.
2. Secondly, these are utilized in an optimization model of the FlexHeat system, which schedules an optimal pattern for electricity consumption given the demand situation in the area. This optimization performs a 48-hour optimization but only utilizes the next 24 hours – this is done in order to find the optimal level in the storage tank for the coming days as well. These are delivered to the BRP.
3. Next, the BRP delivers a capacity limitation plan based on the demand from the DSO. This plan issues how much the facility can use of its maximum capacity for each hour.
4. The optimization model is rerun with the capacity limitation to figure out a new optimal production pattern given the constraint. This updated schedule is delivered to the BRP and afterwards executed.

A more detailed description of this setup can be found in d7a. Furthermore, the BRP performs smaller intraday corrections in the setup in cooperation with the flexibility asset.

FlexHeat activation in an unforeseen scenario

The unforeseen scenario is built on top of the foreseen scenario in regard to communication. Here, step 3. and 4. in figure 5 are omitted as there are no DSO constraints in day-ahead.

Here, the BRP can enforce a capacity constraint for the flexibility asset throughout these 24 hours, and thus generate an unforeseen scenario with sudden restrictions on the FLEXIBILITY ASSET.

More details on the methodology for the BRP to enforce a restriction on behalf of the DSO is indicated in d7a and the DSO demand is detailed in d7b. Also, in d7a, the costs inflicted on the flexibility asset are also presented to broaden the view on delivery of DSO-services.

Concluding remarks

The TPS design proved to work satisfactorily. The test described in D7.b was performed without significant problems with the TPS design.