

Milestone 4

2.08 Grid OS Flexibility Market Simulation

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Scottish & Southern
Electricity Networks



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Contents

1	Executive Summary.....	2
2	GridOS DSP: Flexibility Market Simulations	2
2.1	The GridOS Approach.....	3
2.2	Flexibility Services Simulation	4
2.2.1	Users	4
2.2.2	Services	4
3	Flexibility Market Simulation - DSP Walkthrough.....	0
3.1	Step 1: Market Setup	0
3.2	Step 2: Flexibility Resource Utilisation Bid and Offer Submission	1
3.3	Step 3: Initiate Simulation.....	3
3.3.1	Market Operation (Day-Ahead and Intra-Day Utilisation Evaluation).....	4
3.4	Step 4: Settlement	6
3.4.1	Settlement Calculation.....	6
3.5	Step 5: Review Results and Exit	7

1 Executive Summary

Project MERLIN investigates the economic implications of utilising flexibility in planning for the grid of the future, and operating markets that use distributed energy resources (DER) to realise those plans.

To evaluate various market scenarios related to utilising flexibility in day-ahead (DA) and intra-day (ID) time frames, Opus One has collaborated with SSEN to develop a tool to model flexibility market simulations. The simulations will be achieved through Opus One's GridOS Distributed System Platform (DSP).

GridOS DSP creates flexibility requests based on contracts submitted by participants against scenarios inclusive of load forecasts, generation forecasts, and a network model supplied by SSEN.

This software is a step beyond traditional market simulation approaches in that it utilises the SSEN network model to create a security constrained flexibility utilisation solution, ensuring that current, power, and voltage limits are respected while flexibility is utilised to meet grid needs.

Flexibility that achieves the grid needs outlined by Project MERLIN is deemed economical if, among other considerations, utilisation and availability costs are lower than the cost of a traditional solution. The cost of the traditional solution that the flexibility resources are being evaluated against is modelled within GridOS Integrated Distributed Planning (IDP), deployed alongside the DSP in a separate workstream as part of project MERLIN.

This report is organised into two chapters, covering the following aspects:

Section 2: GridOS DSP: This section details the objectives of the tool, the data requirements and provides a detailed process flow walkthrough

Section 3: Details the simulated market modelling: This section provides detail around the components of the market simulation modelling with GridOS DSP

2 GridOS DSP: Flexibility Market Simulations

Electricity market simulation software has traditionally focused on the transmission system. These transmission system software tools enable evaluation of the large generators and loads that define transmission market planning. In evaluating network impacts, these solutions generally evaluate one-way power flow from transmission system assets to distribution system networks.

Generally, these transmission markets software packages make assumptions about the power system that are relevant to the transmission system, such as single phasing and balanced power flow, that are not applicable to the distribution system without simplifying the problem in ways that potentially limit distributed energy resources (DER) utilisation.

Distribution level markets are enabled by DER that both modify their energy consumption and inject energy into the distribution system. Injections of energy into the distribution network alter load shape in aggregate, and potentially cause two-way flow within networks.

This altered load shape created through use of DER is key to understanding the total system impact of distributed resources, and accurate simulation of this altered load shape requires a bottom up

understanding of the impacts of these DER. Determination of the shape is based on DER saturation and the markets that determine permissible transactions between those DER.

Determining the impact of the DER can be performed in various ways. The utility can own and operate the resources, the resource owners can choose to operate them based on contracts between each other, or a system can exist to determine safe operation of those resources within the bounds of the contracts struck by the resources.

The system allows users to input flexibility bids and offers for various power services, and then output a utilisation schedule for those resources based on the submitted bids and offers and the utility's need, as described by the load and generation scenarios loaded into the software and the physical needs of the network.

Due to the novel nature of distribution system markets, an approach that allows prosumers to learn the implications of changing bids and offers is crucial to market animation. Instead of launching a market and expecting the users to learn-by-doing, SSEN will hold workshops that demonstrate the implications of various bids and offers through live participation of the to-be-prosumers that will enable the to-be-business-models trialled by TRANSITION, LEO, and MERLIN.

2.1 The GridOS Approach

The DSP evaluates day-ahead and intra-day markets for flexibility utilisation based on DER penetration, system load and generation scenarios submitted by the utility, and bids and offers submitted against the DER by representative prosumers.

For MERLIN, the services include:

- DSO Constraint Capacity
- Offsetting / Peer to Peer (P2P)
- DSO Peak Management
- Maximum Import / Export Capacity Trading (formerly Authorised Supply Trading Capacity)
- Historic Service

The utility's network model is the foundation of all the analysis of services utilisation performed. The model defines the system's capabilities to host and allow for import or export through asset ratings such as voltage and current limits. DER are added to the model at nodes specified by either prosumers or utility staff.

The network model and load and generation profiles define a scenario.

Within a scenario, the DER operator defines the flexibility utilisation bids and offers for the services being trialled within the market.

Each service will be active for a period specified by the bid and offer submitted by the user. Each service's utilisation cost will be evaluated based on the price submitted by the user.

The market administrator will decide the time interval to simulate through the software. This interval will be bounded by the scenario submitted.

Flexibility bids and offers will be paid a market clearing price (i.e., all offers below the highest offer that clears are paid the price of the highest offer) or paid-as-bid (i.e., all resources paid their offer).

The DSO user will initiate market evaluations and create market scenarios, and the market participant users will compete to determine market outcomes.

2.2 Flexibility Services Simulation

2.2.1 Users

Industry actors engaged in the energy transition are the DSO, ESO, and DER owner/operator peers. For the Project MERLIN exercises, only the DSO and DER owners and operators will be simulated.

Opus One's software will allow participating users to act as DER owners/operators as well as the DSO. Flexibility services will be submitted by the users simulating DER owner/operators. Flexibility service evaluation will be initiated by the user acting as the DSO.

2.2.2 Services

The DER owner/operators will submit bids and offers through the software to simulate utilisation request creation in response to scenarios created by the DSO.

The flexibility services that will be trialled in this simulation are a subset of those identified in "Transition – Services in a Facilitated Market"¹ (TSFM) and detailed in Table 1.

Service Name	Service Description	Trigger	Flexibility Price	Flexibility Quantity
DSO Constraint Management	Generation increase or demand reduction to mitigate effect of a network constraint	Optimal Power Flow (OPF) Analysis requests service based on utilisation contract	>£0/MWh for utilisation of service, submitted by DER operator	Able to supply up to the MW quantity stated, or reduce demand by the quantity stated
Offsetting / P2P	MW consumption at one entity and generation at another in equal and opposite quantities over the same duration.	Flexibility participant requests to purchase or sell for a defined time period	N/A	One participant submits bid, other submits an offer for the same quantity and price.
Peak Management	Generation increase or demand reduction to mitigate effect of peak demand on an asset	OPF Analysis requests service based on utilisation contract	>£0/MWh for utilisation of service, submitted by DER operator	Able to supply up to the MW quantity stated, or reduce demand by the quantity stated
Marginal Import Capacity (MIC) / Marginal Export Capacity (MEC) Trading	Connectivity rating (i.e. connected kVa) increase or decrease in network model at node associated	Flexibility participants submit requests that are then implemented in the network model	N/A	Flexibility participant states quantity of KVA increase/decrease

¹ <https://ssen-transition.com/wp-content/uploads/2019/08/TRANSITION-Task-4.5-Services-in-a-Facilitated-Market-v3.0.pdf>

	with flexibility resource			
Historic Service	Bilateral contract between DNO and a participant for supply during constrained periods	OPF analysis requests service based on utilisation contract	£0/MWh	Able to supply up to the MW quantity stated, or reduce demand by the quantity stated

Table 1: Flexibility Services to be offered in MERLIN

Table 2 details how these flexibility services will be implemented and the result from GridOS.

Service Name	Implementation	Result
DSO Constraint Management	Load forecast states that additional service is needed on network, due to a planned / unplanned outage. Resources with availability are called upon to provide the service.	GridOS evaluates a cost minimising dispatch of flexibility to reduce loading on feeder or substation, then posts those results to the user interface.
Offsetting	Bid from load asset contained within network model. Offer from generation asset contained within network model. GridOS can model whether the bids and offers clear. In cases in which both submit quantities that don't fully clear, the market will supply the balance unless constrained with the offsetting purchase and below the constrained service price.	GridOS evaluates whether offsetting transactions are physically feasible, may reduce quantity from up-to amount to what the OPF permits for entire service area.
Peak Management	Load forecast states that additional service is needed on network. Resources with availability are called upon to provide the service.	GridOS evaluates a cost minimising dispatch of flexibility to reduce loading on feeder or substation, then posts those results to the user interface.
Marginal Import Capacity / Marginal Export Capacity Trading	Change to the connected KVA model, and now a new network model for the utilisation simulation.	New network model is generated with new connected KVA limits. The utilisation market is run with those as the new connected KVA limits for those days.
Historic Service	Resource offers its output to the DSO at a price per MWh. DSO utilises the service if required as per load forecast.	GridOS evaluates a cost minimising dispatch of flexibility to reduce loading on feeder or substation, then posts those results to the user interface.

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Table 2: Flexibility Services Results & Implementation

3 Flexibility Market Simulation - DSP Walkthrough

GridOS DSP is a web-based tool that allows users to simulate a flexibility market by inputting a network model for the market to define constraints, a market scenario to define supply and demand in the system, and flexibility offers to enable smart solutions to mitigate the constraints that result from the market scenario.

3.1 Step 1: Market Setup

Prior to each market simulation, the market administrator will define a flexibility scenario through input of the following data:

- 1) A distribution network model, created or modified through GridOS IDP as necessary.
 - a. If Marginal Import Capacity (MIC)/Marginal Export Capacity (MEC) transactions take place during the offline portion of the simulation, then those MIC/MEC transactions may result in a change to the connected capacity of specified nodes in the simulation. The DSO user will make update the network model analysed by the software.
- 2) A load data series for each network model, hourly for day-ahead (DA) and intra-day (ID) time frames.
 - a. DA, hourly
 - b. ID: one of 5-min, 15-min, or hourly
- 3) A generation data series for each intermittent generator in the network model, hourly for DA and ID time frames.
 - a. DA, hourly
 - b. ID: one of 5-min, 15-min, or hourly

In addition to data input, the market operator will define the following market operation rules:

1. Intra-Day interval length (5-min, 15-min, hourly)
2. Market Pricing algorithm (pay-as-bid, pay-as-clear)



Figure 1: Market setup interface with components to submit load and generation data sets

3.2 Step 2: Flexibility Resource Utilisation Bid and Offer Submission

Once the market scenario has been created, the next step is input of resource participation parameters.

Participants can select to remove a DER from the market, or input its participation parameters through bids and offers. For Battery Energy Storage Systems (BESS) resources, the user selects a checkbox to allow the market to set the resource's participation based on the BESS asset parameters rather than bids and/or offers submitted by the resource.² If the checkbox is selected for a BESS resource, user-entered bids and offers for that BESS resource are ignored, shown in Figure 3 below.

² These automated, optimised schedules for BESS will minimize the cost to resolve constraints through use of BESS, but will not impact the market energy cost.

My Assets

Active 6
Inactive 0

Edit
Enroll Asset

☐ Deactivate

Name	Status	Type	Email	Email Notification
<input type="checkbox"/> Battery 1	Enrolled	BESS	gridos-market-participant2@gridos.com	<input checked="" type="checkbox"/>
<input type="checkbox"/> FlexMarket	Enrolled	BESS	gridos-market-participant2@opusonesolutions.com	<input checked="" type="checkbox"/>
<input type="checkbox"/> FlexMarket	Enrolled	BESS	gridos-market-participant2@opusonesolutions.com	<input checked="" type="checkbox"/>
<input type="checkbox"/> Offsetter_Gen_1	Enrolled	BESS	gridos-market-participant2@gridos.com	<input checked="" type="checkbox"/>
<input type="checkbox"/> Offsetter_Load_1	Enrolled	BESS	gridos-market-participant2@gridos.com	<input checked="" type="checkbox"/>
<input type="checkbox"/> Photovoltaic 2	Enrolled	PhotoVoltaic	gridos-market-participant2@gridos.com	<input checked="" type="checkbox"/>

Figure 2: Resource enrolment setup interface for participants to remove resources from market

Users can submit bids and offers in one of two ways:

1. Standing: These bids and offers can be thought of as representing the procurement commitment of each flexibility resource for a flexibility service. These bids and offers will be utilised for each DA market run, as well as each ID market run. DA and ID interaction are detailed in Section 3.4.1 below.
2. Datetime Specific: Participants can specify a different quantity as well as price for days within their availability period through datetime specific bids and offers.

Configuration ☐ Allow market operator to manage battery charge and discharge schedules

Day Ahead

Standing Offer ☐ Use single price/quantity pair ☒ Use timeseries Delete Save

Start time (America/New_York)	End time (America/New_York)	Bid/Offer	Price (USD/MWh)	Quantity (MW)	Delete
00:00:00	01:00:00	Offer	50	0.7	
01:00:00	02:00:00	Offer	50	0.7	
02:00:00	03:00:00	Offer	50	0.7	
03:00:00	04:00:00	Offer	50	0.7	
04:00:00	05:00:00	Offer	50	0.7	
05:00:00	06:00:00	Offer	50	0.7	
06:00:00	07:00:00	Offer	50	0.7	
07:00:00	08:00:00	Offer	50	0.7	
08:00:00	09:00:00	Offer	50	0.7	
09:00:00	10:00:00	Offer	50	0.7	
10:00:00	11:00:00	Offer	50	0.7	
11:00:00	12:00:00	Offer	50	0.7	

Previous
Page 1 of 2
Next

Figure 3: Market Participant User Procurement Bid/Offer

3.3 Step 3: Initiate Simulation

After the required data have been submitted to the DSP, the market administrator may specify a simulation analysis time period (bounded by the input data).

After selection of the time interval, the user initiates the simulation by selecting 'Generate' in the Generate Pricing Events card of Figure 4.

For each simulated period, flexibility bids or offers will be compared against the data collected in steps 1 and 2.

The market clearing algorithm will perform a cost-minimising optimal power flow analysis to generate a set of DER schedules that resolve constraints at least cost for each operating period evaluated.³

This objective function will dispatch resources to mitigate constraints based on their utilisation bids and offers. The algorithm will minimise the cost to operate the system each day of a simulation (DA separate first, then ID). If a resource is not dispatched, then it is not part of the constraint resolving

³ Periods evaluated are either a full day for a 'day-ahead' analysis, or a user-defined set of intervals for an 'intra-day' analysis

set of resources for that day. If there are no constraints in the system, then no resources will be dispatched.

The simulation can be run based on only the simulated procurement market results, or with modifications to those simulated procurement market results for specific days in either DA or ID periods.

Settlement for services between DA and ID utilisation will take place based on rules, detailed below.

[Admin Panel](#) / Manual Events

<p>Generate PV Forecasts</p> <p>Market: Same Day</p> <p>Generate</p>	<p>Generate Pricing Events</p> <p>Program: Demo</p> <p>Market: Same Day</p> <p>Start Time: < Dec 11, 2020 17:00 EST ></p> <p>End Time: < Dec 11, 2020 18:00 EST ></p> <p>Generate</p>	<p>Clear Market Data</p> <p>Program: Demo</p> <p>Market: Same Day</p> <p>Start Time: < Dec 11, 2020 17:00 EST ></p> <p>End Time: < Dec 11, 2020 18:00 EST ></p> <p>Clear Market Data</p>
<p>Sync DER Info</p> <p>Sync</p>	<p>Run Settlement</p> <p>Nov 11, 2020 to Dec 11, 2020</p> <p>Run</p>	<p>Train Load Forecasters</p> <p>Train</p>

Figure 4: Simulation Initiation Page

3.3.1 Market Operation (Day-Ahead and Intra-Day Utilisation Evaluation)

3.3.1.1 Energy Markets Overview

Energy markets generally establish resource availability through long-term contracts (e.g. month-ahead, year-ahead), and then procure utilisation based on shorter-term trading between network operators, retailers, and generators (e.g. day-ahead, intra-day) based on those available resources.

In these utilisation markets, DA energy trading generally begins at least a day-ahead of the operating day analysed, and closes roughly 12 hours ahead of the trading day. Once the DA market closes, DA awards are posted to participants through markets software.

- Example: The DA market for January 5 12:00am – 11:59pm would open on January 4 at 12:00am, close at 9am on January 4, and post results by 12pm on January 4

ID deviations from DA schedules are created through ID trading and market analyses. ID analysis is in many ways similar to DA analysis, but is generally performed for a shorter time period – a single hour or a sub-hourly interval, rather than all twenty four intervals of a day.

3.3.1.2 *GridOS Simulation of Energy Markets*

GridOS facilitates energy interactive services simulation as follows:

- **Availability:** Standing bids and offers are submitted by participants after a flexibility response set is agreed upon. Availability can be submitted for both DA and ID analyses.
- **Utilisation:** Participants either leave the standing bids and offers as is, or enter datetime specific bids and offers for utilisation to replace the standing bids and offers.
 - Resources do not need to have an availability contract to enter a utilisation bid or offer.
 - Utilisation bids and offers are submitted for the full DA period for an operating day's utilisation analysis
 - The markets software evaluates those DA utilisation bids and offers and issues awards for the operating day.
 - Modifications to those awards can be made for that day's simulated intra-day period.
 - If no modifications are made, then the DA bids and offers are used to pre-populate the ID analysis. If load and generation do not change between DA and ID, and bids and offers do not change between DA and ID, the user should expect identical results for DA and ID market analyses.
 - ID intervals are evaluated one-at-a-time rather than jointly for the entire day. This principally impacts BESS optimisation. Because the BESS are expected to be optimised across a day, but only a single interval is evaluated during ID analyses, the software utilises the DA schedule for the BESS rather than optimising the BESS in each interval.

3.3.1.3 *Service Selection and Compensation Considerations*

For each service, the software will select the cost minimising set of resources required to resolve constraints. The DSO user will select pay as clear or pay as bid as the market compensation method.

- For each analysis:
 - In a pay as bid market, each resource will be paid its offer.
 - In a pay as clear market, the highest priced offer the software utilises per service will be the utilisation price paid to all resources providing that service.

Participation in the simulation will be per-DER, per-service. Each DER's participation in a trading interval (e.g. March 2, 2021, hour beginning 4) will be bounded by that DER's capacity. Solar resources will be submitted to the market as generation based on their forecast.

For BESS, state of charge (SOC) will bound the dispatch schedule awarded by the OPF.

The user should account for state of charge when deciding whether to participate in the intra-day market, however the OPF will ensure that any schedule generated is able to be completed by both the system and the resource. GridOS uses, among other data, the state of charge remaining from the previous hour and the planned *previous* DA quantity to calculate the ID award for that interval.

After creating the availability contracts offline, the administrator will announce that they are evaluating the market for a day.

- The DA analysis for a day will make use of the availability contracts as bids and offers submitted to the market, unless the DER owner/operator participants alter them.
- The ID analyses for a day will make use of intra-day bids and offers for utilisation as per the availability contracts, unless the DER owner/operator participants alter them.

3.3.1.4 Day-Ahead Intra-Day Interdependency

The following bulleted list details the logic the OPF will employ to evaluate utilisation of flexibility services.

- Day-Ahead:
 - The software will select the least cost set of flexibility offers that are required to safely operate the system given a load and generation scenario for each day analysed.
- Intra-Day:
 - The software will select the least cost set of flexibility offers that are required to safely operate the system given a load and generation scenario for each interval analysed.
 - **With** a DA award for an interval of the day:
 - **Without** an ID bid or offer submitted:
 - *For BESS*: The ID award will be calculated based on the BESS SOC remaining from the previous hour, the DA award for that interval, and the ID OPF analysis using that DA award.
 - *For Other Resources*: The ID award will be calculated based on the DA award and the ID OPF analysis.
 - **With** an ID bid or offer submitted:
 - ID bid or offer evaluated as an adjustment to the DA award for that interval, either increasing or decreasing the quantity depending on a utilisation price and the ID OPF analysis.
 - **Without** a DA award:
 - **Without** an ID bid or offer:
 - Unit not in market.
 - **With** an ID bid or offer submitted:
 - The ID award will be based on the ID bid or offer as evaluated by the OPF.

3.4 Step 4: Settlement

The DA analysis will generally precede the ID analysis, and the operator will announce to the DER owner/operator users that they may alter their ID bids and offers ahead of the ID market analyses for that DA day.

3.4.1 Settlement Calculation

For each flexibility resource, there will be one simulated financial settlement value for each interval of an analysed day, as opposed to separate settlement values for DA and ID transactions. The settlements will be based on the DA and ID awards and clearing prices generated by the software.

The Award (i.e. schedule/dispatch amount and associated price) for an accepted bid or offer on an interval for both markets and each service type is based on:

- the load forecast
- the result of the OPF
- participants utilisation price (£/MW or £/MVar).

The clearing price for each service in each interval for both the DA and the ID markets will be based on the highest priced resource required to resolve constraints in the cost-minimisation optimisation.

Awarded quantities and clearing prices across DA and ID markets will differ due to load forecast changes, generation forecast changes, and bid or offer changes between the DA and the ID market analyses.

A single settlement value for each transaction as will be calculated as outlined in Table 3.

Market	Condition	Settlement Value
DA bid or offer, no ID bid or offer	DA Award >= ID award	$ClearingPrice_{DA} * Award_{ID}$
DA bid or offer, no ID bid or offer	ID Award > DA Award	$ClearingPrice_{DA} * Award_{DA} + ClearingPrice_{ID} * (Award_{ID} - Award_{DA})$
DA bid or offer, ID bid or offer to increase DA award	ID award > DA Award	$ClearingPrice_{DA} * Award_{DA} + ClearingPrice_{ID} * (Award_{ID} - Award_{DA})$
DA bid or offer, ID bid or offer to reduce DA award	ID Award <= DA award	$ClearingPrice_{DA} * Award_{ID} - ClearingPrice_{ID} * (Award_{DA} - Award_{ID})$
Only ID bid or offer	ID Award Only	$ClearingPrice_{ID} * Award_{ID}$

Table 3: Proposed Settlement Equations

3.5 Step 5: Review Results and Exit

After the simulations complete, the market operator can view results of the market through an operator dashboard. Participants can review their market awards through the same interface they entered bids and offers within. The results of the market are also exportable to spreadsheet format (csv).

The export data will contain:

1. Utilisation (£, £/MWh) by DER
2. Settlement results

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