# Ontario's GridOS TEMS Deployment Milestone 5 Final Report

In Support of Opus One's IESO CFUND Transactive Energy Project

December 23rd, 2021

*Disclaimer: This project is supported by the financial contribution of the Independent Electricity System Operator (IESO), through its Conservation Fund. However, the views, opinions and learnings expressed in this report are solely those of Opus One Solutions.*

# Contents

# Lexicon

| | |
|---|---|
| BESS | Battery Energy Storage System |
| CIM | Common Information Model |
| DER | Distribute Energy Resource(s) |
| DLMP | Distributional Locational Marginal Pricing |
| DR | Demand Response |
| DSO | Distribution System Operator |
| DSP | Distribution System Platform |
| GIS | Geographic Information System |
| HOL | Hydro Ottawa Limited |
| IESO | Independent Electricity System Operator |
| ISO | Independent System Operator |
| LDC | Local Distribution Company |
| LMP | Locational Marginal Price |
| MPI | Market Participant Interface |
| OE | Optimization Engine |
| TEMS | Transactive Energy Market Systems |
| THESL | Toronto Hydro-Electric System Limited |
| UK | United Kingdom |

# 1 Introduction

## 1.1 The CFUND Transactive Energy Project Project

The Independent Electricity System Operator ("IESO") established a fund (the "ConservationFund") in 2005 to provide funding for action-oriented, sector-specific Conservation pilot projects. Opus One Solutions has been awarded a project to demonstrate a shadow transactive energy operational market in an effort to advance Ontario's distributed energy resources (DER) landscape. This project is the first of its kind to generate economic marginal pricing at the distribution system and deploy this to market platforms.

This project deploys Opus One Solutions' software solution GridOS Transactive Energy Market Systems (TEMS) at three Ontario Local Distribution Companies (LDCs): Hydro Ottawa Limited (HOL), Toronto Hydro-Electric System Limited (THESL), and Lakeland Power. Specifically, this project supports the development of a Distributional Locational Marginal Pricing (DLMP) model that is deployed within GridOS TEMS to generate location and time specific DLMP signals and economic dispatch schedules that schedule asset dispatch for cost minimization.

GridOS TEMS consists of two separate platforms that engage with one another: The Distribution System Platform (DSP) for use by a distribution system operator and the Market Participant Interface (MPI) for use by market participants. These two roles are further defined in sections 2.1 and 2.2 of this report

All cost-optimized asset dispatches are calculated by the GridOS Optimization Engine (OE) which executes 3-phase unbalanced powerflow analyses with different optimization goals. This is further supported by a distributional locational marginal pricing model unique to Opus One Solutions, which incorporates congestion, voltage, and loss components into cost-optimization analyses.

The two key outputs of the IESO-CFUND project are:

- the design and deployment of a transactive energy market platform for operators and aggregators that allows distribution-connected DER owners to participate in a local competitive market
- the development and deployment of a DLMP and economic dispatch model that optimizes asset dispatch to reduce cost of LDC operations

Software development of both the DLMP model and the platform concluded in Milestone 3 of the project and was composed of two release: Release 1 and Release 2. This report serves as a final and concluding report to support the final milestone submission, milestone 5.

This report builds on previous milestones and documentation that would be useful to reference in addition to this report, namely:

- DLMP model whitepaper submitted as a part of milestone 3
- Project Demonstration material updated as a part of milestone 3
- GridOS TEMS functionality specifications submitted with each milestone

## 1.2 This Report

The objective of this report is to provide a summary of the learnings and findings from the project. Specifically, these are focused on the technical and commercial applications of transactive energy markets in Ontario. this report serves as a final and concluding report to support the final milestone submission, milestone 5. Specifically, this report focuses less on the technical components of the solution developed (various reports introduced above cover this) and more on the overall commentary on distribution-level transactive energy markets in Ontario and beyond.

This Milestone 5 report outlines the benefits and uses associated with market operations for three key stakeholder groups: Local Distribution Companies (LDCs), Market participants, and the Independent Electricity System Operator (IESO). LDCs operate and maintain distribution networks, ensuring grid safety. Market Participants are asset owners and/or aggregators that can control distribution connected assets to participate in a local market. The IESO is a system operator, responsible for operating the bulk electricity system in Ontario and delivering required inputs for DLMP calculations purposes. For each of these actors, the report outlines:

- quantifiable and qualifiable benefits of a transactive energy market for the actor group. This will be illustrated in some instances using simulated scenarios on a synthetic and publicly available Greensboro distribution network model. A full set of scenarios is provided as a part of the Milestone 3 demonstration material
- uses the actor group can engage for with either of the two GridOS TEMS platforms. This covers how the actor group interacts with and engages the market and is illustrated in some instances with screenshots from the IESO deployment of GridOS TEMS

# 2 Transactive Energy Market Actors

Three stakeholder groups can engage with GridOS TEMS platforms: LDCs, market participants, and the IESO.

In this section, the benefits to each stakeholder group actor are identified. Likewise, the ways by which each of these roles interacts with GridOS TEMS are documented.

## 2.1 Local Distribution Companies

The primary stakeholder group for distribution-level transactive energy markets are LDCs as they own and operate distribution networks and assets. In Ontario, LDCs are responsible for delivering power to customers in a safe and reliable manner.

The construct of a distribution-level market introduces a new role in LDCs, the market operator, often referred to as a Distribution System Operator (DSO). This role would be responsible for managing the operations of a market. For this innovation project deployment, no specific DSOs were assigned or hired and instead project team members at the IESO and LDCs were granted platform access that reflects DSO access. Additionally, this project facilitated automated market operations in place of manual interventions required by DSOs to decrease level of effort at the LDCs.

Distribution system operators have access to the DSP platform on which they can visualize the network model, the DERs enrolled in the market, and their DLMP and dispatch schedules. The DSP platform also allows the operator to setup and configure the market operations specific to their market deployment instance.

LDCs benefit from a transactive energy market by ensuring cost-optimized operations and provide inputs required by the optimization engine, such as forecasted feeder loading and asset schedules.

### 2.1.1 Benefits

#### 2.1.1.1 Decreasing distribution system costs

Traditionally, LDCs purchase all power at feeder substations and deliver to customers. Transactive energy markets allow an LDC to consider another source of service provision: distribution connected assets. The DSP allows LDCs to enrol assets and owners in order to purchase electricity at a more competitive price, leading to an overall lesser system cost, as multiple participants can be enrolled in the same program.

The asset dispatches are computed by the optimization engine's use of the DLMP model, which ensures that the system costs are minimized. Most importantly, this DLMP respects market participant bids and offers as well as distribution asset ratings and powerflows.

The distribution locational marginal price (DLMP) is the sum of three components corresponding to marginal cost of energy, congestion, and residuals (encompassing voltage components and losses). This is detailed in the DLMP paper submitted. The DLMP is essentially calculated as follows:

$$\lambda_{DLMP}(t,i) = \lambda_{Energy}(t,i) + \lambda_{Congestion}(t,i) + \lambda_{Residual}(t,i)$$

The marginal cost of energy λEnergy corresponds to the locational marginal price ("LMP") of the system operator, which is replaced by IESO shadow price for this project.

LDCs can view the DLMP associated with each asset for any time interval of the day, giving an estimate of the dispatch value at that location for a specific time. This benefits LDCs as it allows DSOs to quantify the real cost to serve energy at nodes in which market participants are connected.

Implementing uncontrolled DERs can lead to remarkably high loadings and congestion on the network. The congestion price component λCongestion quantifies how dispatch on a specific asset would positively or negatively affect the overall stability of the network. A positive congestion price component indicates that the asset is downstream of congestion: dispatching it would lead to relaxing constraints and provide additional benefits to the system. Due to these benefits, a generator at that point can be dispatched at a higher price than the DLMP energy price component. On the other hand, if a congestion price component is negative, then the congestion is acting to decrease the DLMP of the asset compared to the DLMP energy price component. This occurs when an asset is upstream of congestion. This visibility is valuable to LDCs as it allows the quantification of congestion-related benefits offered by DER.

The loss component λLoss is calculated at every point by running a powerflow analysis with a 1kW perturbation and computing the difference in losses between the optimal dispatch and the perturbated state. A positive price component suggests that a dispatch will reduce overall losses on the network, while a negative price component disincentivizes to generate as it indicates that dispatching the asset will result in more losses.

The deployment of this DLMP model benefits an LDC in that it provides an optimal dispatch of assets that minimizes the cost to serve the distribution network and quantifies the value-add of asset market participation to DSOs.

#### 2.1.1.2 Maintaining Safe Network Operations

The GridOS Optimization Engine considers network ratings and computes the maximum safe dispatch per DER, ensuring that no network violation will occur, even if market participants set unsafe bids and offers. The platform also offers to allow or restrain reverse active and reactive powerflow and set voltage limits across the feeder. This is valuable to an LDC as it ensures that any DER participation in a local market is safe.

The scenario visualized in Figure 1 provides an example to capture this value. In this scenario, the solar panel has an available generation of 67kW at 12:00, and its owner set an offer of 6$/MWh, which is lower than the energy price at the substation. However, as displayed by the DLMP, the node at which the solar panel is located is experiencing congestion (a thermal violation), making the actual cost to serve power entirely from this asset higher than it appears if the market participant's offer to generate is compared only against the energy component. For these reasons, the optimal dispatch is not equal to the available capacity, as more dispatch could lead to network violations. Instead, the asset is dispatched to the extent that it would save the LDC money to deliver the feeder loading. This scenario reflects a future world in which DER penetration increases and solar capacities increase on distribution grids. While overall the GridOS TEMS solution facilitates this and dispatches these assets to reduce costs, it only does so to the extent that the network is safe and reliable.

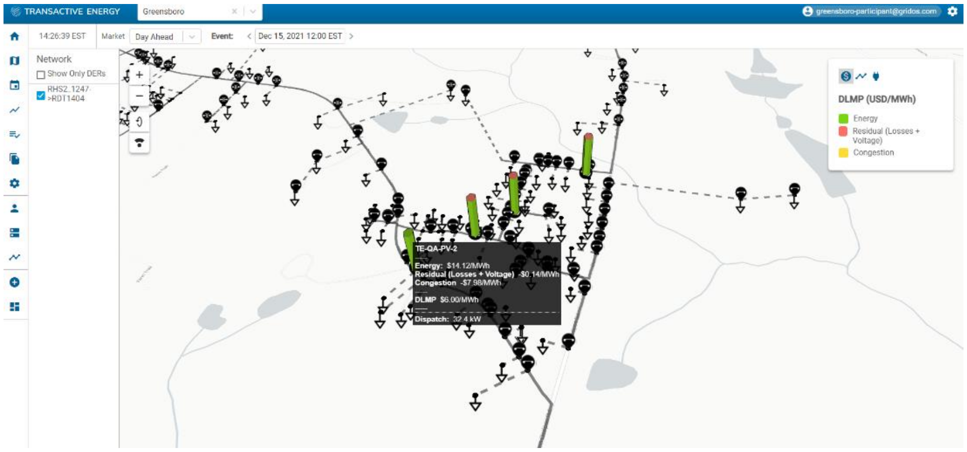


*Figure 1: Solar Curtailment Scenario*

The solution can not only ensure that safe operations are maintained, but also release network constraints in some scenarios. If the feeder head loading is unusually high, congestion will occur within the network. The presence of curtailable and shifting demand response loads scheduled for dispatch by the DLMP model will reduce congestion and release stress from the network.  This is demonstrated in the scenarios outlined in the Milestone 3 submission material.

#### 2.1.1.3 Visualizing Optimal Dispatch & Cost to Serve

The DSP includes a map view that displays the DLMP associated with each DER and their dispatch schedule for same-day and day-ahead market. Viewing the DLMP allows for LDCs to see the actual cost to serve load at a node and visualizing where congestion occurs in the network.  While the primary benefit is to generate these dispatches, this visualization is not something a DSO would otherwise access.

### 2.1.2 Uses

#### 2.1.2.1 Network model & data inputs

LDCs provide the network models that are stored within GridOS TEMS and on which AC 3-phase unbalanced powerflow analyses can be executed by the OE. Having access to this tool is necessary in case the network model and its assets need to be updated. The provided model must be Common Information Model (CIM) compliant and needs to be updated when new market participants are added to a program, as it is where the asset ratings are stored, making it necessary to compute the DLMP. Once the model has been updated, TEMS will be able to run cost-optimized powerflow analyses for same-day and day-ahead market participation.

The second input required from DSOs for the DLMP model are feeder-level load and generation forecasts that are used to determine power flows across the network.

#### 2.1.2.2 Market setup & configuration

Before taking part in the market, some assets require to have their power generation schedules uploaded. This is done by the distribution system operator for most assets, but GridOS can also generate forecasts for specific asset types, such as Photovoltaic assets.

The platform implements two different markets, namely same-day and day-ahead markets. The day-ahead analysis computed by the OE consists of 24 time intervals of an hour each. Market participants can set a constant offer throughout the day or upload a timeseries with unique hourly values. They can also participate in a same-day market for which the pricing events can be generated for wider choice of time intervals, respectively 5, 15, 30 minutes and 1 hour.

Once a participant has set an offer than meets a power request from the DSO and a price lower than its DLMP, the operator can confirm the event and start the asset dispatch process. It is also possible to allow the platform to automatically confirm events if both the power request and price components of the market participant offer fit the network's need.  This was selected for this deployment as no DSO role was allocated.

Some assets, such as battery energy storage systems (BESS) can be controlled and optimized by GridOS to meet the network's needs if its owner allows it. In this case, the market participant will not upload any bid or offer and will generate revenue based on the optimal battery dispatch and its DLMP valuation.

Finally, the DSO configures the market to match their specific needs by configuring parameters including:

- Market gate closure times
- Frequency of price generation
- Feeder voltage limits
- ISO shadow node corresponding to feeder location

#### 2.1.2.3 Market operation

Pricing events display a summary of the DERs behavior for same-day and day-ahead markets. Every asset pricing event includes a time interval (5 minutes for same-day and 1 hour for day-ahead), a power request, the asset's DLMP and the total offer price. These events are automatically generated based on the bids and offers set by market participants and the optimization engine cost-optimized analysis results, but they can also be manually created on the platform.

For the needs of this project, the pricing events are automatically generated for each time interval, based on the bids and offers set up by market participants and the optimization engine cost-optimized powerflow analysis output.  The DSO would be responsible for monitoring these market operations and unenrolling market participant assets as needed.

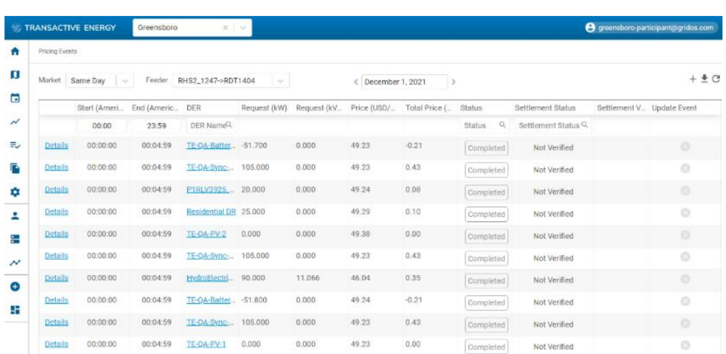


*Figure 2: Market Operations Pricing Event View*

## 2.2 Market Participants

GridOS TEMS deploys an MPI for use by market participants that represent aggregators and/or asset owners. Multiple participants can be added to the same market program and are setup by the DSO in market configuration. For this project, market participants were not involved and LDCs have access to the MPI. The Opus One project team worked with LDCs to setup market participant data inputs.

## 2.2.1 Benefits

### 2.2.1.1 Generating revenue from market participation

Integrating asset owner in a competitive market will bring financial benefits to both the distribution system operator and the market participants, thanks to the bid and offer system. As GridOS TEMS ensures that bids and offer are always respected, market participants only need to set up an offer that meets the asset market valuation in order to start generating revenue. This means that an asset will not be scheduled to dispatch unless its DLMP (assumed its settlement for this deployment) is above its minimum offer price. In this way, the OE ensures that market participant assets are able to generate revenue from market participation though the overall primary objective is LDC cost reduction.

### 2.2.1.2 Aggregating multiple assets

Instead of creating a contract for each asset, The MPI allows for asset owners to aggregate multiple assets, simplifying the enrolment process for both the market participants and the distribution system operator. This would facilitate aggregation of assets and allow more simplified market participation.

### 2.2.1.3 Visualizing market trends

The MPI visualizes to market participant trends in the DLMP prices that would allow them to best price their assets. Having access to this data allows for the platform users to make more educated decisions about the bids and offers they submit into the market as they can visualize the pricing trends their assets are following for both same-day and day-ahead market relative to the DLMPs.

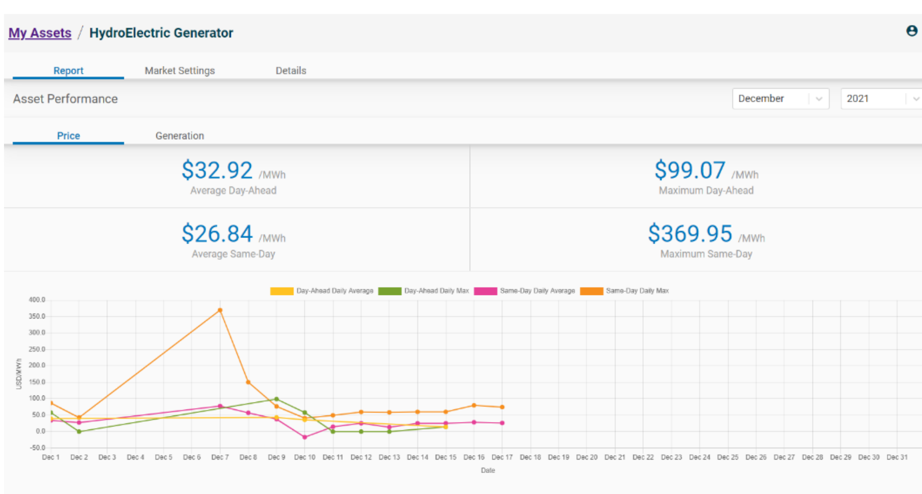


*Figure 3: Market Trends Visualization for Market Participants*

## 2.2.2 Uses

### 2.2.2.1 Submitting bids & offers

Market participants have the capability to set up offers at any time of the day, for both same-day and day-ahead market.  An offer represents an offer to sell electricity back into the grid.  For battery energy storage systems (BESS) and shifting demand response loads, a bid represents an offer to dray electricity from the grid (to charge, for example). A market participant can either set a constant offer for every hour of the day by using the "use single price/quantity pair" or upload a price/quantity timeseries to set different offers depending on the time of the day. Market participants can also set up unique timeseries pairs for specific calendar days.

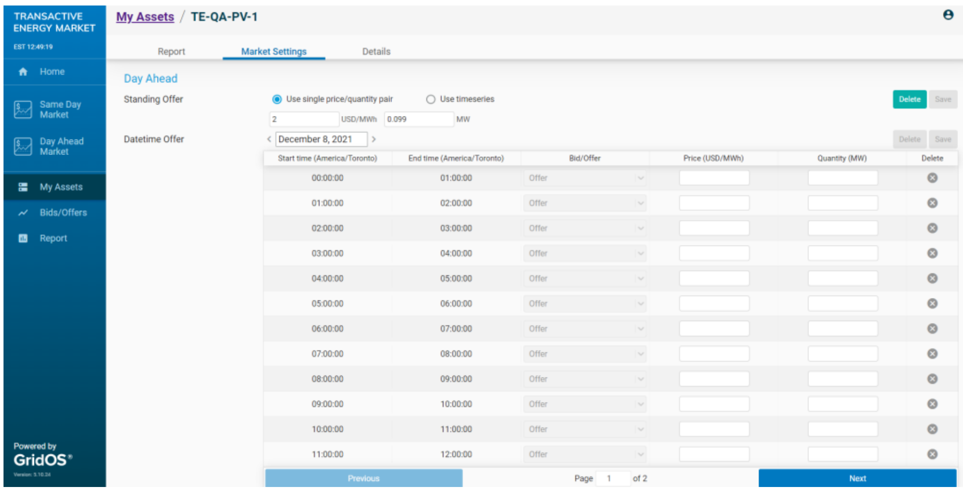


*Figure 4: MPI Solar Asset Bid Submission*

Once the market participant has updated its assets, bids and offers will be displayed, with a confirmation on whether or not the offer is cleared.

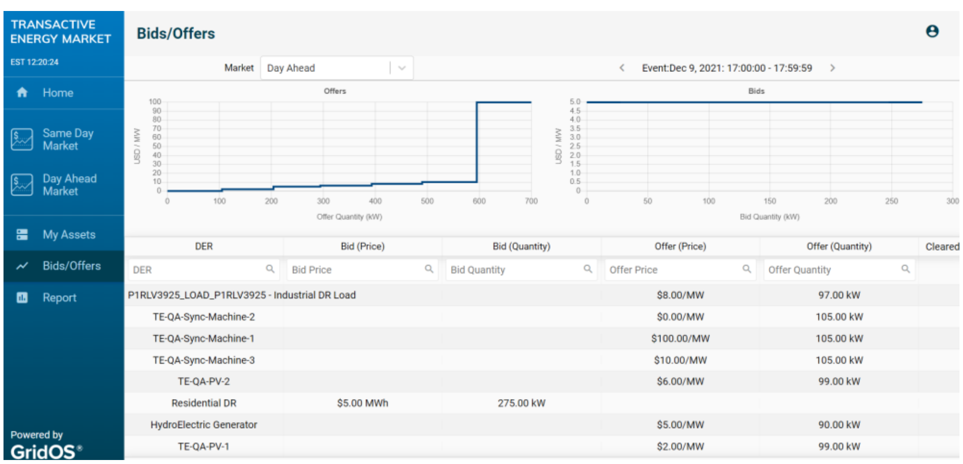


*Figure 5: MPI Bids and Offers View*

### 2.2.2.2 Viewing asset dispatch commands

Once the market participants have set up their bids and offers, the GridOS OE runs a cost-optimized powerflow analysis and create a dispatch schedule for every asset by taking into account the offer as well as the asset rating. Those dispatch schedules are available for both same-day and day-ahead.

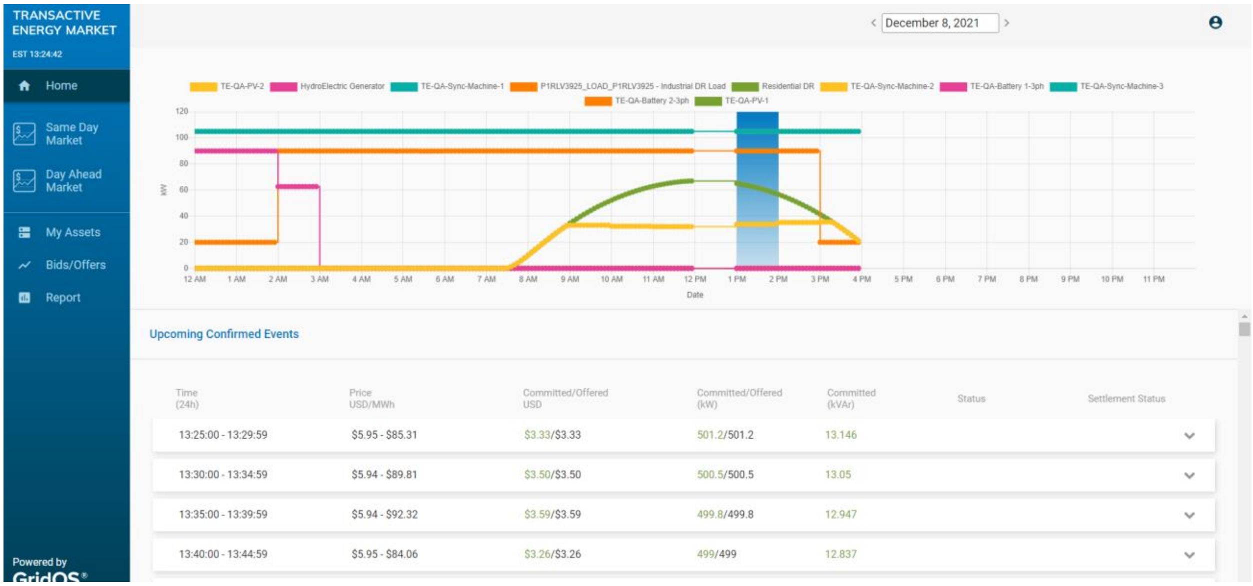


*Figure 6: MPI Asset Dispatch View*

## 2.3 The IESO

The IESO is responsible for ensuring the balance of the Ontario bulk electrical system and provides inputs for GridOS to compute DLMPs. The IESO has also partially funded the development of the DLMP model for this project.

### 2.3.1 Benefits

#### 2.3.1.1 Utilizing distribution-connected assets to standardize LDC demand

While the IESO does not engage directly with GridOS TEMS, it would in theory benefit from the standardized use and dispatch of distribution-connected assets to meet LDC distribution loading. This is because as distribution-connected assets become available within these markets, the IESO can expect to see potentially less fluctuations in demand from LDCs.

Similarly, when the LMP shadow price is exceptionally high, which may reflect nearing capacity, it can be expected that distribution-connected assets would be more likely to be dispatched which would meet the intended purpose of a higher shadow nodal price at the IESO.

#### 2.3.1.2 Enhancing Shadow Nodal Pricing

Once LDCs begin to utilize shadow nodal pricing for DLMP calculation, the IESO may be further incentivized to explore the benefit of more granular shadow pricing. At present, each Ontario LDC corresponds to a single shadow node, regardless of geographic coverage.

### 2.3.2 Uses

#### 2.3.2.1 LMP shadow price integrations

GridOS TEMS integrates with the IESO shadow nodal price to serve as the LMP input into the DLMP model. This corresponds to the energy price component of the DLMP. This shadow price is updated 50 minutes before each same-day event, while it is updated once for the day-ahead analysis 10 hours and 15 minutes before the first event. The IESO makes this information publicly available and this database is scraped to capture shadow nodal price for all Ontario nodes. The IESO has also identified which nodes correspond to specific Ontario LDCs.

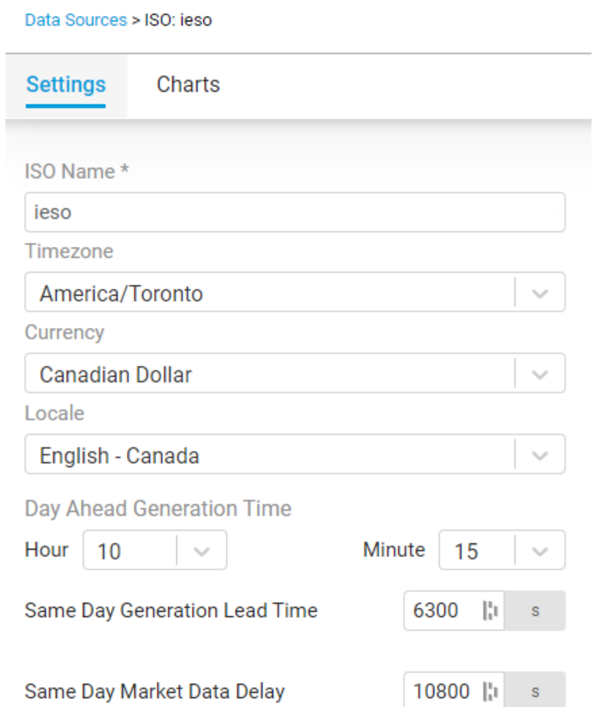


*Figure 7: DSP ISO Shadow Node Configuration*

# 3 Findings & Commentary

This section presents project outcomes, focusing on the lessons learned throughout the solution development and project delivery processes. Following, thoughts on how transactive energy markets can be scaled in Ontario and beyond are presented.

## 3.1 Learnings

To deliver on the two project outcomes of market interfaces and a DLMP model the following project activities were completed in an agile manner, and concurrently over the course of the project duration:

- LDC engagement and data preparation
- DLMP Model design and development
- GridOS TEMS platform design and development
- Solution testing and delivery

In this section, challenges and lessons learned are outlined across the categories of activities presented, with implemented project enhancements or improvements identified where the project team has captured them. These differ from a later commentary on scalability as they relate to activities specific to this innovation project whereas scalability activities would build off this project.

### 3.1.1 LDC Engagement and Data Preparation

LDC distribution networks and data serve as the foundation for optimizations performed by the OE. Distribution-level transactive energy markets could also be operated and facilitated by LDCs in the future. For this reason, LDC engagement and data preparations were crucial for the delivery of this project. The following are lessons learned and potential areas to improve if this project were to be repeated:

- The quality and availability of data impact the value that can be captured from a transactive energy deployment. The more granular and accurate network data is, the more useful and realistic the optimizations performed. The quality of network model, asset and system forecast, and pricing data is important. To ensure that LDCs were equipped to demonstrate the best feeders in this project, the project team worked with LDCs to determine feeders that may have the most DER penetration and that may have the most up to date and quality data. In the future, we would want to ensure that feeders selected for market participation have a breadth and depth of data available
- Network model data is often stored across multiple data sources to contain topological, customer data, asset property, and geographic information that are collectively used to represent distribution network models in GridOS, in a CIM-compliant format. Not all data sources are maintained at the same frequency and granularity within LDCs, which has made the network modelling and conversion processes involve various teams and departments within utilities. Most notable, all LDCs are working towards centralizing and standardizing network model data, which will support in future effectiveness with any network-model based optimizations. At one of the LDCs, the project team built a CIM compliant network model as it did not exist prior to. This was useful as a tool to convert planner-input network data (primarily from Geographic Information System (GIS) sources) was developed to facilitate the process and can be tailored for future reuse with clients

- While LDCs are keen to understand what DLMP signals are generated for market participants, the first question asked is always regarding a system-level analysis of benefits. This would consider the market impacts not at individual DER and/or individual timestamps but across networks and participants. While this analysis was not in scope given the shadow market, the demonstrations presented to all project partners highlighted a *system-wide* analysis of various market scenarios. For example, the simulations demonstrated begun by comparing feeder-level costs, losses, and dispatch as a whole before focusing on per-asset dispatch and pricing
- Network data within LDCs is confidential and deployed only to each LDC's specific production environments. For this reason, demonstrations to the IESO and reporting needed to be deployed on a non-LDC network model. A publicly available Greensboro synthetic network model used for research and demonstration was utilized and has proven valuable in standardizing and generalizing the benefits of GridOS TEMS deployment on a distribution network. This analysis is shared in demonstration material delivered with milestone submissions

### 3.1.2 DLMP Model Design and Development

The majority of lessons learned and future work tied to the design and deployment of a DLMP model are outlined in the DLMP paper delivered as a part of this project. Specifically, lessons learned worth highlighting include:

- Distribution Locational Marginal Pricing is an emerging concept, and so there is no specific pricing model in place that can be referred to or replicated. For this reason, there is an iterative discovery phase associated with agreeing upon a DLMP pricing model. It is also important to iterate on how this DLMP model is realized in market platform deployments to ensure it is reflective of operations. This project delivered two iterations of a DLM model, one per release
- It is more effective to perform DLMP calculation in a single step without linearization. For this reason, this was updated in the DLMP methodologies delivered in Release 1 and Release 2 of the software deployments. This is outlined in DLMP reporting
- Residual component is a satisfactory alternative to loss and voltage components, especially recognizing that voltage components are not likely to and do not consistently contribute to residual components. As of present, there does not seem to be a need or captured value to segmenting these components. For this reason, residual components were included into the second release of the DLMP methodology

### 3.1.3 GridOS TEMS Software Design and Development

While the GridOS TEMS platform was deployed to three Ontario LDCs for this project, the aim of the platform development is to feed into a product that can be delivered across LDCs. The three LDC feeders participating in this program were diverse in nature; urban, suburban, and mixed community. Likewise the maturity and availability of data, demand response programs, and DER varied. Based on this, lessons learned regarding the build of a transactive energy market that can be deployed across jurisdictions include:

- LDCs do not all collect and/or store data of the granularity and accuracy to support complete visibility of distribution networks. For this reason, GridOS-TEM deployments are designed to accommodate a range of data quality. For example, uploaded data does not have to be of the same granularity defined by market structures. Additionally, the solution was designed to accept data with missing intervals or pieces, though no price signals and/or dispatch would be output. This is to facilitate the data that may be available
- Certain network properties and conditions impact the flows that are allowed through the GridOS TEMS optimizations. These are not consistent across distribution feeders, even within the same LDC. Based on the current project partners, the following variables are configurable by the operator to facilitate a variety of network model parameters that can change:
    - Upper and lower voltage limits
    - Overall system thresholds
    - Whether reverse powerflow at the feeder head is permissible as a part of optimizations or not
- State of charge modeling over multiple intervals of analysis is as of yet not standardized across markets. A simple example of this is the use of the terms *bid* and *offer* in markets. Technical as well as commercial properties must be jointly evaluated to determine how state of charge modeling would be best implemented to represent battery participation in a market. In the current deployment, energy was managed across a battery's participation in a day by assuming a start and end state of charge of 25%
- DER (including demand response (DR)) program parameters are unique to each LDC and standardizing participation in transactive energy markets requires further stakeholder engagement to shape a way to configure DR assets that aligns with various DR programs. At present, DR program participation is capped and bounded by the offers and bids submitted by market participants but this can be updated in the future to account for parameters such as maximum and minimum runtimes as well as maximum and minimum power dispatch quantities.

### 3.1.4 Project Delivery

This project is an innovation project that funds the research and development of a DLMP model and market platform software. This poses both opportunities and challenges to the delivery of the project and leads to discussions centered about how this project can be scaled and/or contribute to future work at LDCs, with market participants, and at the IESO to transition the province towards a more resilient and distributed grid. This is presented in the following section.

As it pertains to the delivery of this CFUND project, the following have been captured as lessons learned:

- While this is an innovation project, it requires input and generates learnings for a variety of business as usual (BAU) teams and departments within LDCs and at the IESO. It is sometimes challenging to ensure that resources are allocated to oversee project work and contribute. This is important as long term it may position the project towards a smoother and better transition to BAU. A couple ways this challenge was addressed are:

    - Demonstrating project progress, findings, and value at milestone gates to varied audiences at LDCs and with the IESO beyond just the innovation project teams. This helped ensure other colleagues were aware of the project without necessitating their frequent involvement.
    - Align the project with roadmap and strategy initiatives at LDCs and at the IESO early on during the project where applicable
- An operational market cannot guarantee showcasing all scenarios under which market deployments can be valuable since inputs cannot always be controlled. Specifically, IESO Locational Marginal Pricing (LMP) signals and LDC forecasts cannot or should not be altered by an operator frequently. This was a challenge as the project team was keen to demonstrate what the market deployment on the Greensboro feeder would capture as value under various conditions such as congestion, large generator dispatch, and competitive markets. The project team built an optimization harness that allowed for simulated inputs into the same DLMP model that runs the GridOS TEMS deployment. This allowed the team to demonstrate *what-if scenarios* to showcase a number of situations in which a transactive energy market deployment would lower cost to serve incurred by utilities and allow market participants to utilize DER in the process.
- LDCs and the IESO are not aware of what bids and offers market participants and asset owners would incentivize them to participate in a transactive energy market. This is because they do not own and operate these assets. For this reason, bids and offers submitted within each of the deployments do not reflect bids and offers that would be submitted by market participants. In the future it would be useful to engage aggregators or asset owners to reflect values that would reflect positive value propositions for market participants.

## 3.2 Scalability & Future Work

This project develops and demonstrates market interfaces and a DLMP model that could be utilized to operationalize a market in a live deployment. While this project was shadow and primarily focused on developing the solutions, it has positioned Ontario well to be able to trial these markets. Future work beyond this project may focus on a number of different areas, all looking to scale and operationalize the market, dispatching live distribution-connected assets optimally and realizing a direct cost reduction at Ontario's LDCs.

### 3.2.1 GridOS TEMS Feature Development

This project and engagements within the emerging space of transactive energy management have allowed the Opus One team to identify a number of functionality that will be useful to develop into a future transactive energy market platform:

- Develop a simulator mode that would allow operators to trigger market events and transactions given specific inputs. This is essentially a platform deployment of the harness developed to facilitate the DLMP model as a part of this project. This would allow an LDC to run the market under specific scenarios and conditions before moving to a live trial

- Facilitating longer and shorter term trading, allowing LDCs to procure resources potentially further in advance of dispatch (week ahead) and allow market participants more certainty around market participation and compensation
- Settle for both availability payments and utilization payments, the former of which can be shaped by DLMP pricing
- Nodal DLMP calculation that exposes DLMPs calculated at each node to LDCs and not just at nodes at which DER are connected.
- Allow the submission of metering data for live trials such that settlement data can compare delivered energy to market commitments
- Segment offer curves for market participants to reflect cost of operations for market participants and accommodate must-run generation types
- Configure demand response asset participation more closely with demand response frameworks within LDCs
- Enable weather-enhanced generation forecasting

Through a number of engagements to facilitate transactive energy markets in the United Kingdom (UK), Opus One is currently developing a number of these features into its GridOS TEMS functionality.

## 3.2.2 Integrating with Stakeholder Data & Programs

This project can be enhanced and scaled by further integrations with data, programs, and initiatives with the three stakeholder groups identified

### 3.2.2.1 Local Distribution Companies

At local distribution companies, GridOS TEMS can be integrated with real-time telemetry such as Supervisory Control and Data Acquisition (SCADA) and metering systems to enhance forecasting and settlement functionality.

Future work may also involve updating network model quality and data as well as enrolling a greater number of feeders which would allow LDCs to explore the benefits that can be captured across different feeders, and how this value may change or relate to feeder-specific properties. Simulation capabilities developed into GridOS TEMS would also serve as very useful to LDCs, allowing them to capture value in various future conditions before facilitating trials.

Finally, if LDCs are interested in capturing value from a deployment, a live trial would be considered as this usually allows LDCs to work alongside aggregators to explore how DER participation in a local market can facilitate market for cost reduction.

### 3.2.2.2 Market Participants

Since market participants were not engaged in this project, future work would involve aggregators and/or asset owners utilizing the MPI interface. This will allow for offer and bid submission that is more favourable for asset owners and would allow Opus One to develop the MPI platform in a way that incentivizes use and participation. Pivotal to the deployment of live or operational markets is whether they can clear asset dispatch at prices that market participants would want to participate in.

### 3.2.2.3 The IESO

In the future, the IESO may want to consider how DLMP constructs and markets deployed at distribution networks may impact transmission systems and/or the high voltage level LMP. While no impact would be expected at a small scale, there is a future DSO world in which distribution markets operate at scale and magnitude enough to impact the pricing mechanisms operated by the IESO at the transmission level.

### 3.2.3 Operationalizing Markets

Operationalizing a transactive energy market is the natural next step to deploying a shadow market. This refers to ensuring that assets are dispatched as per the economic dispatch schedules and DLMP price signals optimized by GridOS TEMS. It is important to note that this is not currently allowed or facilitated based on current regulation of LDCs. So, future work would involve regulating bodies to allow LDCs to trial live markets. Working towards operationalizing these markets would require:

- Enrolment of market participants and asset owners with DER that can contribute to market operations. Market participants would likely be required compensation for their participation in a trial. This may come in the form of an innovation project at an LDC and/or a demand response or flexibility program that enrols customers within the LDC jurisdiction. If compensation is provided, LDCs will want to invest effort and resources to monitor metering data submission and ensure that value forecasted from the market is captured.
- Enhanced forecasting capabilities for feeder load and generation. At present, historical loading was forecasted, sometimes with an assumed growth factor, to reflect future feeder forecasts. An operational market would require more accurate and real-time forecasts that can be enhanced by: weather weighting, smart forecasting models, and integration with operational telemetry
- Updated network model data and integrations. Since live networks do incur topological changes in BAU processes, an operational market would be best suited to integrate with network models that reflect *as-is* and not *as-built* conditions. This could be facilitated by updating GridOS TEMS with CIM difference files that reflect network model changes and/or integrating with network model versions updated in LDC control rooms which operate in near real-time.

### 3.2.4 Scaling Across Jurisdictions and Market Structure

While this project was focused on the development of interfaces and a DLMP model, the business and market rules that shape a transactive energy market will shape how LDCs and market participants benefit from distribution level markets. The following are potential avenues for future work that can be explored to facilitate distribution level trading as a part of BAU:

- Deployment of various pricing and clearing mechanisms, comparing them against one another. While this project demonstrated settlement of market participants based on DLMPs, other pricing models exist. For example, LMP+D models that add a distribution factor to ISO LMPs. Additionally, there are market structures that would settle market participants based on bids and offers submitted into the market. These can be pay-as-bid or pay-as-clear structures. There are a variety of settlement structures that would impact the costs and benefits incurred by all stakeholders. In the future, it would be useful to consider how these settlement structures vary and which may be the most cost and grid efficient for LDCs.

- The current operational interface does not support simulation functionalities. The Opus One team did build a simulation DLMP harness that allowed the team to simulate conditions given controlled market inputs. This has highlighted the importance of developing a simulation functionality within GridOS TEMS solutions that the team is exploring. The development of a simulation tool would allow stakeholders to explore markets under varied conditions before solidifying market rules and structures. Building on the point above, a simulator tool for example would allow an LDC to simulate market operations under various settlement structures, leading to a more informed decision on the best settlement structures to pursue.
- Integrating with other system operators. The current deployment integrates with the IESO's shadow price platform, which is only specific to Ontario. Future work may involve considering other jurisdictions, especially those that have LMP signals generated at the transmission-distribution interface.

## 3.3 Conclusion

This project has been successful at developing both a DLMP model and two transactive energy interfaces that showcase how an operational distribution-level market can be utilized to decrease LDC cost of system operations. Most significantly, these deploys were specific to three Ontario LDCs. To Opus's knowledge, this is the first of its kind deployment.

It has offered the LDCs, Opus One, and the IESO various learnings, specifically focused on data required for market operations, how market value is captured, and how a market is operationalized.

Finally, this project has identified a number of pathways to build off this work and work towards trialing transactive energy markets with the end goal of exploring whether distribution-level markets can utilize existing and ever increasing distribution-connected DER to be of benefit to LDCs, asset owners, and the IESO. We are hopeful that some of these can be explored and coupled with learnings from various transactive energy and flexibility market trials globally to realize a future distribution grid that makes use of distributed and renewable assets.