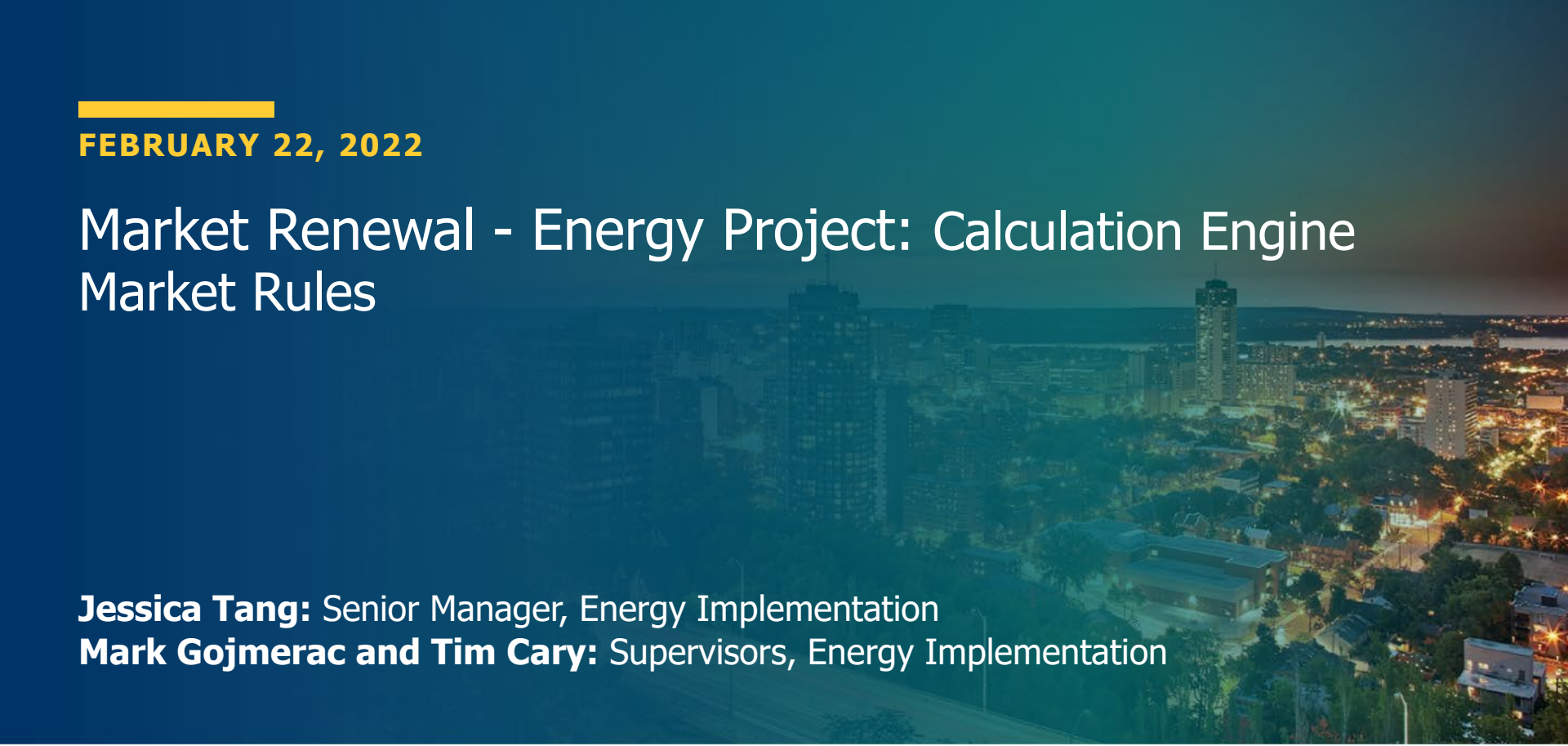
FEBRUARY 22, 2022

Market Renewal - Energy Project: Calculation Engine Market Rules



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Disclaimer

This document provides an overview of certain draft amendments to the market rules proposed in connection with the Market Renewal Program (MRP). The content of the proposed amendments is subject to further revision and the overview contained herein is provided for information purposes only.

The information contained in this document shall not be relied upon as a basis for any commitment, expectation, interpretation and/or decision made by any market participant or other interested party.

The market rules and market manuals, applicable laws, and other related documents will govern the future market.

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Meeting Purpose and Agenda

Purpose: Prepare stakeholders for their review of the proposed market rules that codify the Day-Ahead Market (DAM), Pre-Dispatch (PD) and Real-Time (RT) calculation engine detailed designs

Agenda:

- Refresher on the engagement approach for market rules and market manuals
- Overview of structure and content of the proposed market rules for the calculation engines

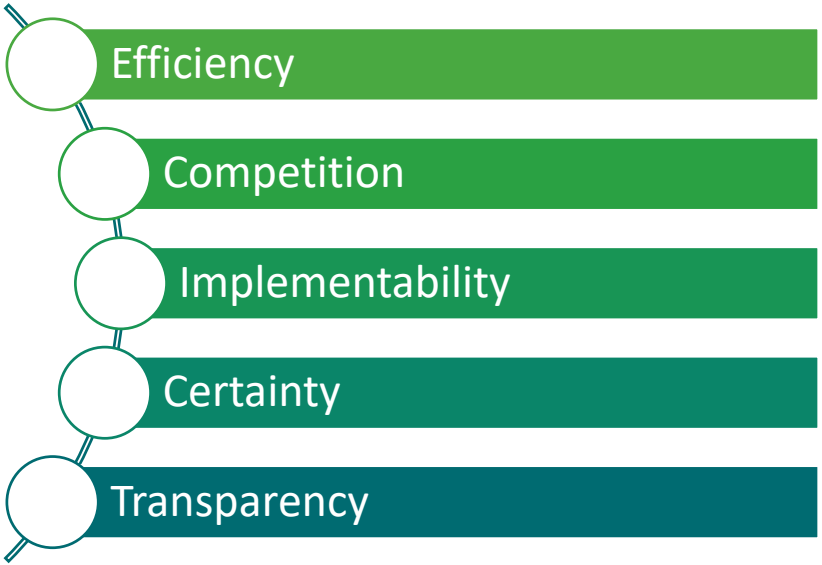
Refresher: Engagement on Market Rules and Market Manuals

Engagement on Market Rules and Manuals

- Provide transparency and an opportunity to review and provide feedback on the draft market rules and manuals
- Ensure the spirit of the Market Renewal principles and the detailed design are captured in the codified rules prior to formal Technical Panel (TP) and IESO Board review processes

More information on the purpose and method of engagement can be found in the Implementation Engagement Plan

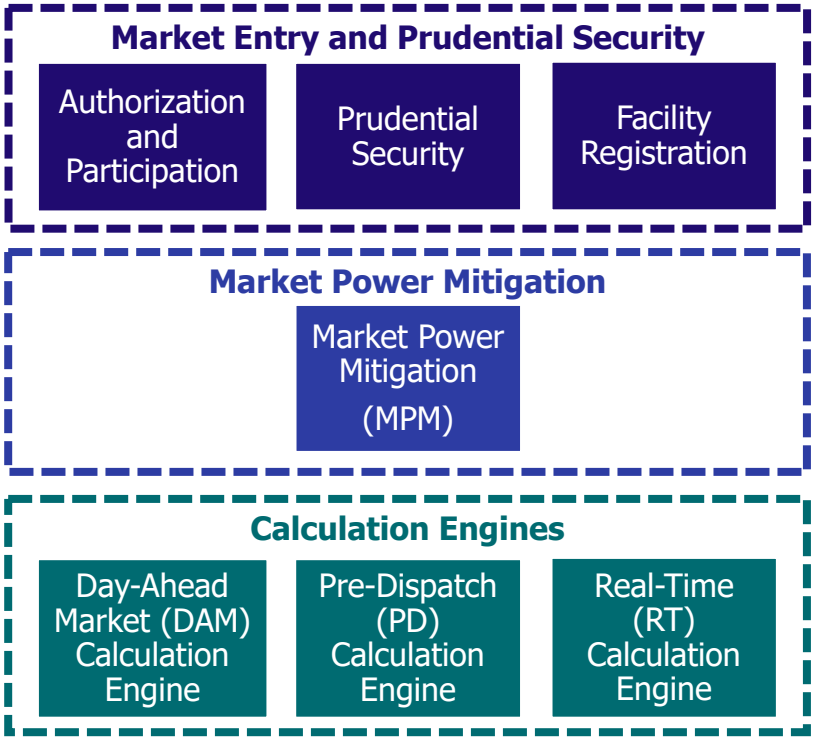
Market Renewal Principles

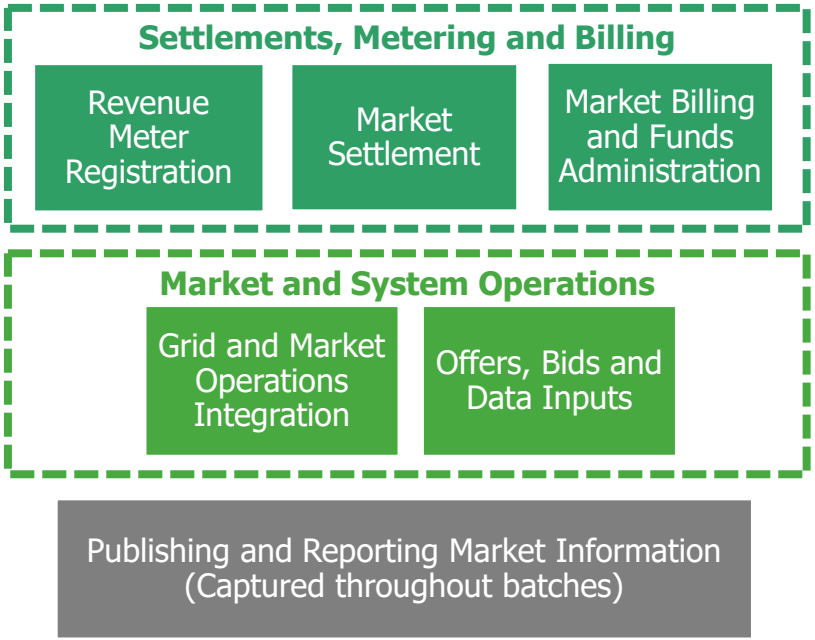


Market Rules and Manuals Batches

- Market Entry and Prudential Security (Provisionally Approved by Board)
- Market Power Mitigation (Currently Under TP Review)
- Calculation Engines (Published for Stakeholder Review)
- Market Settlement, Metering, and Billing (Stakeholder Review Q3 2022)
- Market and System Operations (Stakeholder Review Q4 2022)

Market Rules & Manuals Batch-Detailed Design Mapping





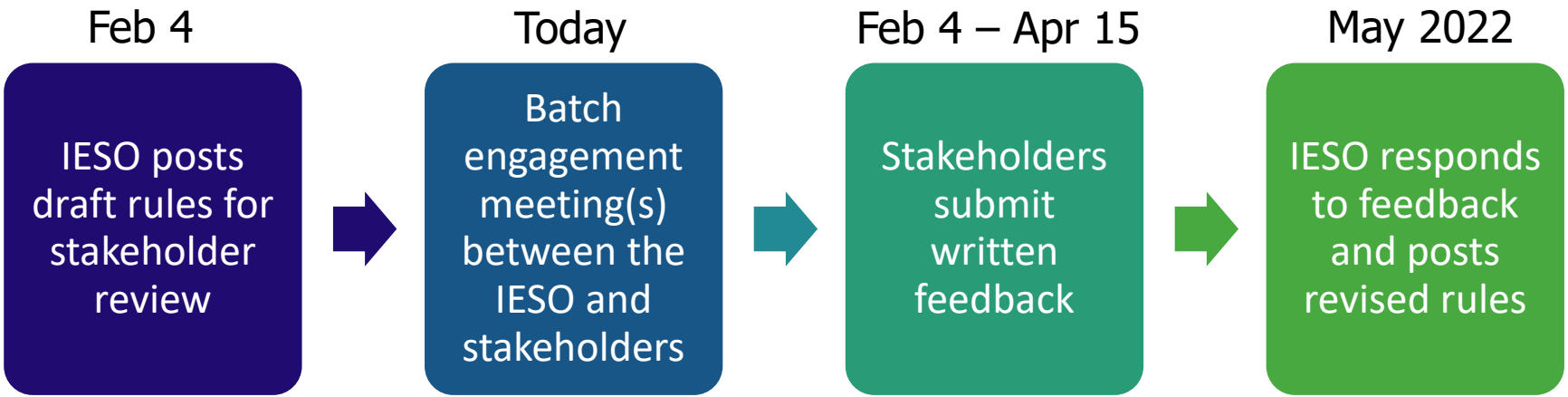
Background: Calculation Engine Rules

- Define the mathematical terms and algorithms that optimize dispatch data from market participants to meet power system needs
- Terms and algorithms for the current calculation engines are captured in appendices, providing transparency for how the IESO meets its Chapter 7 obligations for algorithms to schedule and price the market
- Conforming Chapter 7 obligations to be included in the Market and System Operations batch of market rules and manuals
- The IESO has maintained this approach in codifying the terms and algorithms used to support the renewed market

Expectations for Stakeholder Review

- The calculation engine appendices codify the highly technical content reviewed by stakeholders during detailed design
- The IESO has cross-checked the content against the detailed design
- A third-party audit is planned as part of the project to ensure the appendices match tool functionality
- Clarifying questions and feedback on the ability to navigate the appendices is recommended as the focus for stakeholders

Calculation Engines Batch Review Process



Stakeholder feedback on the draft market rules will be summarized and provided to the Technical Panel and IESO Board of Directors

Calculation Engines: Batch Summary

Market Rules

Impacted Market Rules and Manuals

Market Rules	
Market rule provisions that describe the obligations regarding calculation engine functionality, including new defined terms.	Chapter 7 Appendix 7.1A (DAM Calculation Engine) Chapter 7 Appendix 7.2A (PD Calculation Engine) Chapter 7 Appendix 7.3A (RT Calculation Engine) Chapter 11 – Definitions

Market Manuals
Market manuals not impacted. Conforming changes to be captured during the settlements and market and system operations batch reviews.

Calculation Engines Batch: Appendix Sections

- Information Used by the Calculation Engines
- Initialization Process
- Security Assessment Function
- Optimization Functions (Scheduling, Pricing and Ex-Ante MPM)
- Pseudo-Unit (PSU) Modelling
- Pricing Formulas

Section Overviews

An overview of each section follows and is meant to orient stakeholders with:

- The purpose that each appendix section serves
- Common and unique functions that apply to the optimization process for each calculation engine
- New information and features and to which calculation engine they apply

Calculation Engine Section Summary:
Information Used by the Calculation Engines

Information Used by the Calculation Engines

Describes the sets, indices, and parameters used in the mathematical formulation of the optimization functions, which include:

- Market participant data parameters: offers and bids, dispatch data parameters, etc.
- IESO data parameters: reliability requirements, demand forecasts, ex-ante MPM parameters, and the network model

New Information Used by the Calculation Engines

- Additional dispatch data for dispatchable hydro-electric resources and eligible non-quick start (NQS) resources
- Market participant submitted forecast quantities for dispatchable wind and solar resources
- Dispatch data for price responsive load (PRL) and virtual transactions
- Reference level values for financial dispatch data parameters
- Pricing locations for all resource types
- Four area demand forecasts

Calculation Engine Section Summary:
Initialization Process

Initialization Process

Describes the set-up procedures that occur prior to execution of each calculation engine

New Initialization Feature	DAM	PD	RT
Determination of islanding conditions	Yes	Yes	Yes
Determination of tie-breaking conditions for wind and solar resources	Yes	Yes	Yes
Selection of dispatch data to use across two dispatch days	No	Yes	No
Selection of start-up costs to use for NQS resource advancements	No	Yes	No
Selection of NQS resource first time-step available to start	No	Yes	No
Additional initial scheduling assumptions for hydro and NQS resources	Yes	Yes	Yes

Calculation Engine Section Summary:
Security Assessment Function

Security Assessment Function

Describes how the schedules produced by the optimization functions are assessed to ensure they respect system security limits such as stability limits and thermal ratings of transmission equipment:

- Interaction between the security assessment function and optimization functions
- Inputs into the security assessment function
- Security assessment function processing
- Outputs from the security assessment function

New Security Assessment Features

New Security Assessment Feature	DAM	PD	RT
Calculation of Marginal Loss Factors	Yes	Yes	Yes
Distribution of Virtual Transactions	Yes	No	No

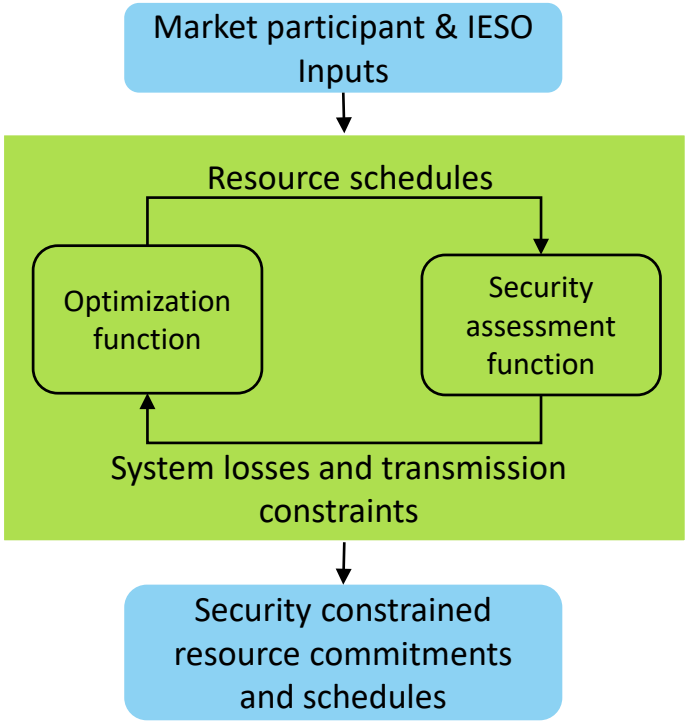
Calculation Engine Section Summary:
Optimization Functions (Scheduling, Pricing and Ex-Ante MPM)

Optimization Functions

- Describes the algorithms used to optimize scheduling and pricing decisions over a given time horizon, comparing different solutions in determining the ideal outcome
- Two main algorithms are used by all three engines: the scheduling algorithm and the pricing algorithm
- The goal of each algorithm is to maximize or minimize the value of an objective function (e.g. maximizing gains from trade) taking into account one or more resource and system constraints

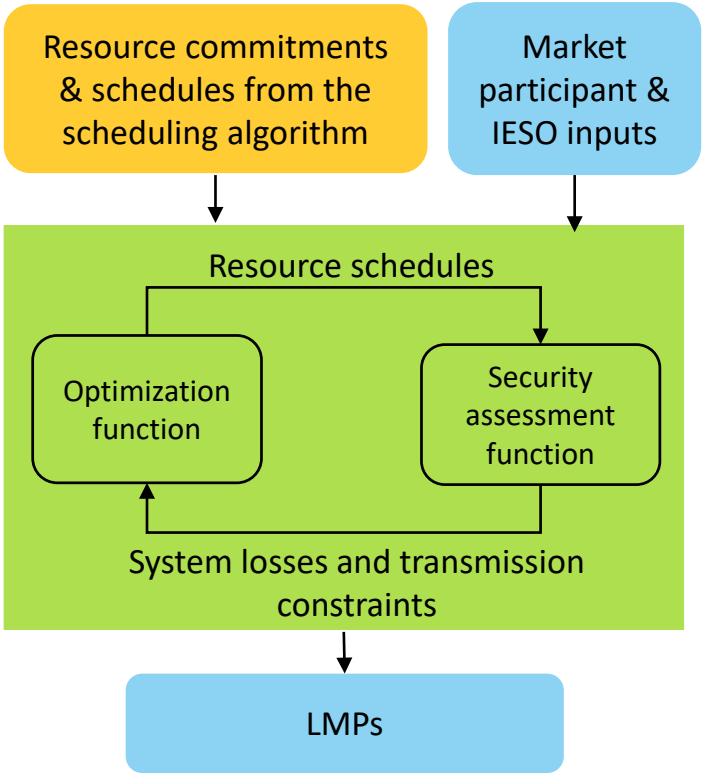
The Scheduling Algorithm

- Performs a security-constrained unit commitment and economic dispatch through multiple iterations of the optimization function and the security assessment function
- The optimization function determines the optimal resource schedules for energy and operating reserve
- The security assessment function assesses the security of the resource schedules by calculating system losses and checking whether the resource schedules violate transmission system limits



The Pricing Algorithm

- The pricing algorithm performs a security-constrained economic dispatch through multiple iterations of the optimization function and the security assessment function
- The optimization function calculates schedules in accordance with price-setting eligibility principles
- Price-setting eligibility principle: The locational marginal price (LMP) at each location is set by the offer or bid that is able to supply the next increment of demand at that location



New Optimization Features of the Calculation Engines

New Optimization Features	DAM	PD	RT
Evaluation of new and existing dispatch data for dispatchable hydro-electric resources	See slide 29 for applicability		
Evaluation of additional dispatchable NQS resource dispatch data for physical units or PSUs (see slides 28 to 30)	See slides 30 to 32 for applicability		
Evaluation of market participant submitted forecast quantities for dispatchable wind and solar resources	Yes	No	No
Evaluation of dispatch data for price responsive loads	Yes	No	No
Evaluation of dispatch data for virtual transactions	Yes	No	No
Conduct and impact tests to support the application ex-ante MPM within the scheduling and pricing algorithms	Yes	Yes	No (applied from PD)

Hydroelectric Dispatch Data Included in Optimization

Dispatch Data	Description	DAM	PD	RT
Minimum Hourly Output	The minimum hourly dispatchable output required if economic	Yes	Yes	No
Hourly Must Run	The minimum hourly non-dispatchable output required	Yes	Yes	Yes
Maximum Number of Starts Per Day	Maximum number of times a resource can be scheduled above an energy quantity threshold across an entire day	Yes	Yes	No
Forbidden Regions	Up to five regions a resource must not be scheduled within	Yes	Yes	Yes
Max Daily Energy Limit	Maximum energy that can be scheduled across an entire day	Yes	Yes	No
Min Daily Energy Limit	Minimum energy that must be scheduled across an entire day	Yes	Yes	Yes
Linked Resources, Time Lag and MWh Ratio	Intertemporal dependencies between 2 or more resources on the same cascade owned by the same participant across a day	Yes	Yes	No

NQS Parameters Included in Optimization

Parameter	Description	DAM	PD	RT
Steam Turbine Percentage Share	A PSU only registration parameter that defines the amount of steam turbine capacity associated with each PSU	Yes	Yes	Yes
Steam Turbine Duct Firing Capacity	A PSU only registration parameter that defines the capacity available from the duct firing of a steam turbine generation resource	Yes	Yes	Yes
Energy Offer	A dispatch data parameter representing incremental energy costs	Yes	Yes	Yes
Start-Up (SU) Offer	A dispatch data parameter that represents the cost of bringing an offline generation resource through all of start-up procedures	Yes	Yes	No
Speed-No-Load (SNL) Offer	A dispatch data parameter that represents the cost of operating a resource synchronized with zero net energy injected for an hour	Yes	Yes	No

NQS Parameters Included in Optimization (con't)

Parameter	Description	DAM	PD	RT
Energy Ramp Rate	A dispatch data parameter that defines the rate of energy increase and decrease	Yes	Yes	Yes
Minimum Loading Point (MLP)	Minimum output that must be maintained to remain stable	Yes	Yes	Yes
Minimum Generation Block Run Time (MGBRT)	Minimum number of consecutive hours that must be at minimum loading point	Yes	Yes	Yes via PD
Minimum Generation Block Down Time (MGBDT)	Minimum number of consecutive hours between minimum loading point before desynchronization and minimum loading point after resynchronization	Yes	Yes	Yes via PD
Single Cycle Mode	A PSU only dispatch data parameter that signals combustion turbine operation without an associated steam turbine	Yes	Yes	Yes

NQS Parameters Included in Optimization (con't)

Parameter	Description	DAM	PD	RT
Duct Firing 10-minute Reserve Capability	A PSU only registration parameter that define which classes of operating reserve can be scheduled in the duct firing region.	Yes	Yes	Yes
Lead Time	A daily dispatch parameter that define the amount of time needed for a resource to start-up and reach its MLP from an offline state	No	Yes	No
Ramp Up Energy to MLP	Two dispatch data parameters (1. Ramp hours to MLP; 2. Energy per ramp hour) that define the energy that a resource is expected to produce from the time of synchronization to the time it reaches its MLP	Yes	Yes	No

Optimization Function Overview: DAM Calculation Engine

Overview: DAM Calculation Engine Optimization

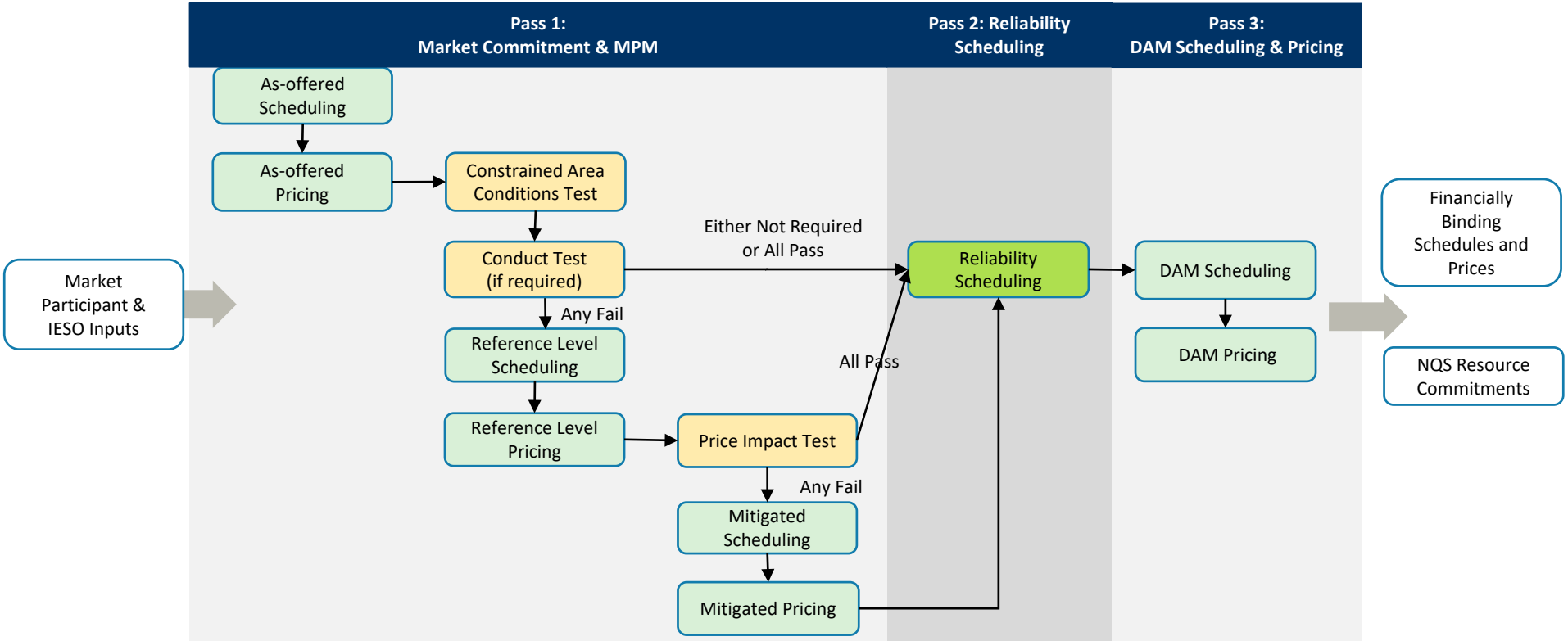
The DAM calculation engine will execute three passes to:

- Evaluate PSUs and additional hydroelectric and NQS dispatch data
- Generate commitment decisions for eligible NQS resources
- Apply ex-ante MPM processes
- Produce hourly financially binding schedules and prices for energy and operating reserve

Passes of the DAM Calculation Engine

Pass 1 Market Commitment & MPM	Pass 2 Reliability Scheduling	Pass 3 DAM Scheduling and Pricing
• Determines an initial set of schedules and prices as well as initial commitments for eligible NQS resources • Includes the ex-ante MPM process	• Determines additional NQS resource commitments if required to meet peak forecast demand • Uses as-offered or mitigated dispatch data, resource schedules & LMPs from Pass 1 • Uses IESO's centralized forecast for wind and solar resources • Excludes virtual transactions and bids from price responsive loads	• Determines final financially binding energy and operating reserve schedules and corresponding shadow prices used to calculate settlement-ready LMPs • Uses NQS commitment decisions and import and export schedules determined in Pass 1 and Pass 2 • Uses the same set of market participant and IESO inputs used in Pass 2

DAM Calculation Engine Execution



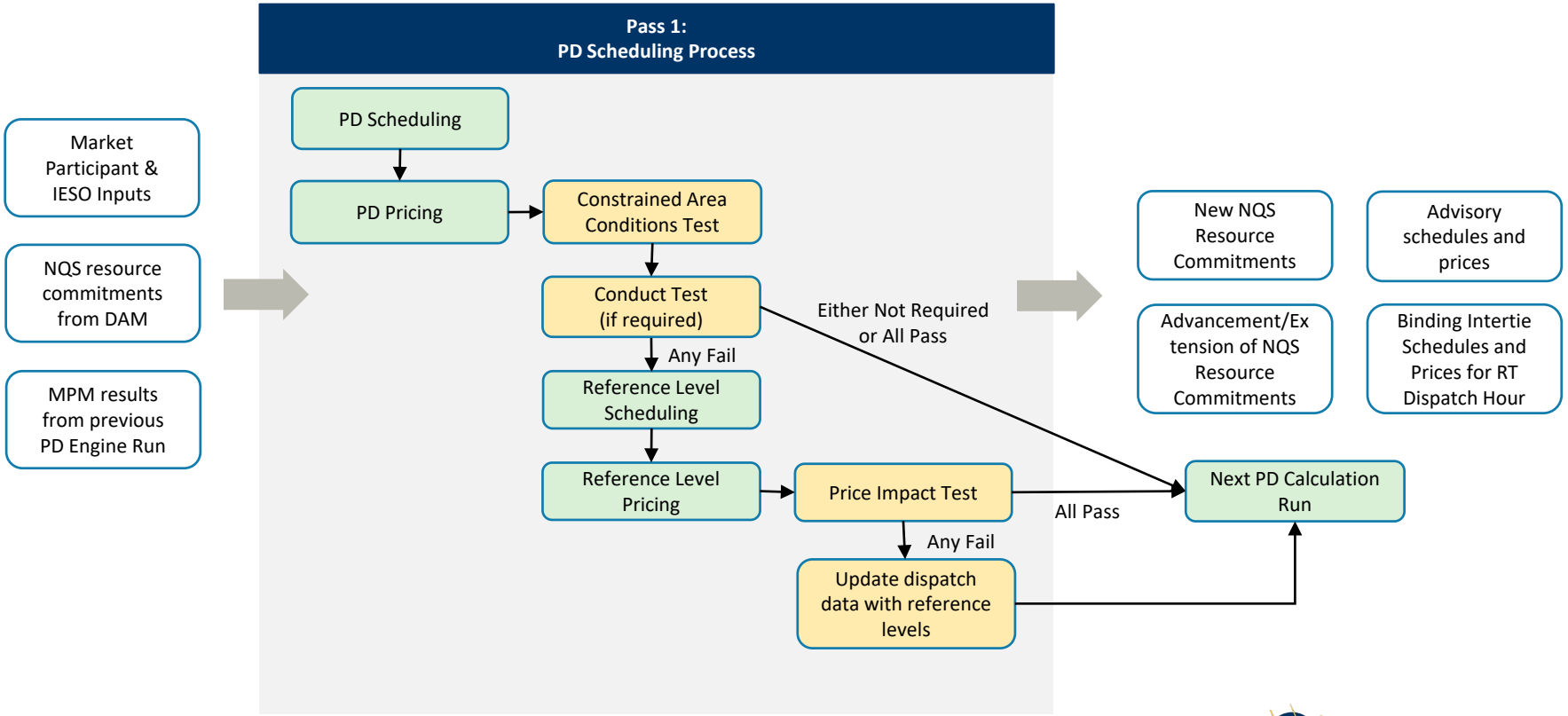
Optimization Function Overview: PD Calculation Engine

Overview: PD Calculation Engine Optimization

The PD engine will execute one pass to:

- Apply NQS commitments from DAM
- Evaluate PSUs and additional hydroelectric and NQS dispatch data
- Exclude non-DAM imports and exports until 2 hours prior to real-time
- Apply ex-ante MPM processes
- Produce hourly advisory schedules and prices for energy and operating reserve
- Generate new commitment decisions, and advance or extend DAM commitment decisions, for eligible NQS resources

PD Calculation Engine Execution



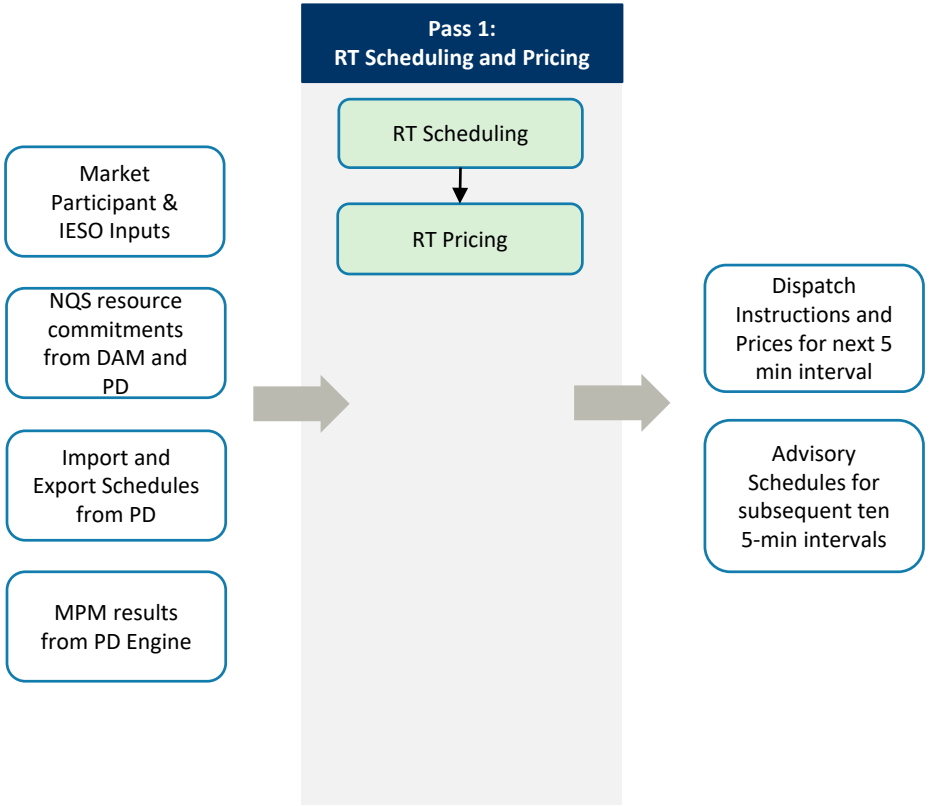
Optimization Function Overview: RT Calculation Engine

Overview: RT Calculation Engine Optimization

The RT calculation engine will execute one pass to:

- Apply NQS commitments from DAM and PD
- Evaluate PSUs and translate to physical resource dispatch instructions
- Evaluate minimum hourly output and forbidden regions for hydro resources
- Apply ex-ante MPM results from the PD engine
- Produce dispatch instructions and prices for energy and operating reserve for the next 5-minute interval
- Produce advisory schedules and advisory prices for energy and operating reserve for the subsequent ten 5-minute intervals

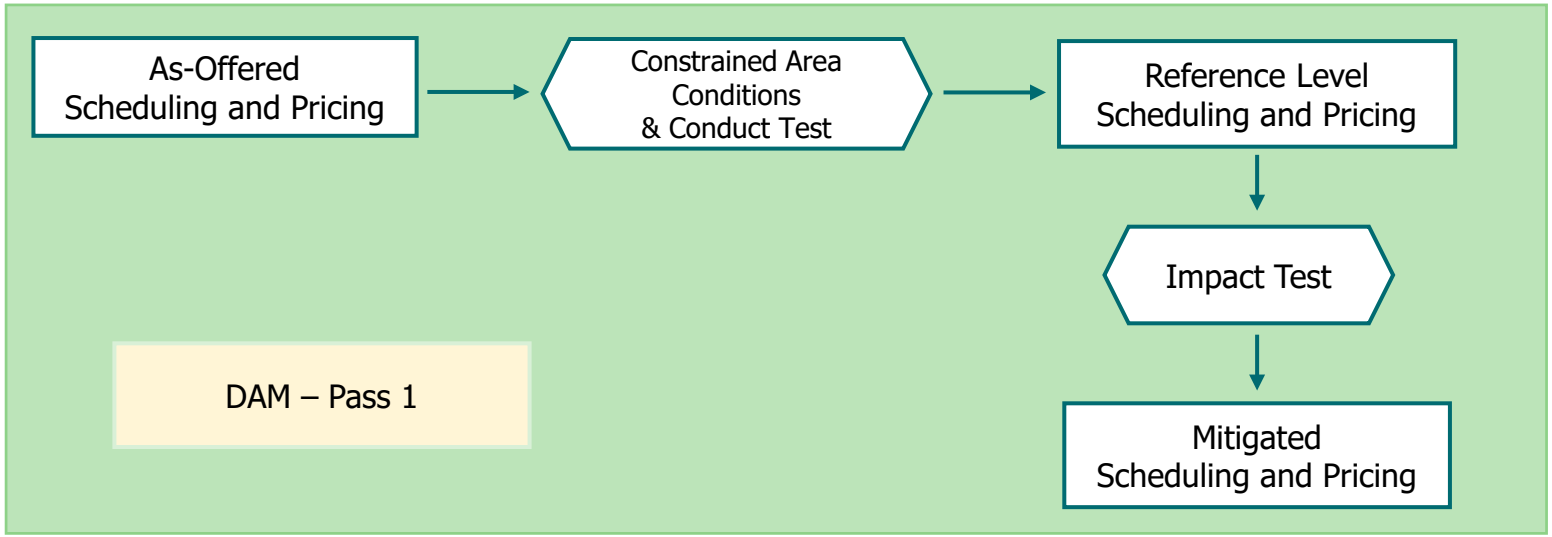
RT Calculation Engine Execution



Optimization Function Overview: Ex-ante MPM Process

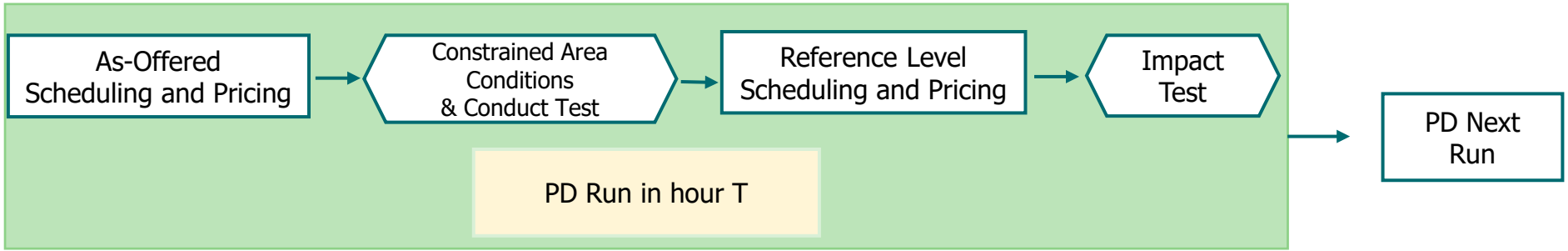
Ex-ante MPM in DAM

- Pass 1 of DAM applies the ex-ante MPM using the Conduct and Impact tests
- Ex-ante MPM uses up to six scheduling and pricing algorithms: As-Offered, Reference Level, and Mitigated



Ex-ante MPM in PD

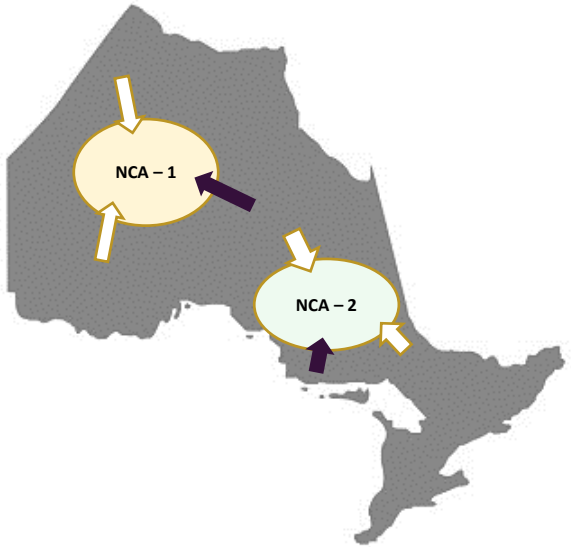
- MPM results are provided to the next scheduling algorithm of the PD engine
- Once PD applies mitigation to a resource, the subsequent PD calculation engine executions will use the resource's reference level values so mitigation decisions will be accumulated in PD



Constrained Area Conditions

- The MPM logic will activate Narrow Constrained Areas (NCAs) based on the NCA binding lines (shown in black)
- The following table shows two mitigation examples for two resources in active NCAs

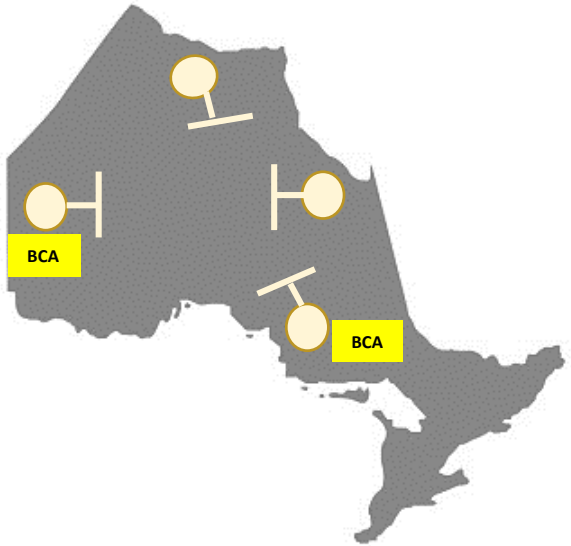
	Resource A – NCA "1"	Resource B – NCA "2"
Energy Offer	100	80
Reference Level (REL)	40	60
NCA Threshold	MIN (50%, 25$)	MIN (50%, 25$)
REL + Threshold	40 + MIN (20, 25) = 60	60 + MIN (30, 25) = 85
Conduct Test	Failed	Passed
Impact Test	Failed	N/A



Constrained Area Conditions

- The MPM logic identifies resources meet Broad Constrained Area (BCA) condition (LMP congestion > 25$/MWh)
- The following table shows two mitigation examples for two resources in the BCA

	Resource A – BCA	Resource B – BCA
Energy Offer	120	150
REL	40	60
BCA Threshold	MIN (300%, 100$)	MIN (300%, 100$)
REL + Threshold	40 + MIN (120, 100) = 140	60 + MIN (180, 100) =160
Conduct Test	Passed	Passed
Impact Test	N/A	N/A



How DAM Mitigation Works?

The example below shows how DAM mitigation assessment is working, all the mitigation decisions are reflected in the final results of the DAM run

	HE1	HE2	HE3	HE4	HE5 to HE21	HE22	HE23	HE24
As-Offered Scheduling & Pricing	<---------- Offer ---------->							

Constrained Area Conditions and Conduct Test

	HE1	HE2	HE3	HE4	HE5 to HE21	HE22	HE23	HE24
Reference Level Scheduling and Pricing	Offer	RLV	Offer	RLV		RLV	RLV	Offer

Impact Test

	HE1	HE2	HE3	HE4	HE5 to HE21	HE22	HE23	HE24
Mitigation Decisions	Offer	RLV	Offer	Offer		Offer	RLV	Offer

* HE = Hour Ending; RLV = Reference Level Value

How PD/RT Mitigation Works?

The example below shows how PD mitigation is working within the PD engine, and how the mitigation decisions are accumulated from different PD runs

PD at HE6

HE7	HE8	HE9	HE10	HE11 to HE21	HE22	HE23	HE24
Offer	Offer	Offer	Offer		Offer	Offer	Offer

PD at HE7

HE8	HE9	HE10	HE11 to HE21	HE22	HE23	HE24
Offer	Offer	RLV		Offer	Offer	Offer

PD at HE8

HE9	HE10	HE11 to HE21	HE22	HE23	HE24
Offer	RLV		Offer	Offer	RLV

Quick & Non-Quick Start Resources: Hourly Assessment

MPM constrained area conditions are determined each hour for:

- Energy Offers* (NCA, Dynamic Constrained Area (DCA), BCA or Global Market Power (GMP))
- Operating Reserve (OR) Offers (OR-Local or OR-GMP)

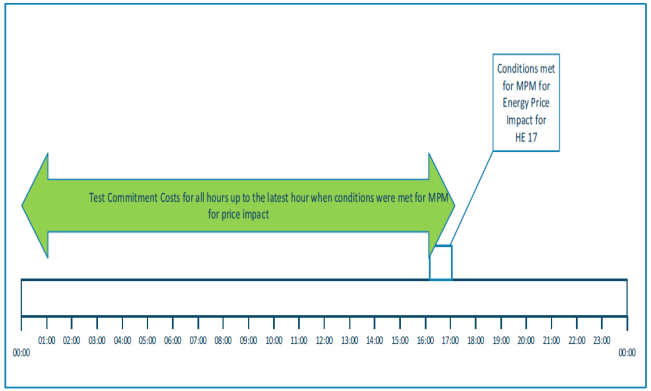
The table below shows how the hourly assessment works:

	HE1	HE2	HE3	HE4 to HE22	HE23	HE24
Energy Conditions	BCA		BCA/NCA		GMP	
OR Conditions		OR-LOCAL	OR-GMP			
Energy Offer Testing	BCA Threshold		NCA Threshold		Global Threshold	
OR Offer Testing		OR-Local Threshold	OR-GMP Threshold			

* For energy offer testing, non-quick start resources are tested above MLP

Non-Quick Start Resources: Cross-Hour Assessment

- Commitment Costs (CC), which include SU, SNL, and Energy up-to MLP (EMLP), would be assessed based on the Look-Ahead Period (i.e. from first hour to the last hour has a constrained area condition)
- The table below shows an example of how Commitment Costs are assessed



	HE7	HE8	HE9	HE10 to HE13	HE14	HE15 to HE24
Energy Conditions	BCA		NCA		GMP	
Look-Ahead for CC						
SU, SNL, EMLP	Most Restricted Threshold (from BCA, GMP, NCA) – in this case it would be NCA					

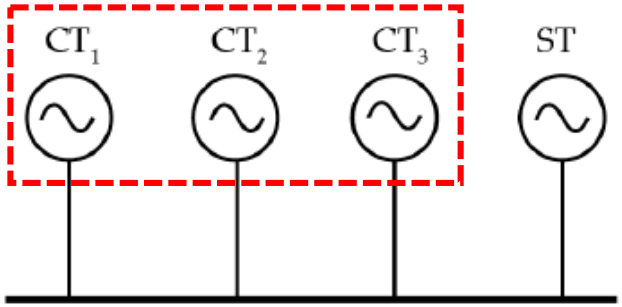
Calculation Engine Section Summary:
PSU Modelling

Overview of PSU Modelling

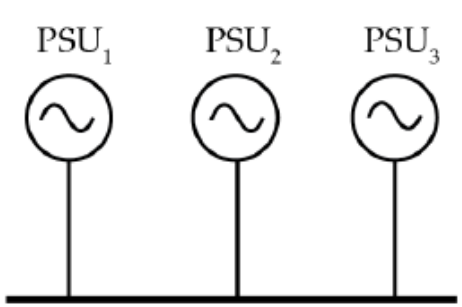
- The calculation engines model combined cycle facilities with one or more combustion turbines (CT) and one steam turbine (ST) as one or more PSUs
- Each PSU models one CT and a portion of the ST
- Each PSU is scheduled independently and proportionally according to a fixed ratio of energy output between the CT and ST within specific operating regions
- All three calculation engines will evaluate a combined cycle facility that elects PSU modelling as a set of PSU resources that capture the joint economics of operating the CT and the affiliated portion of the ST together

Overview of PSU Modelling

- Each PSU consists of one CT and its associated portion of the ST capacity to capture their operational dependency
- It will then be optimized as any other NQS resource



Physical Model



Pseudo Unit Model

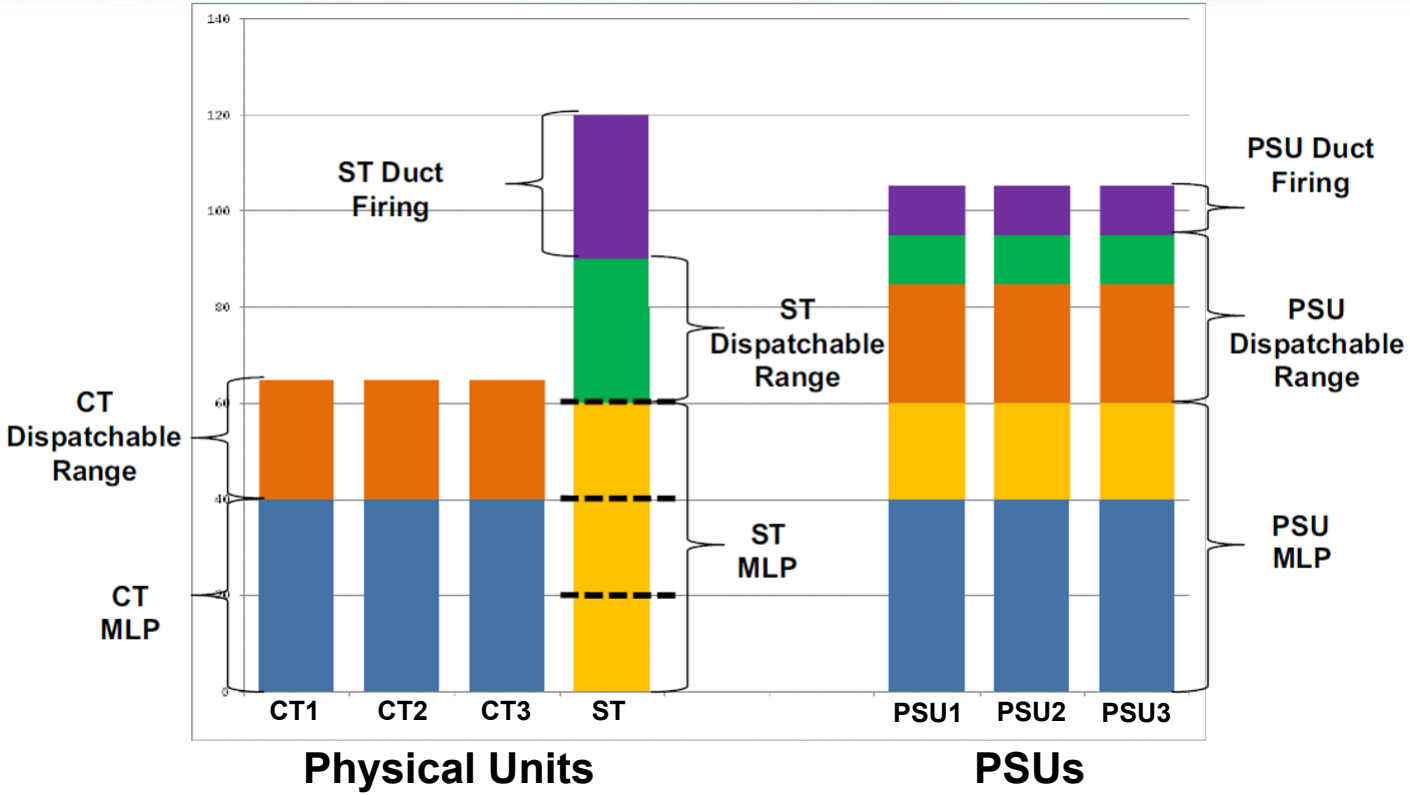
$PSU_1 = CT_1 + 1/3\ ST$

$PSU_2 = CT_2 + 1/3\ ST$

$PSU_3 = CT_3 + 1/3\ ST$

- In this example, there are three CTs and only one ST
- This plant operates in three by one (3:1) configuration
- Each CT forms a PSU with its share of the ST. In this example, the ST is shared equally with the three CTs

Overview of PSU Modelling



Three Operational Ranges:

1. Minimum Loading Point (MLP)
2. Dispatchable Range above MLP
3. Duct Firing Range

PSU Modelling

Describes the modelling and parameters of PSUs.

New PSU Modelling Features	DAM	PD	RT
Recognition of additional PSU parameters	Yes	Yes	Yes
Conversion of physical resource sensitivity factors and marginal loss factors to PSU	Yes	Yes	Yes
Conversion of PSU schedules to physical resource schedules	Yes	Yes	Yes
Translation of steam turbine forced outages	No	Yes	Yes
Translation of single-cycle mode across two dispatch days	No	Yes	No
Calculation of initial PSU schedules from translation of physical resource telemetry	No	No	Yes

Calculation Engine Section Summary:
Pricing Formulas

Pricing Formulas

Describes the calculation of LMPs using the prices coming from the pricing algorithm and adjusts them based on constraint sensitivities and marginal loss factors:

- Energy LMPs for delivery points, intertie metering points, virtual transaction zones, Ontario zonal price, and PSUs
- Operating reserve LMPs for delivery points and intertie metering points
- Price Capping Logic
- Pricing islanded nodes

Pricing Formulas

New Pricing Formula Features	DAM	PD	RT
LMP (Internal and External)	Yes	Yes	Yes
Price Capping Logic	Yes	Yes	Yes
Pricing for Islanded nodes	Yes	Yes	Yes

Next Steps

February 4 – April 15: Opportunity for stakeholders to submit clarifying questions and written feedback on the calculation engines batch

- Submit questions and feedback to engagement@ieso.ca

May: IESO to post feedback responses and revised market rules

Thank You

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