Market Rule Amendment Proposal

PART 1 – MARKET RULE INFORMATION

Identification No.:	MR-00265-R00			
Subject:	**Day-Ahead Market (DAM)**			
Title:	**DAM Calculation Engine**			
Nature of Proposal:	☐ Alteration	☐ Deletion	☒ Addition	
Chapter:	12 (new)	Appendix:	12.1 (new)	
Sections:	All			
Sub-sections proposed for amending:				

PART 2 – PROPOSAL HISTORY

Version	Reason for Issuing	Version Date
1.0	Initial submission to Technical Panel (sections 1&2 only; without Proposal Form)	October 14, 2004
2.0	Revised submission (all sections; initial submission of Proposal Form)	October 28, 2004
3.0	Revised to incorporate Technical Panel comments and prepare for Stakeholder review and comment	November 5, 2004
Approved Amendment Publication Date:		
Approved Amendment Effective Date:		

PART 3 – EXPLANATION FOR PROPOSED AMENDMENT

Provide a brief description of the following:

- The reason for the proposed amendment and the impact on the *IMO-administered markets* if the amendment is not made
- Alternative solutions considered
- The proposed amendment, how the amendment addresses the above reason and impact of the proposed amendment on the *IMO-administered markets*.

Background

In consultation with market participants and other stakeholders, the IMO developed a high level design for a day-ahead market (DAM). The IMO-Board endorsed proceeding with the development of a day-ahead market and directed the IMO to proceed with the detailed design and market rule amendments for the DAM. A detailed design document describing the DAM Calculation Engine was produced in August and subsequently updated, and represents the basis for the market rule amendments proposed for Appendix 12.1

Overview of DAM Calculation Engine

The calculation engine is the core component of the DAM. The engine receives many different inputs from market participants and the IMO, and determines financially binding DAM schedules for energy and operating reserve and corresponding DAM prices. The calculation engine also produces advisory schedules and prices for information purposes. Market rule specification of the DAM calculation engine comparable in scope and level of detail to the existing specification of the real-time market dispatch algorithm, is necessary to establish and maintain transparency and stakeholder confidence regarding the determination of the DAM schedules and prices.

The key features of the DAM calculation engine are:

1. Simultaneous co-optimization of energy and operating reserve over the full 24 hours of the next dispatch day.

2. Schedules based on maximizing the gain from trade. This is the same optimization objective as the real-time dispatch algorithm. The DAM calculation engine uses the bids and offers from market participants as the measure of the value of buying and selling electricity and operating reserve.

3. A security assessment functionality and a scheduling functionality. The security assessment functionality determines the loss factors, loss adjustments and transmission limits (including pre and post-contingency limits) as conditions to be met by the scheduling functionality in determining the scheduling of bids and offers.

4. A sequence of five passes in order to determine the financially binding schedules and prices as well as the advisory schedules and prices. The first four of these passes use the same constrained model of the IMO-controlled grid as is used in the real-time constrained

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dispatch sequence. The fifth pass uses the same unconstrained IMO-controlled grid model as is used in the real-time unconstrained dispatch sequence.

The five passes are as follows:

Pass 1 determines a security constrained, optimized load and generation resource unit commitment to meet **bid** load and IMO specified operating reserve requirements for the dispatch day. Commitments results and hourly import schedules from this pass may be financially binding (where there is a a production cost guarantee). Results from this pass are used internally by the IMO as inputs to pass 2 and settlements.

Pass 2, using the unit commitment results of pass 1, determines a security constrained, optimized load and generation resource unit commitment to meet the **IMO's forecast** of (Ontario) load and IMO specified operating reserve requirements for the dispatch day. This pass is intended to ensure that sufficient physical resources are committed and/or available to meet the IMO's expectation of load for the dispatch day. Schedules from this pass are **not** financially binding. Commitments are used internally by the IMO as inputs to settlements and passes 3, 4 and 5.

Pass 3, using unit commitment results of pass 1 and pass 2, determines security constrained optimized schedules for generation, imports, virtual supply and price-responsive loads to meet **bid** load and IMO specified operating reserve requirements for the dispatch day. Except for price sensitive loads and virtual transactions, these schedules are financially binding as the schedules are used in Settlements to balance actual real-time physical injections, imports and withdrawals. This pass also produces a set of location specific prices for energy and operating reserve for information purposes only.

Pass 4, using the unit commitment results of pass 2, determines security constrained optimized schedules for generation, imports and price-responsive loads to meet **IMO forecast** load and IMO specified operating reserve requirements for the dispatch day. The intent of this pass to produce advisory schedules which provide information to the IMO and market participants as to what may occur on the dispatch day.

Pass 5, using unit commitment results of pass 1 and pass 2, determines an **unconstrained** optimized schedules for generation, imports, virtual supply and price responsive loads to meet **bid** load and IMO specified operating reserve requirements for the dispatch day. This pass determines the uniform Ontario prices for energy and operating reserves that are used for settlement purposes. This pass also determines the unconstrained resource schedules used in the calculation of the Congestion Management Settlement Credit (CMSC) payments.

Summary of the Proposed Market Rule

This market rule amendment proposal describes in detail the calculations to determine the day-ahead commitment of resources, schedules and prices. A high level overview of the DAM Calculation Engine, is provided in section 3 of proposed new Chapter 12, (MR-00264).

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Similar to the summary above, that section identifies the inputs to the DAM calculation engine, the multiple passes of the calculation engine, their optimization objectives, and the various outputs of the calculation engine. It also describes the determination of the financially binding constrained schedules and uniform market prices for the day-ahead market. Proposed Appendix 12.1 elaborates on all these aspects of the day-ahead market.

The proposal for Appendix 12.1 contains an initial introductory section, comparable to section 3 of proposed Chapter 12, that goes into more depth on a number of matters pertinent to the inputs, outputs and the calculation. As described above, the DAM calculation encompasses 5 passes. Each of these passes constitutes a section in the proposed appendix. These sections are explained below, with emphasis on the section for pass 1. Subsequent sections are described relative to the section for pass 1.

Section 1:

Following a brief overview, this section deals with some of the major elements of the calculation – bids and offers, commitment, the IMO-controlled grid model, the forecast of Ontario load, other inputs and major outputs of the calculation. As in real-time, the DAM calculation engine uses both a constrained grid model (the first four passes) and an unconstrained grid model (pass 5). For passes 1, 3 and 5 load is determined from input bids only, and lead to financially binding schedules (pass 3 and some pass 5 schedules) as well as congestion management credits (CMSC). Passes 2 and 4 use a forecast of the Ontario load for the next day. The commitment process leads to the determination of starting and stopping times for generation and load reduction, and the scheduling of bids or purchases for a block of hours, which feed into settlements calculations for production cost guarantees (PCG).

Section 1 describes the treatment of the many types of bids and offers for energy and operating reserve, including the conditions for committing or scheduling the associated resources.

There are several examples of where the treatment of resources is noteworthy.

- The calculation engine models price responsive load bids by first assuming consumption equivalent to the maximum load reduction amount, then offsetting this by some quantity of load reduction, depending on the bid price. This is analogous to modelling the load as fixed and the load reduction as if it were a load displacement generator.

- A single load facility may bid a variety of load components into the day-ahead market, using combinations of price responsive bids, including block bids, as well as hourly and multi-hour price sensitive load bids. Each component and bid is treated independently as if it were located at a separate bus.

- The treatment of virtual bids, virtual offers and price sensitive load in passes 1 and 3 using the transmission constrained model of the IMO-controlled grid is noteworthy in two ways. First, these bids and offers are not associated with a specific location, rather their quantities are allocated across the province similar to the distribution of non-dispatchable load. This

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is done in order to minimize the possibility of creating false congestion that would not otherwise physically appear in real time. Consistent with this approach, these resources are scheduled in the constrained model based on the weighted average nodal price (locational marginal price) for energy across the province. The financially binding schedules for these resources come from the unconstrained pass 5, in which the scheduling decision is based on the uniform market price, so this treatment in pass 1 and pass 3 should not be a concern for the market participants.

- Some generating facilities may be registered as *hourly committable generation*. This means they can be scheduled to operate or not operate in any hour irrespective of their operation in other hours. Depending on how these facilities are offered for a given day, the DAM calculation engine will treat them as committable (i.e. available for scheduling) each hour, or treat them like other generation facilities where their commitment over several hours is interdependent. The calculation also allows the reverse treatment, for generation facilities which are not registered as hourly committable generation and price responsive load. Thus, if certain values in the offer or bid are zero, the facility will be treated as committable (available) each hour independently.

- Market participants for non-dispatchable facilities (self-scheduled, intermittent and transitional scheduling generation) submit self-schedules or estimates of production for the real-time market. In the day-ahead market they can choose to be scheduled by the market. If offers are submitted for these facilities, the DAM calculation engine will treat them like other generation in passes 1, 3 and 5. In the reliability passes 2 and 4 (for which forecast load is used) the estimated production for non-dispatchable loads is used as an input.

- Energy limited resources are generation facilities for which the offer designates a daily upper limit for the total scheduled energy. Because these facilities can also offer and be scheduled to provide operating reserve, it may be necessary to hold some quantity of their energy in reserve in the event that their scheduled operating reserve is activated. To recognize this, the energy limit is applied each hour by limiting the total energy scheduled up to that hour plus the operating reserve scheduled in that hour. The assumption is that if operating reserve is activated in that hour in real-time, the market participant would be able to modify its offers for successive hours and manage the remaining water available.

- As described later (in section 2) each pass includes two steps, in order to achieve a 24 hour optimization and at the same time account for multiple ramp rates which may be submitted for resources. Step 1 performs the 24 hour optimization calculation with an “effective uniform ramp rate”, while step 2 performs 24 individual one hour optimization calculations with multiple ramp rates as submitted. Because scheduling energy limited resources is done over 24 hours, energy limited resources cannot be rescheduled in step 2 with multiple ramp rates. (This is under review.)

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Section 2:

This section describes pass 1, which performs a unit commitment and security constrained scheduling process to meet bid load and IMO-specified operating reserve requirements. The first five sections are more of a verbal description of the pass, covering inputs and outputs, the optimization objective (in words), and the security assessment function. Mathematical descriptions follow these, in which variables are defined, the objective function equation is presented, constraints identified and price calculations presented and explained. Except for the security assessment description, these sub-sections are common to most other passes and later sections. The final sub-section for pass 1 is the description of step 2, which uses multiple ramp rates as input and performs 24 one hour optimization calculations.

The primary inputs to pass 1 are bids and offers for energy and operating reserve, the constrained grid model, operating reserve and other ancillary service requirements. The primary outputs (used only by other IMO processes) are i) the commitment of resources to meet the bid load and operating reserve requirements, ii) schedules for energy limited resources, imports, and exports, and iii) locational marginal prices (LMP) for energy. Commitments and the specific schedules identified are used in later passes. Commitments are also used in the settlements process. Pass 1 locational marginal prices for energy are used only in the subsequent pass 2.

The optimization performed is based on maximizing the gains from trade – the value of consumption (as represented by bids) less the cost of meeting load and other requirements (as represented by offers). The optimization for this pass is capable of performing both unit commitment and constrained scheduling processes by including commitment variables and costs along with scheduling variables and costs in the objective function. Commitment variables are associated with the startup and ongoing minimum production costs at a generation facility, and costs to initiate and continue load reduction at the minimum level for a price responsive load. The inclusion of other commitments variables – hourly blocks of imports, exports and price sensitive load – requires the value or costs associated with these block schedules be reflected in the objective function as well.

There are two groups of constraints: those which ensure that the optimization does not violate parameters specified in the bids and offers; and those which ensure that the optimization does not violate reliability criteria. In the former group are constraints which recognize energy or operating reserve limits (maximum, minimum levels, daily energy limit) and ramping limits, as well as duration requirements (minimum down times and minimum run times). The latter group includes the load balancing and operating reserve requirements, transmission and security limits within Ontario, and limits at the interties.

Similar to the real-time optimization of the Dispatch Scheduling Optimization (DSO), the DAM calculation engine objective function includes many violation variables which represent the relaxation of constraints within the formulation. These are included to ensure the processing leads to feasible solutions. The violation prices for these violation variables are the

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same as used in the real-time market for the comparable quantities.

The locational marginal price for energy can be viewed as the cost of satisfying another MWh of load at a particular location on the grid. It accounts for the cost of energy at the reference bus, losses between the reference bus and the remote location, and the additional costs from increasing congestion on any constrained transmission paths in Ontario between the two locations.

Step 2 is a variation on the formulation described in the section in detail for step 1. Step 1 performs the 24-hour optimization calculation as described. To do so however, requires using a single ramp rate (for example, for ramping up) for generation facilities or load reduction, rather than multiple ramp rates which may submitted in the bid or offer. The effective uniform ramp would allow the resource to ramp up (or down) between the minimum and maximum levels in the same time it would take using the multiple ramp rates. Initial schedules, produced in step 1, are fed into step 2 where individual hourly optimizations are performed sequentially around these, this time applying the multiple ramp rates as bid or offered. Energy limited resources require optimization over a full 24-hour period, so schedules for these are based on step 1 only.

Section 3**:**

This section describes pass 2, which performs a unit commitment and security constrained scheduling process to meet forecast Ontario load and IMO-specified operating reserve requirements. Using the forecast Ontario load allows pass 2 to determine commitments and minimum schedules day-ahead as necessary to satisfy the forecast reliability requirements for the next day.

Pass 2 has two iterations. The first iteration, pass 2A, leads to additional commitments and potentially additional imports. Pass 2B identifies minimum output levels for energy limited resources in each hour, as may be necessary to meet forecast reliability requirements.

The inputs to pass 2 differ from pass 1, in that pass 2 uses a modified forecast of Ontario load, does not use virtual bids and offers or price sensitive load bids, uses modified bids and offers for other energy resources and operating reserve, and applies limitations on import and export schedules. The primary outputs are the commitment of additional resources to meet the forecast load requirements, import schedules and minimum schedules for energy limited resources. These additional commitments are used in later passes and in the settlements process. The specified output schedules are used in later passes and as settlement information.

The purpose of pass 2A is to commit sufficient resources, in particular slow ramping generation facilities, to satisfy the next day's reliability requirements. In doing so, there is a preference given the initial determinations in pass 1, since some of these may translate into financial commitments. Commitments from pass 1 are assumed in pass 2. Exports from pass 1 are treated as fixed in pass 2 (essentially accepting these as part of the target requirements), while imports from pass 1 become minimum levels in pass 2A. Because energy limited

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resource schedules from pass 3 would be financially binding, and since these would be similar to the schedules in pass 1, it is desirable for the pass 2 schedules to be similar as well, unless there are significant benefits from modifying these.

Accordingly, two types of modifications are made to offers and bids within pass 2. For energy limited resources offer prices for the quantities scheduled in pass 1 (excluding minimum generation levels) are set to the negative locational marginal price for energy at its bus (assuming the value is positive). Since it is a negative offer price, this creates a preference for scheduling the resource to this level. It also implies the more valued the energy is at its location and in specific hours (i.e. the higher the locational marginal price) the greater will be the preference for scheduling the resource as in pass 1. For the remaining energy limited resource portions not scheduled and all other energy from generation facilities and price responsive load, offer and bid prices are set to a very small nominal price (e.g. 10 cents). Operating reserve offers prices for such Ontario resources are similarly set to this low nominal amount. These modifications result in a preference for scheduling Ontario facilities ahead of additional imports, which is consistent with relying primarily on Ontario resources to ensure reliability.

With these modifications to the offer and bid prices, the optimization objective in pass 2A - to maximize gains from trade - serves to effectively minimize the cost of committing additional resources to meet the IMO's forecast of Ontario load for the next day.

The outputs of pass 2A are additional commitments and scheduled imports. Both of these are treated as fixed for pass 2B. Pass 2B also takes as input a further modification to prices for all energy limited resources offered (incremental to the minimum generation levels). These prices are set very high, at two times MMCP plus the original offer price.

With imports fixed and energy limited resources priced so high, the optimization calculation will select all available alternatives sources – energy or operating reserve from other generation facilities or dispatchable load – before it schedules any energy from energy limited resources. Any such scheduled energy from energy limited resources becomes a minimum requirement in later passes. This is the sole output from pass 2B. Since pass 2B is performed to create minimum energy limited resource schedules only, which are determined in step 1, there is no need for step 2 in pass 2B.

Section 4:

This section describes pass 3, which given the commitments of pass 1 and pass 2, performs a security constrained scheduling process to meet bid load and IMO-specified operating reserve requirements. This pass leads to the financially binding constrained schedules for most resource types (except virtual bids and offers, and price sensitive load).

Like section 2 for pass 1, this section begins with a verbal description of the pass (input, output, objective) followed by the mathematical statement of the formulation, including the

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manner in which locational prices are calculated for energy and operating reserve.

Inputs to pass 3 are similar to those for pass 1 – (unmodified) bids and offers for energy and operating reserve, the constrained grid model, operating reserve and other ancillary service requirements. However, pass 3 also takes as input the commitments as determined in pass 1 and 2 (for startups etc. and multi-hour transactions), as well as the minimum schedule requirements for energy limited resource. The primary outputs are constrained schedules, and locational prices for energy and operating reserve. Pass 3 also calculates losses (scheduled supply minus scheduled purchases) for later input to pass 5.

The optimization calculation performed maximizes the gains from trade – the value of consumption less the cost of meeting load and other requirements. Pass 3 decides the optimal hourly scheduling of resources (the constrained scheduling process) and ignores any fixed costs associated with already determined commitments.

Section 5:

This section describes pass 4, which given the commitments of pass 1 and pass 2, performs a security constrained scheduling process to meet forecast load and IMO-specified operating reserve requirements. This pass provides advisory schedules for the IMO and market participants regarding the next day's production, consumption and locational marginal prices, taking into account the forecast load and commitments from the day-ahead market. There are no settlements associated with the results of this pass, which are used for information only.

Like pass 2, pass 4 uses forecast load, excludes virtual bids and offers and price sensitive load, and fixes exports at the pass 1 levels. Like pass 3 it uses bids and offers as submitted for generation facilities and price responsive load, the commitments from pass 1 and pass 2, and the minimum energy limited resource schedules. Imports schedules and estimated production for non-dispatchable generation facilities are fixed at the levels determined in pass 2.

With imports and exports fixed, the optimization calculation performed minimizes the cost of meeting forecast Ontario and operating reserve requirements. Pass 4 decides the optimal hourly scheduling of resources, leading to projected constrained schedules and projected locational prices for energy and operating reserve.

Section 6:

This section describes pass 5, which given the commitments of pass 1 and pass 2, performs an unconstrained scheduling process based on bids and offers. Inputs to pass 5 are identical to pass 3, except that pass 5 uses the unconstrained grid model and estimates losses based on the results of pass 3. This pass produces unconstrained schedules and the unconstrained market prices for energy and operating reserve, including uniform prices for Ontario and prices in the intertie zones. These are used in the settlements process. These pass 5 prices are the basis for all day-ahead settlements. Unconstrained schedules for price sensitive load and virtual transactions become the financially binding day ahead market schedules. For other resources

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differences between the constrained schedules of pass 3 and the unconstrained schedules of pass 5 may translate into congestion management settlements credits (CMSC).

PART 4 – PROPOSED AMENDMENT

See Attachment.

The attached proposed amendments, while not shown as (redlined) changes to existing market rules, represent entirely new sections in the market rules.

PART 5 – IMO BOARD COMMENTS

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Appendix 12.1: Day-Ahead Market Calculation Engine

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Appendix 12.1: Day-Ahead Market Calculation Engine

1.1 Overview

1.1.1 This Appendix sets forth a description of the *DAM calculation engine* and the inputs and process used to determine *day-ahead market constrained schedules*, *unconstrained schedules*, constrained (shadow) prices and unconstrained prices. Specifically, the *DAM calculation engine* produces the following primary outputs for the *day-ahead market*:

1.1.1.1 based on the *bids* and *offers* received:

i) *constrained schedules* and *facility* commitments,

ii) constrained *locational marginal prices* for *energy*,

iii) *unconstrained schedules*, and

iv) unconstrained uniform *market prices* for *energy* and *operating reserve*.

which support the determination of *market participant* financial obligations and payments associated with *bid* load and *operating reserve* requirements; and

1.1.1.2 based on *bids* and *offers* received and *forecast Ontario load* for the next day:

i) additional *constrained schedules* and *facility* commitments, and

ii) corresponding constrained *locational marginal prices* for *energy*.

which support the *IMO security* assessment and commitment payments related to the additional *forecast Ontario load*.

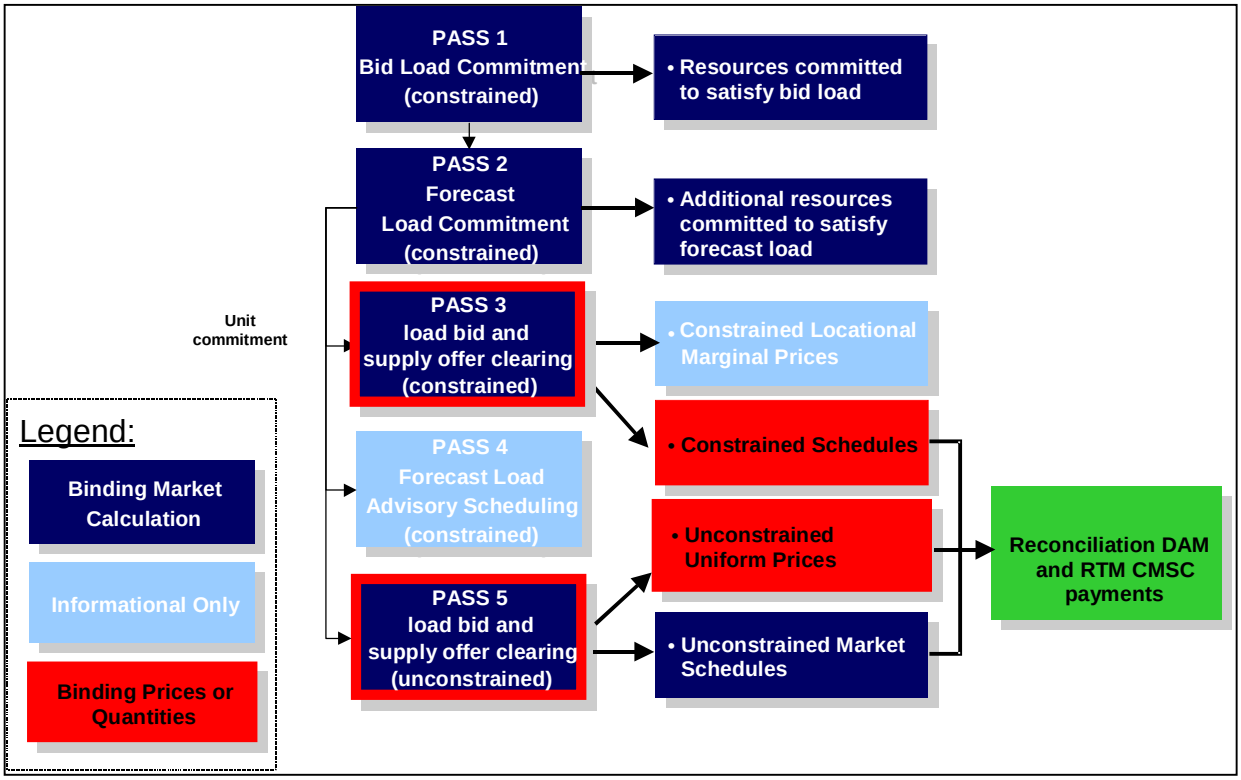
1.1.2 The *day-ahead market* shall be cleared by the *DAM calculation engine,* which is composed of multiple passes. Each pass has a distinct role in creating financially binding *day-ahead market* schedules and prices (*pass 3* and *pass 5*), and anticipated (but non-binding) schedules and prices for the real-time market (*pass 4*). The multiple pass *DAM calculation engine* determines the optimal commitment of resources and *constrained schedules* over a 24 hour period for *energy* and *operating reserve*

1.1.3 The *DAM calculation engine* is able to optimize resource selection with and without consideration of transmission constraints. It also is able to assess the *security* of the *IMO-controlled grid*, for those passes which consider transmission constraints.

1.1.4 An overview of the five passes of the *DAM calculation engine* is provided in section 3 of Chapter 12 A detailed mathematical description of the *DAM calculation engine* formulation is provided through the description of each of the passes in sections 2 through 6 of this Appendix.

1.1.5 The relationship of the different passes of the *DAM calculation engine* is shown in Figure 1.The first four passes consider transmission constraints and associated *security* limits. The fifth pass ignores transmission constraints and *security* within Ontario in its calculations.

Figure 1: DAM Calculation Engine – Relationship of Passes



1.1.6 The inputs into the *DAM calculation engine*, the formulation of the algorithm to produce schedules and prices, and outputs are described generally in this section 1 of this appendix. The *security* assessment activity is described in section 2, as part of the description of process for the *pass 1*.

1.2 Load and Bids to Purchase Energy

1.2.1 *Bids* to purchase *energy* or provide load reduction in the *day-ahead market* shall be interpreted as follows and used in the optimization calculations accordingly:

1.2.1.1 Each *price-quantity pair* in a *price sensitive load bid* or *virtual bid* designates the maximum amount of *energy* that the *registered market participant* wishes to purchase if the price for *energy* is no more than the *bid* price. In the unconstrained scheduling process of *pass 5*, this means that binding financial schedules to purchase *energy* occur if the uniform *market price* for *energy* is no more than the *bid* price.

1.2.1.2 In a constrained scheduling process purchases scheduled from *price sensitive loads* and *virtual bids* shall be represented as load distributed across Ontario, in order to minimize the potential congestion which might occur if these were applied in a single location. These *bids* will be distributed at locations and in the same proportion as the forecast *non-dispatchable load*. Along with the treatment in section 1.2.1.1, this means that in a constrained scheduling process such distribution will result in non-binding schedules to purchase *energy* if the *bid* price is more than the average *locational marginal price* for *energy* weighted by the same proportions as the load distribution.

1.2.1.3 Multi-hour *bids* for *price sensitive load* shall be scheduled for all hours designated in the *bid* if the average price for *energy* in those hours is less than the *bid* price.

1.2.1.4 *Multi-part bids* from *price responsive load* designate:

i) the maximum *energy* to be purchased irrespective of price and assuming no load reduction,

ii) the minimum amount of load reduction,

iii) the costs if load reduction is initiated, and

iv) prices at which the *market participant* is willing to reduce load by the specified quantity incrementally above the *minimum load reduction*.

The scheduling process assumes the maximum quantity is scheduled for purchase then, depending on the total costs of load reduction relative to other options, may schedule load reduction as well.

1.2.1.5 Multiple block *bids* for *price responsive load* represent discrete levels of load reduction within a *load facility*. Such *bids* shall be scheduled for load reduction for all hours designated in the *bid* if the average price for *energy* in those hours is more than the *bid* price.

1.2.1.6 Each *price-quantity pair* in an hourly *bid* to *export energy* at an *intertie zone* designates the maximum amount of *energy* that the *registered market participant* wishes to purchase if the *energy* price at the *intertie zone* is no more than the *bid* price.

1.2.1.7 Multi-hour *bids* to *export energy* at an *intertie zone* shall be scheduled for all hours designated in the *bid* if the average price for *energy* in the *intertie zone* in those hours is less than the *bid* price.

1.2.2 *Price responsive load bids* may include multiple ramp rates for load reduction. As described more fully for *pass 1*, in step 1 of all passes multiple ramp rates are replaced by a uniform ramp rate. The effective uniform rate requires the same time as the *bid* ramp rates to ramp up or down between the *minimum load reduction* level and the *maximum load reduction bid*. Step 2 of each *pass* uses multiple ramp rates as submitted.

1.2.3 Multiple *load component bids* may be submitted for a single load *facility*. Each *bid* shall be treated separately. Each *price sensitive load bid* for a *facility* is scheduled independently based on the assumed distribution of loads. Combinations of multi-part *bids* for *price responsive load* and block *price responsive load bids* shall be treated as being at separate buses. The optimization relies on separate checks of the submitted *bids* against the registration data to ensure the total maximum purchases *bid* for the *facility* do not exceed the physical capability of the *load facility*

1.2.4 *Bid*s from *price responsive loads* which have the following portions of the *bid* data set to zero will be treated as committed for all *bid* hours in all passes. Such data indicate there are no costs associated with their commitment nor any restriction on hours committed. The data which must be set to zero for this treatment include:

1.2.4.1 *minimum load reduction*;

1.2.4.2 costs associated with initiation of load reduction and operation at the *minimum load reduction*; and

1.2.4.3 *minimum load reduction time* and *minimum time between load reductions*.

1.3 Generation and Offers to Sell Energy

1.3.1 *Offers* to sell *energy* in the *day-ahead market* shall be interpreted as follows and used in the optimization calculations accordingly:

1.3.1.1 In a constrained scheduling process v*irtual offers* shall be represented as distributed across Ontario, at locations and in the same proportion as the forecast *non-dispatchable load*. In a constrained scheduling process such distribution will result in non-binding schedules to sell *energy* if its *offer* price is no more than the average *locational marginal price* for *energy* weighted by the same proportions as the load distribution. . In the unconstrained scheduling process of *pass 5*, this means that binding financial schedules to sell *energy* occur if the uniform *market price* for *energy* is more than the *offer* price.

1.3.1.2 *Multi-part offers* for a *generation facility* designate any *minimum generation level* to be sold if committed, incremental *energy* above the *minimum generation level*, the ongoing and startup costs for the *facility* and prices at which the *market participant* is willing to sell the incremental *energy*.

1.3.1.3 Each *price-quantity pair* in an hourly *offer* to *import energy* at an *intertie zone* designates the maximum amount of *energy* that the *registered market participant* wishes to sell if the *energy* price at the *intertie zone* is no less than the *offer* price.

1.3.1.4 Multi-hour *offers* to *import energy* at an *intertie zone* shall be scheduled for all hours designated in the *offer* if the average price for *energy* in the *intertie zone* in those hours is no less than the *offer* price.

1.3.2 *Non-dispatchable generation facilities* may *offer* to sell *energy* in the *day-ahead market*.

1.3.2.1 In *pass 1* such *facilities* may be committed and scheduled to produce *energy* based on their *offers.*

1.3.3 *Non-dispatchable generation facilities* are required to submit data representing expected production in each hour of the next day if the *energy market price* exceeds the price specified in the submitted data.

1.3.3.1 Based on this data and anticipated *market prices* for *energy* for the next day the *IMO* will estimate expected production from these *facilities*.

1.3.3.2 In the event that the *facility* is committed and scheduled in *pass 1*, the estimated production will be set to be no lower than the total

output scheduled for the *facility* in *pass 1*, including any *minimum generation level* committed.

1.3.3.3 This estimated production will be used as an input to *pass 2* and *pass 4* only. In other passes, *offers* as submitted by the *market participant* and the commitments from *pass 1* will be used as inputs.

1.3.4 *Offer*s from *energy limited resources* may specify a limit on the total *energy* which may be scheduled for the day.

1.3.4.1 The optimization in each pass will respect such input daily *energy* limits.

1.3.4.2 The total *energy* scheduled for the day will include a contribution from scheduled *operating reserve*, representing the quantity of energy which may be activated (being called on to produce *energy*). Since in real-time a *market participant* may modify *offers* for subsequent hours following any activation of *operating reserve*, only one hour of *operating reserve* at a time will be considered day-ahead in the application of the energy limit.

1.3.5 *Offers* for *generation facilities* may include multiple ramp rates. As described more fully for *pass 1*in section 2.10, in step 1 of all passes multiple ramp rates are replaced by an effective uniform ramp rate. At the effective uniform rate the time required to ramp up or down between the *minimum generation level* and the maximum *offer* is the same as at the *offer* ramp rates. Step 2 of each *pass* uses multiple ramp rates as submitted.

1.3.6 *Offer*s for *energy limited resources* may include multiple ramp rates for *energy*. However, schedules for *energy limited resources* will be determined in step 1 of each pass, which is based on the effective uniform ramp rate.

1.3.7 G*eneration facilities* which are not registered as *hourly committable generation* may be treated as committable hourly. *Generation facilities* with *offer*s which have the following portions of the *offer* data set to zero will be deemed to be committable hourly and will be committed for all *offered* hours in all passes. Such data indicate there are no costs associated with their commitment nor any restriction on hours committed. The data which must be set to zero for this treatment include:

1.3.7.1 *minimum generation level*;

1.3.7.2 costs associated with startup and operation at the *minimum generation level*;

1.3.7.3 *minimum run times* and *minimum down times; and*

1.3.7.4 *maximum stops per day*.

1.3.8 *Offer*s from ho*urly committable generation* may indicate the *facility* is to be treated as committable hourly. Such *facilities* may be committed in *pass 1* for any or all hours, according to the submitted *offer* data.

1.3.8.1 For such *facilities*, excluding *energy limited resources*, the commitments in *pass 1* are used to indicate availability for *pass 3* and *pass 5* scheduling. If such resources are not committed in *pass 1* these will then be treated in *pass 2* and *pass 4* as committed for all *offered* hours, without any costs associated with their commitment or restriction on hours committed.

1.3.8.2 For such *facilities* which are *energy limited resources*, if not committed in *pass 1* these will then be treated in *pass 2* and and all subsequent passes as committed for all *offered* hours, without any costs associated with their commitment or restriction on hours committed.

1.3.9 *Offer*s from ho*urly committable generation* may indicate through the withdrawal flag that the *facility* is not to be treated as committable hourly. Such facilities may be committed in *pass 1* for any or all hours, according to the submitted *offer* data. If not committed in *pass 1*, their commitment in *pass 2* will continue to be based on their submitted *offer* data. Commitment in *pass 1* or *pass 2* then leads to being committed for all subsequent passes, the same treatment as other *generation facilities*.

1.4 Offers for Operating Reserve

1.4.1 *Offer*s to provide *operating reserve* may be submitted for *dispatchable generation facilities* , *price responsive dispatchable load* resources, and hourly *import* or *export* resources. Such *offers* shall be used as input to the optimization calculations.

1.4.2 *Operating reserve offers* may be scheduled to meet the requirements for synchronized *ten minute operating reserve*, total *ten-minute operating reserve* and *thirty-minute operating reserve*, in accordance with the class of *operating reserve offered*. In addition these *offers* may be used to meet reserve area *ten-minute* and *thirty-minute operating reserve* requirements in a constrained optimization, for the areas in which they are located.

1.4.3 *Operating reserve offered* for qualified *price responsive loads* and hourly exports may be scheduled to provide *operating reserve* only to the extent there is a purchase scheduled for the resource. In the case of a *price responsive dispatchable load* resource, the *operating reserve* schedules are limited by the net purchase (accounting for any scheduled load reduction).

1.4.4 Only those *generation facilities* committed may be scheduled to provide *operating reserve*.

1.5 Commitment and Availability of Resources for Scheduling

1.5.1 The *unit commitment* process in the *DAM calculation engine* deals with the availability of resources for scheduling where schedule decisions in a group of hours may be linked or where there are minimum levels which must be considered. There are three types of decisions in *pass 1*and *pass 2,* from which the availability of these resources is determined namely:

1.5.1.1 the commitment of *generation facilities* and *price responsive load* reductions, which identify the hours of scheduled operation or load reduction, respectively;

1.5.1.2 the commitment of multi-hour *bids* for *price sensitive load* and exports and multi-hour *offers* for imports, which is based on the decision to schedule the *bid* or *offered* quantity for all hours specified in the *bid* or *offer*; and

1.5.1.3 the commitment of *generation facilities* and *price responsive load* reductions which are deemed to be available (that is, committable hourly) in subsequent passes. This may apply to resources for which *bid* and *offer* data contains zeros, as specified in sections 1.2.4 and 1.3.7.

Commitments of the first two types may lead to production cost guarantee payments except for price sensitive load and exports. Commitment of the last type is meaningful only for the purpose of the *DAM calculation engine*, which uses this as intermediate information input to later passes.

Commitment is necessary in *pass 1* or *pass 2* to allow the DAM calculation engine to schedule these resources in *pass 3, pass 4* or *pass 5*.

1.5.2 *Unit commitment* takes place in *pass 1* to meet the requirements of *bid* loads and *operating reserve*, and in *pass 2* to satisfy any additional requirements associated with the *forecast Ontario load*. The two *pass* approach for commitment permits distinguishing commitments for *bid* and *operating reserve* requirements from those additional commitments required for the *forecast Ontario load*.

1.5.3 Minimum or multi-hour fixed uniform schedules levels may be associated with the *facility commitment* for a given *bid* or *offered* resource. As such, the *facility* commitments and related minimum or uniform schedules may occur

for multi-part and block *bids* for *price responsive load,* multi-part *offers* for *generation facilities,* and multi-hour *bids* and *offers.*

1.5.4 For all other resources no commitment decision is needed and these resources are considered to be available for scheduling in all hours *bid* or *offered,* with the following exceptions*:*

1.5.4.1 the schedule for hourly exports in *pass 1* is used as the schedule for *pass 2* and *pass 4*; and

1.5.4.2 the schedule hourly imports in *pass 1* becomes a minimum schedule for *pass 2* and the *pass2* schedule is used as the schedule for *pass 4.*

1.5.5 Facilities providing AGC and *reliability must-run resources* will be committed in all passes

1.6 IMO-Controlled Grid Model

1.6.1 There are two treatments for the modelling of the *IMO-controlled grid*, one for the constrained optimization used in *pass 1* through *pass 4* and one for the unconstrained optimization in *pass 5*.

1.6.2 The requirements for the *constrained IMO-controlled grid model* for the *day-ahead market* are the same as those for the *real-time market* as described in section 2.4 of Appendix 7.5 of Chapter 7.

1.6.3 The requirements for the *unconstrained IMO-controlled grid model* for the *day-ahead market* are the same as those for the real-time market as described in the pertinent sub-sections of section 3.2 of Appendix 7.5 of Chapter 7, namely sections 3.2.1.1, 3.2.1.1.A, 3.2.1.2, and 3.2.1.3.

1.7 Forecast Ontario Load

1.7.1 The *IMO* shall prepare the *forecast Ontario load*, the total amount of load in Ontario for each hour *h* of the next day, and adjustments for estimated consumption that would occur from *price-responsive bids*.

1.7.2 For input to the DAM calculation engine each hour's forecast shall be modified as necessary to represent the *IMO's* expectation of the total Ontario load, , at the time during hour *h* at which load may be highest, reduced by the estimated *price responsive load*.

1.7.3 The load forecasts will take into account all significant factors that are likely to affect load, including:

1.7.3.1 how consumption has varied in the past as a result of weather conditions at various locations throughout Ontario;

1.7.3.2 day of the week;

1.7.3.3 consumption in preceding days; and

1.7.3.4 any load growth factors needed to reflect changes relative to past consumption.

In addition, these may take into account the anticipated effect of prices on the amount of *energy* consumed, using the *locational marginal prices* calculated in *pass 1*.

1.7.4 The modified forecast of Ontario load referred to in section 1.7.2,will be used as inputs to *pass 2* and *pass 4.*

1.8 Other Inputs

1.8.1 Initializing variables must be input for the *day-ahead market unit commitment* and scheduling processes to represent conditions in the last hours of the previous day's *day-ahead market*. Such data will represent the number of consecutive hours of run-time or down-time, for a *generation facility*, or consecutive hours of load reduction or hours not providing load reduction, for a *price responsive load*, in the schedules at the end of the previous day's *day-ahead market. A*s well, operating levels scheduled for the last hour of this previous day are required.

1.8.2 Normally, such initialization variables are based on the outcomes of the previous day's *day-ahead market* commitments from *pass 2* and schedules from *pass 4*, which provide projections of anticipated operation. The *IMO* may update such default data to reflect significant operational changes, such as *outages*, deratings or unscheduled *facility* starts.

1.9 Global Outputs

1.9.1 The *DAM calculation engine* shall provide the following *facility* commitment and schedule information:

1.9.1.1 commitments for the startup and operation of *generation facilities* at *minimum generation levels* and the initiation and continued *minimum load reduction* of *price responsive resources*;

1.9.1.2 commitments for multi-hour schedules:

1.9.1.3 financially binding schedules for the sale and purchase of *energy* for each hour;

1.9.1.4 financially binding schedules for the provision *of operating reserve* for each hour;

1.9.1.5 *unconstrained schedules* for the sale and purchase of *energy* for each hour;

1.9.1.6 *unconstrained schedules* for the provision of *operating reserve* for each hour;

1.9.1.7 a set of advisory schedules for the *IMO security* assessment for the next day;

1.9.1.8 violation variables indicating supply shortfalls or surpluses and constraint violations in the schedules.

1.9.2 The *DAM calculation engine* shall be capable of providing the following price or cost related information for each hour:

1.9.2.1 uniform *day-ahead market prices* for *energy* and different types of *operating reserve*, including corresponding prices for *intertie zones*;

1.9.2.2 *day-ahead locational marginal prices* for *energy*;

1.9.2.3 the marginal value (shadow prices) of relaxing constraints which are binding;

1.9.2.4 total cost of the objective function.

1.10 Interpretation

1.10.1 This appendix describes in detail step 1 for each pass, with all variables, the optimization objective and constraints expressed as they are used in the first step. The further requirements for step 2 are described for each pass as the modifications necessary to the step 1 definition.

1.10.2 Unless as otherwise noted, all variables and parameters shall be non-negative.

1.10.3 Boolean status variables take on values 1 or 0 indicating whether the condition does or does not apply, respectively.

1.10.4 Where a verbal equation or expression conflicts with a corresponding mathematical expression or equation, the mathematical expression or equation shall take precedence.

1.10.5 Reference to transmission flows, limits and constraints in this Appendix includes ***security*** related flows, limits and constraints and may represent constraints which are combinations of flows across separate internal transmission or ***intertie facilities***. References to transmission constrained or ***security*** constrained are to be treated equivalently.

1.10.6 References to "least cost" or "optimal" should be interpreted as consistent with the optimization objective of maximizing gains from trade based on ***bids*** and ***offers***, which for fixed purchases would be achieved by minimizing costs.

2. Pass 1: Constrained Commitment to Meet Bid Load

2.1 Pass 1 Overview

2.1.1 This *pass 1* for the *day-ahead market* performs least cost *security constrained unit commitment* and *constrained scheduling* processes to meet load as *bid* and *IMO*-specified *operating reserve* requirements.

2.1.2 This pass will use *bids* and *offers* submitted by registered market participants to maximize gains from trade. The optimization is subject to the constraints accompanying those *bids* and *offers*, and constraints imposed by the *IMO* to ensure reliable service, as described in section 2.8.

2.1.3 In order to accommodate multiple ramp rates (up and down) in *bids* and *offers, pass 1* and the other passes perform two steps. Step 1, which is described in detail, performs a 24 hour optimization using two uniform ramp rates, one for ramping up and one for ramping down. In step 2, as described in section 2.10,commitments and schedules are used from step 1 to perform 24 independent hourly optimizations in which multiple ramp rates are recognized.

2.2 Inputs for Pass 1

2.2.1 Inputs to the *pass 1* process are required to represent:

2.2.1.1 *bids* to purchase *energy* or provide load reduction including characteristics of associated physical *facilities*;

2.2.1.2 *offers* to sell *energy* including characteristics of associated physical *facilities*;

2.2.1.3 *offers* to provide *operating reserve*;

2.2.1.4 the *IMO-controlled grid* and *interties*, including flow limits and *security* constraints on these;

2.2.1.5 ancillary service requirements including *operating reserve* requirements;

2.2.1.6 other assumptions such as load distributions, initializing assumptions from the previous day; and

2.2.1.7 cost coefficients for violations variables which represent a relaxation on specified constraints.

2.2.2 *Pass 1* shall accept as input the following types of *bids* to purchase *energy*:

2.2.2.1 *bids* for *price sensitive load*;

2.2.2.2 multi-hour *bids* for *price sensitive load*;

2.2.2.3 block *bids* for *price sensitive load*;

2.2.2.4 *multi-part bids* for *price responsive load*;

2.2.2.5 block *bids* for *price responsive load*;

2.2.2.6 *virtual bids*;

2.2.2.7 hourly *bids* to *export energy*; and,

2.2.2.8 multi-hour *bids* to *export energy*.

Bids may include data representing the operating characteristics of the resource, such as ramp rates, *minimum load reduction* levels, *minimum load reduction time*, *minimum time between load reductions*, *maximum load reduction cycles per day*, start and end hours for multi-hour *bids*.

2.2.3 *Pass 1* shall accept as input the following types of *offers* to sell *energy*:

2.2.3.1 *offers* for *generation facilities*, including *dispatchable* and *non-dispatchable generation facilities*;

2.2.3.2 *virtual offers*;

2.2.3.3 hourly *offers* to *import energy*; and

2.2.3.4 multi-hour *offers* to *import energy*.

Offers may include data representing the operating characteristics of the resource, such as ramp rates, *minimum generation levels*, *minimum run-time*, *minimum down time*, *maximum stops per day*, *maximum daily energy limit*, start and end hours for multi-hour *offers*.

Additional data must be input to identify any *outages* or deratings of the *generation facility*.

2.2.4 *Pass 1* shall accept as input the following *offers* to provide *operating reserve*:

2.2.4.1 *offers* from *dispatchable generation facilities*;

2.2.4.2 *offers* associated with *multi-part bids* for *price responsive dispatchable load* ;

2.2.4.3 *offers* associated with hourly *offers* to *import energy*;

2.2.4.4 *offers* associated with hourly *bids* to *export energy*.

Ramp rates for *operating reserve* will be specified in the *bids* or *offers*.

2.2.5 The *IMO* will specify for *pass 1* data describing the *IMO-controlled grid* and *interties*, including flow limits and *security* constraints on these. These include:

2.2.5.1 the operating characteristics of the *IMO-controlled grid* and *interties* not limited to, the physical flow and loss characteristics and flow limits of transmission and *intertie facilities;*

2.2.5.2 *security* constraints determined by the *IMO* to be applicable;

2.2.5.3 the *outage* schedules for transmission and *intertie facilities*; and

2.2.5.4 data describing flows caused by imports and exports, as well as unscheduled flows.

2.2.6 The *IMO* will specify for *pass 1* data describing ancillary service and must-run requirements, including:

2.2.6.1 total *ten-minute operating reserve* and total *thirty-minute operating reserve* requirements and the fraction of *ten-minute operating reserve* which must be synchronized;

2.2.6.2 reserve area requirements and limits, for *ten-minute* and *thirty-minute operating reserve*;

2.2.6.3 maximum or minimum limits on net injections by *generation facilities* providing voltage support;

2.2.6.4 any requirements for *reliabilty must-run resources*.

2.2.7 The *IMO* will specify other data for *pass 1*:

2.2.7.1 data representing the distribution of load across the *IMO-controlled grid*; and

2.2.7.2 initializing assumptions describing the operation of *generation facilities* or *load components* at the end of the previous *day-ahead market*, as may be adjusted for unplanned *outages* or starts.

2.2.8 The *IMO* will input to *pass 1* the current cost coefficients for violations variables, as established for the *real-time market*, representing a relaxation of the constraints for:

2.2.8.1 *non-dispatchable load* requirements;

2.2.8.2 *operating reserve* requirments; and

2.2.8.3 transmisison limit constraints for internal transmission and *intertie facilities*.

2.3 Optimization Objective for Pass 1

2.3.1 The objective function of *pass 1* is to maximize the gains from trade. (See section 2.7 for the complete statement of the objective function.) This is accomplished by maximizing the sum of the following hourly and daily quantities:

For each hour of the trade day

the value of:

- scheduled *price sensitive load* (i.e. scheduled *energy* * *bid* price)
- scheduled *virtual bids*
- scheduled hourly exports

less the cost of:

- scheduled *operating reserve* from exports
- the foregone opportunity due to scheduled *price responsive load* reductions, incremental to any committed *minimum load reduction*
- ongoing hourly costs or lost value at *minimum load reduction* for committed *price responsive load*
- initiating the committed *minimum load reduction* for *price responsive load*
- scheduled *operating reserve* from *price responsive load*
- scheduled *virtual offers*
- scheduled hourly imports

- scheduled *operating reserve* from imports
- scheduled *operating reserve* from *generation facilities*
- scheduled *generation offers*, incremental to any committed *minimum generation level*
- ongoing hourly costs at *minimum generation level* for committed *generation*
- startup cost for committed *generation*

less the cost of:

- scheduled violation variables

One time quantities for the day

the value of:

- multi-hour exports, over all scheduled hours

less the cost of:

- multi-hour imports, over all scheduled hours

the value of:

- multi-hour *price sensitive load*, for all hours scheduled

where:

the cost for each violation variable each hour is the hourly magnitude of the violation variable multiplied by the price (in $ per MW per hour) for relaxing the particular constraint. The hourly cost associated with all violations variables is the sum of the individual hourly costs for:

- forecast load curtailment (= 0 for *pass 1*) due to a supply deficit
- scheduling additional load to offset surplus must-run *generation* requirements (the minus sign is required since the violation price is negative)
- *operating reserve* requirement deficits

- all reserve area minimum *operating reserve* requirement deficits
- all reserve area *operating reserve* excesses above maximum requirements
- pre-contingency and post-contingency limit violations for internal *transmission facilities*
- pre-contingency limit violations for *import* or *export interties*
- exceeding the up or down ramp limits for the total net schedule change for imports and exports.

2.3.1 The objective function for *pass 1* (and other pases) includes quantities and associated costs which are variable and affect the optimization. Quantities which are constant, such as the maximum consumption by price responsive load, are omitted from the objective function but do appear in the constraints, for example as withdrawals at a bus, if these are affected.

2.4 Security Assessment

2.4.1 For the *constrained scheduling* process, the *security* assessment function iterates with the scheduling function. The scheduling function produces schedules which are passed to the *security* assessment function. The security assessment function determines losses and additional constraints which feed back to the subsequent iteration of the scheduling function.

The *security* assessment function used by *pass 1*is common to the first four passes of the *DAM calculation engine* which account for transmission constraints.

2.4.2 The *security* assessment performs following calculations and analyses:

2.4.2.1 Base case solution: For the hour and the *load* and *generation facility* schedules produced by the scheduling function of the *DAM calculation engine*. a base case solution function prepares a power flow solution for each hour. This fucntionautomatically selects the power system model state (i.e., breaker/switch status, tap positions, desired voltages, etc) applicable to the forecast of conditions for the hour and input schedules.An AC load flow program is used,

howevera DC load flow may be used should the AC load flow fail to converge.

2.4.2.2 Loss calculation: The solved power flow is used to calculate Ontario transmission system losses, incremental loss factors and loss adjustments to be used in the power balance constraint of the scheduling function.

2.4.2.3 Pre-contingency *security* assessment: Continuous thermal limits for all monitored equipment and operating *security limits* are monitored to check for pre-contingency limit violations. Violated limits are linearized and incorporated as constraints for use by the scheduling function . This list is passed on to the scheduling function.

2.4.2.4 Linear contingency analysis: A variation of the DC load flow is used to simulate all contingencies which may be of concern for the given power system model state, calculate post contingency flows and check for limited time (i.e. emergency) thermal limit violation. Violated limits are linearizedincorporated as constraints for use by the scheduling function.

2.4.3 In the first iteration before any processing by the *security* assessment functions, an initial default set of incremental loss factors and loss adjustments are used in the scheduling function. In this iteration there are no transmission constraints from the security assessment -. In subsequent iterations, the outputs from the *security* assessment function are used.

2.4.4 The *IMO* maintains a set of databases for use in the security assessment processes for the real-time market and operation. The DAM security assessment function will use this same set of databases to obtain:

2.4.4.1 the power system model;

2.4.4.2 status of power system equipment;

2.4.4.3 list of contingencies to be simulated;

2.4.4.4 list of monitored equipment;

2.4.4.5 equipment thermal limits; and

2.4.4.6 operating *security limits* (angular stability, voltage stability and voltage decline).

Additional capability should be provided to control the use of this data and manually override it and to manually provide input that is required only by the *day-ahead market*.

2.5 Output from Pass 1

2.5.1 The primary outputs of *pass 1* which are used in subsequent passes or other *day-ahead market* processes include the following:

2.5.1.1 *facility* commitments;

2.5.1.2 schedules for *energy limited resources* and *non-dispatchable generation*

2.5.1.3 schedules for hourly imports and exports; and

2.5.1.4 *locational marginal prices* for *energy.*

2.5.2 *Pass 1 facility* commitments from step 1 are used in all subsequent passes. (*Pass 2* may create additional *facility* commitments.) Step 1 also produces the schedules of *energy limited resources* which are used in *pass 2* to modify *bid* and *offer* data, and schedules for *non-dispatchable generation* which are used to estimate the next day's production.

2.5.3 Step 2 hourly *import* and *export* schedules for *energy* and *operating reserve* and *locational marginal prices* for *energy* are output from *pass 1* for use in *pass 2*.

2.5.4 Minimum levels and multi-hour uniform schedules may be associated with the output commitments depending on the *bids* and *offers*. These values will be used in later passes as the minimum or scheduled levels associated with the committed resources.

2.5.5 Step 1 schedules and *facility* commitments are used as inputs to step 2.

2.5.6 Table 1 shows the products of *pass 1* and how these are used in later passes or the *day-ahead market* settlement process.

Table 1: Pass 1 Outputs and Target Processes

Output	Target Pass or Settlement - Application
Commitments	
Must-commit AGC facility and Reliability must-run resource commitments	*Pass 2* – Input commitments Settlement – AGC and *Reliability Must-Run* – contracts, not eligible for PCG
Dispatchable Generation facility commitments	*Pass 2* – Input commitments and availability of hourly resources Settlement – PCG eligible (*bid* load)
Non-dispatchable Generation facility	*Passes 3 and 5* – Input commitments

Output	**Target Pass or Settlement - Application**
commitments	Settlement – PCG eligible (*bid* load)
Price responsive load commitments	*Pass 2* – Input commitments and availability of hourly resources Settlement – Eligible for PCG (*bid* load)
Multi-hour *price sensitive load commitments*	P*asses 3* and *5* – Input commitments
Multi-hour *import* commitments	*Pass 2* – Input commitments, as must-take schedules Settlement –Eligible for PCG (*bid* load)
Multi-hour *export* commitments	All later passes – Input commitments
***Constrained Schedules* and Prices**	
Energy limited resource constrained schedules- energy	*Pass 2* – Hourly schedules used to modify *offers*
Hourly *import constrained schedules* - for *energy* and *operating reserve*	*Pass 2* – Hourly imports as minimum must-take schedules Settlement – PCG eligible(*bid* load)
Hourly *export constrained schedules* - for *energy* and *operating reserve*	*Pass 2* – Hourly exports as must-supply schedules
Locational marginal prices for *energy*	*Pass 2* – To modify *generation facility offer* prices

2.6 Glossary of Sets, Indices, Variables and Parameters for Pass 1

2.6.1 Fundamental Sets and Indices

A	The set of all *intertie zones a.*
B	The set of buses *b* within Ontario, corresponding to *bids* and *offers* at locations on the *IMO-controlled grid*.
C	The set of contingencies conditions *c* to be considered in the *security* assessment.
D	The set of buses *d* outside Ontario, corresponding to *bids* and *offers* at *intertie zones.*
F	The set of *transmission facilities* (or groups of

	transmission facilities) *f* in Ontario for which constraints have been identified.
J	The set of all *bids j* for a given *day-ahead market* day. Each P-Q pair of a *bid* submitted by a *market participant* would be represented by a unique element *j* in the set.
J_b	The subset of those *bids j* consisting of *bids* for a *price responsive load resource* at a bus *b*
K	The set of all *offers* for a given *day-ahead market*. Each P-Q pair of an *offer* submitted by a *market participant* would be represented by a unique element *k* in the set.
K_b	The subset of those *offers* consisting of *offers* for a *generation facility* at a bus *b.*
ORREG	The set of reserve areas, or regions, for which minimum and maximum *operating reserve* requirements have been defined. Each region *r* of the set *ORREG* consists of a set of buses at which *operating reserve* satisfying the minimum and maximum *operating reserve* requirement for that region may be located.
Z_{sch}	The set of all *interties* (or groups of *interties) z* for which constraints have been identified.
a	An *intertie zone*.
b	A bus corresponding to *bids* and *offers*. A single *facility* for which multiple *bids* are allowed may be represented as multiple buses, corresponding to the individual *bids*.
c	A contingency condition considered in the *security* assessment.
d	A bus outside Ontario corresponding to *bids* and *offers* in *intertie zones.*
f	A *transmission facility* for which a constraint has been identified. This includes groups of *transmission facilities.*
h	One of the day-ahead hours, from 1 to 24.
j	A *bid f*or a given *day-ahead market* day, reserernting a single P-Q pair..
k	An *offer f*or a given *day-ahead market* day, representing a single P-Q pair.
r	An *operating reserve* region within Ontario.
z	An *intertie* for which a constraint has been identified. This includes groups of *interties*.

2.6.2 Variables and Parameters

2.6.2.1 Bid and Offer Inputs

Price Sensitive Load and Virtual Bids:

$QPSL_{j,h}$	A quantity of *energy* for a *price sensitive load* that may be scheduled in hour *h* in association with *bid j*.
$PPSL_{j,h}$	The highest price at which the *energy* for a *price sensitive load* specified in *bid j* should be scheduled in hour *h.*
$QMPSL_j$	The quantity of *energy* in each hour which *a price sensitive load* may consume at $PMPSL_j$ in association with the multi-hour *bid j.*
$PMPSL_j$	The highest average price which *the price sensitive load* is willing to pay in association with the multi-hour *bid j.*
$STMPSHR_j$	The start hour of the multi-hour *price sensitive load bid j.*
$ENMPSHR_j$	The end hour of the multi-hour *price sensitive load bid j.*
$QVL_{j,h}$	A quantity of *energy* that may be scheduled in hour *h* in association with *virtual bid j.*
$PVL_{j,h}$	The highest price at which the *energy* specified in *virtual bid j* should be scheduled in hour *h.*

Price Responsive Load:

$MinQPRL_{h,b}$	The amount of *minimum load reduction* that a *a price responsive load* at bus *b* is willing to provide in hour *h*, if scheduled to provide load reduction.
$SUPRL_{h,b}$	The initial *load reduction cost* at bus *b* in hour *h* for the *minimum load reduction.*
$MLBPRL_{h,b}$	The *ongoing cost of minimum load reduction* to continue reducing consumption by *a price responsive load* at bus *b* in hour *h.*
$QPRL_{j,h,b}$	An incremental quantity of reduction in *energy* consumption (beyond the minimum quantity of load reduction) that may be scheduled for a a *price responsive load* in hour *h* at bus *b* in association with *bid j.*
$PPRL_{j,h,b}$	The lowest *energy* price at which the incremental

quantity of reduction in *energy* consumption specified in *bid j* should be scheduled in hour *h* at bus *b.*

$10NQPRL_{j,h,b}$ — The non-synchronized *ten-minute operating reserve* quantity associated with *bid j* in hour *h* at bus *b* for *price responsive loads* qualified to do so.

$10NPPRL_{j,h,b}$ — The price of being scheduled to provide non-synchronized *ten-minute operating reserve* associated with *bid j* in hour *h* at bus *b,* for *price responsive loads* qualified to do so.

$30RQPRL_{j,h,b}$ — The *thirty-minute operating reserve* quantity associated with *bid j*in hour *h* at bus *b,* for *price responsive loads* qualified to do so.

$30RPPRL_{j,h,b}$ — The price of being scheduled to provide *thirty-minute operating reserve* associated with *bid j* in in hour *h* at bus *b,* for *price responsive loads* qualified to do so.

$ORRPRL_{h,b}$ — The *operating reserve ramp rate* for load cuts beyond the *minimum load reduction.* Only one ramp rate is specified each day and is the same for every hour *h.*

$MRTPRL_b$ — The minimum time period for which a *a price responsive load* that has *bid* to provide load reduction at bus *b* must be scheduled to reduce load (*minimum load reduction time*) if its *bid* to provide load reduction is accepted.

$MDTPRL_b$ — The minimum time period between the end of one period when a *a price responsive load* is scheduled to provide load reduction at bus *b* and the beginning of the next period when it is scheduled to provide load reduction (*minimum time between load reductions*).

$URRPRL_{h,b}$ — The maximum rate per minute at which a *a price responsive load* that wishes to consume *energy* at bus *b* can increase the amount of load reduction it supplies (*ramp rate up*) in hour *h.* This is the calculated effective uniform ramp rate for the resource, such that ramping between its *minimum load reduction* level and its *maximum load reduction* limit will take the same time as ramping using its *bid* multiple ramp rates for *energy*.

$DRRPRL_{h,b}$ — The maximum rate per minute at which a a *price responsive load* that wishes to consume *energy* at bus *b* can decrease the amount of load reduction it supplies (*ramp rate down*) in hour *h.* This is the calculated effective uniform ramp rate for the resource, such that ramping between its *maximum load reduction* limit and its *minimum load reduction* level will take the same time as ramping using its *bid* multiple ramp rates for *energy*.

$MaxStopsRL_b$	The maximum number of times per day a *price responsive load* can provide load reduction in one or more successive hours and then be scheduled to consume for at least one hour
XL_b	The time in hours required for a *price responsive load* at bus *b* to ramp up from no load reductionto its *minimum load reduction* level. This is assumed to be no more than 1.0 hour.
YL_b	The time in hours required for a *price responsive load* at bus *b* to ramp down to no load reduction from its *minimum load reduction* level. This is assumed to be no more than 1.0 hour.

Exports:

$QHXL_{j,h,a}$	The maximum quantity of *energy* for which an *export* to *intertie zone a* in hour *h* may be scheduled in association with *bid j.*
$PHXL_{j,h,a}$	The highest price at which *energy* should be scheduled for an *export* to *intertie zone a* in hour *h* in association with *bid j.*
$QX10N_{j,h,a}$	The non-synchronized *ten-minute operating reserve* quantity associated with *bid j* in hour *h* at *intertie zone a* for an *export* qualified to do so.
$PX10N_{j,h,a}$	The price of being scheduled to provide non-synchronized *ten-minute operating reserve* associated with *bid j* in hour *h* at *intertie zone a,* for an *export* qualified to do so.
$QX30R_{j,h,a}$	The *thirty-minute operating reserve* quantity associated with *bid j* in hour *h* at *intertie zone a,* for an *export* qualified to do so.
$PX30R_{j,h,a}$	The price of being scheduled to provide *thirty-minute operating reserve* associated with *bid j* in hour *h* at at *intertie zone a*, for an *export* qualified to do so.
ORR$HXL_{h,a}$	The *operating reserve ramp rate* for exports in hour *h* at *intertie zone a,* as specified by the *IMO*.
$QBXL_{j,a}$	The quantity of *energy* each hour in a multi-hour *export bid j* to *intertie zone a* which may be scheduled.
$PBXL_{j,a}$	The highest average price at which that multi-hour *export bid j* to *intertie zone a* should be scheduled.
$STXHR_{j,a}$	The start hour of the multi-hour *export bid j* to *intertie zone a.*
$ENXHR_{j,a}$	The end hour of the multi-hour *export bid j* to *intertie*

zone a.

Internal Generation and Virtual Offers:

$MinQPRG_{h,b}$	The *minimum generation level* of *energy* that a *generation facility* at bus *b* is willing to produce in hour *h*, if scheduled to operate.
$SUPRG_{h,b}$	Designates the *offered startup cost* that a *generation facility* at bus *b* incurs in order to start and synchronize in hour *h,*which may be a function of the time since last shut down..
$MGOPRG_{h,b}$	The *offered minimum generation cost* incurred by a *generation facility* at bus *b* in order to operate at its *minimum generation level* in hour *h.*
$QPRG_{k,h,b}$	An incremental quantity of *generation* (above and beyond the *minimum generation level*) that may be scheduled at bus *b* in hour *h* in association with *offer k.*
$PPRG_{k,h,b}$	The lowest*energy* price at which incremental *generation* should be scheduled at bus *b* in hour *h* in association with *offer k.*
$10SPPRG_{k,h,b}$	The *offered* price of being scheduled to provide synchronized *ten-minute operating reserve* in the *day-ahead market* in hour *h* at bus *b* in association with *offer k.*
$10SQPRG_{k,h,b}$	The *offered* quantity of synchronized *ten-minute operating reserve* in the *day-ahead market* in hour *h* at bus *b* in association with *offer k.*
$10NPPRG_{k,h,b}$	The *offered* price of being scheduled to provide *ten-minute operating* non-synchronized *ten-minute operating reserve* in the *day-ahead market* in hour *h* at bus *b* in association with *offer k.*
$10NQPRG_{k,h,b}$	The *offered* quantity of non-synchronized *ten-minute operating reserve* in the *day-ahead market* in hour *h* at bus *b* in association with *offer k.*
$30RPPRG_{k,h,b}$	The *offered* price of being scheduled to provide *thirty-minute operating reserve* in the *day-ahead market* in hour *h* at bus *b* in association with *offer k.*
$30RQPRG_{k,h,b}$	The *offered* quantity of *thirty-minute operating reserve* in the *day-ahead market* in hour *h* at bus *b* in association with *offer k.*
$ORRPRG_{h,b}$	The maximum *operating reserve ramp rate.* Only one ramp rate is specified each day and is the same for every hour *h*.

$MRTPRG_b$	The *minimum run time* period for which a *generation facility* at bus *b* must be scheduled to operate if its *offer* to generate is accepted.
$MDTPRG_b$	The *minimum down time* period between the end of one period when a *generation facility* at bus *b* is scheduled to operate and the beginning of the next period when it is scheduled to operate.
$MaxStopsG_h$	The maximum number of times a *generation facility* at bus *b* can be generating in one or more successive hours and then be scheduled not to generate for at least one hour
$URRPRG_{h,b}$	The maximum rate per minute at which a *generation facility offering* to produce at bus *b* can increase the amount of *energy* it supplies (*ramp rate up*) in hour *h*. This is the calculated effective uniform ramp rate for the resource, such that ramping between its *minimum generation level* and its maximum *offer* will take the same time as ramping using its *offerred* multiple ramp rates for *energy*.
$DRRPRG_{h,b}$	The maximum rate per minute at which a *generation facility offering* to produce at bus *b* can decrease the amount of *energy* it supplies (*ramp rate down*) in hour *h.* This is the calculated effective uniform ramp rate for the resource, such that ramping between its maximum *offer* and its *minimum generation level* will take the same time as ramping using its *offerred* multiple ramp rates for *energy*.
XG_b	The time in hours required for a *generation facility* at bus *b* to ramp up from zero output to its *minimum generation* level. This is assumed to be no more than 1.0 hour.
YG_b	The time in hours required for a *generation facility* at bus *b* to ramp down to zero output from its *minimum generation* level. This is assumed to be no more than 1.0 hour.
EL_b	Designates the daily limit on the amount of *energy* that an *energy limited resource* at bus *b* may be scheduled to generate over the course of the day (*maximum daily energy limit*).
$QVS_{k,h}$	A quantity of *virtual* supply that may be scheduled in hour *h* in association with *virtual offer k.*
$PVS_{k,h}$	The lowest price at which the *virtual* supply specified for hour *h* in association with *virtual offer k* should be scheduled.

Imports:

$QHIG_{k,h,a}$	The maximum quantity of *energy* for which an *import* from *intertie zone a* in hour *h* may be scheduled in association with *offer k.*
$PHIG_{k,h,a}$	The lowest price at which an *import* from *intertie zone a* in hour *h* in association with *offer k* should be scheduled.
$QI10N_{k,h,a}$	The non-synchronized *ten-minute operating reserve* quantity associated with *offer k* in hour *h* at *intertie zone.*
$PI10N_{k,h,a}$	The price of being scheduled to provide non-synchronized *ten-minute operating reserve* associated with *offer k* in hour *h* at *intertie zone a*.
$QI30R_{k,h,a}$	The non-synchronized *thirty-minute operating reserve* quantity associated with *offer k* in hour *h* at *intertie zone.*
$PI30R_{k,h,a}$	The price of being scheduled to provide non-synchronized *thirty-minute operating reserve* associated with *offer k* in hour *h* at *intertie zone a*.
$ORRHIG_{h,a}$	The *operating reserve ramp rate* for imports in hour *h* at *intertie zone a,* as specified by the *IMO*.
$QBIG_{k,a}$	The quantity of *energy* for which a multi-hour *import offer k* from *intertie zone a* may be scheduled.
$PBIG_{k,a}$	The lowest average price at which a multi-hour *import offer k* from *intertie zone a* should be scheduled.
$STIHR_{k,a}$	The start hour of the multi-hour *import offer k* from *intertie zone a.*
$ENIHR_{k,a}$	The end hour of the multi-hour *import offer k* from *intertie zone a.*

2.6.2.2 Transmission and Security Inputs and Intermediate Variables

$EnCoeff_{a,z}$	The coefficient for calculating the contribution of scheduled *energy* flows (and *operating reserve,* in the case of inflows) over *intertie a* which is part of the *intertie* group *z,* using positive numbers to describe scheduled flows into Ontario.
$MaxExtSch_{z,h}$	The maximum flow over an *intertie z* in hour *h*.
$ExtDSC_h$	The maximum decrease in total net flows over all *interties* from hour to hour, which limits the hour-to-hour decreases in net imports (calcaulted as imports less exports) from all the *intertie zones*.

$ExtUSC_h$	The maximum increase in total net flows over all *interties* from hour to hour, which limits the hour-to-hour increases in net imports (calcaulted as imports less exports) from all the *intertie zones*.
$PF_{h,a}$	The anticipated inflow into Ontario from *intertie zone* ***a*** in hour ***h*** that result from loop flows.
$MglLoss_{h,b}$	The marginal impact on transmission losses resulting from transmitting *energy* from the *reference bus* to serve an increment of additional load at the bus ***b*** in hour ***h***.
$LossAdj_h$	Any adjustment needed for hour ***h*** to correct for any discrepancy between actual Ontario total system losses using a base case power flow from the *security* assessment function and system losses that would be calculated using the marginal transmission losses.
$With^1_{h,b}$	The total amount of withdrawals scheduled in *pass 1* at each bus ***b*** in each hour ***h***, for scheduled *virtual offers* and *generation* for internal buses.
$With^1_{h,d}$	The total amount of withdrawals scheduled in *pass 1* at each bus ***d*** in each hour ***h***, for imports and inflows associated with unscheduled loop flows for buses in *intertie zones*.
$Inj^1_{h,b}$	The total amount of injections scheduled in *pass 1* at each bus ***b*** in each hour ***h***, for *scheduled price sensitive loads*, *virtual* loads and *price responsive loads* for internal buses.
Inj^1_{hdb}	The total amount of injections scheduled in *pass 1* at each bus ***d*** in each hour ***h***, for exports and outflows associated with unscheduled loop flows for buses in *intertie zones*.
$WithT^1_{h,b}$	The total amount of withdrawals scheduled in *pass 1* at each bus ***b*** in each hour ***h***, similar to $With^1_{h,b}$, defined for internal buses only.
$InjT^1_{h,b}$	The total amount of injections scheduled in *pass 1* at each bus ***b*** in each hour ***h***, similar to $Inj^1_{h,b}$, defined for internal buses only.
$WithX^1_{h,d}$	The total amount of withdrawals scheduled in *pass 1* at each bus ***d*** in each hour ***h***, similar to $With^1_{h,b}$, defined for buses in *intertie zones*.
$InjX^1_{h,d}$	The total amount of injections scheduled in *pass 1* at each bus ***d*** in each hour ***h***, similar to $Inj^1_{h,b}$, defined for buses in *intertie zones*.
$PreConSF_{b,f,h}$	The fraction of *energy* injected at bus ***b*** which flows on *transmission facility f* during hour ***h*** under pre-contingency conditions.

$PreOprgSF_{b,f,h}$	A coefficient which accounts for the impact of the commitment of the ***generation facility***at bus ***b*** on ***transmission facility f*** during hour ***h*** for pre-contingency conditions.
$AdjNormMaxFlow_{f,h}$	The maximum flow allowed on ***transmission facility f*** in hour ***h*** as determined by the ***security*** assessment for pre-contingency conditions.
$SF_{b,f,c,h}$	The fraction of ***energy*** injected at bus ***b*** which flows on a ***transmission facility f*** during hour ***h*** under post-contingency conditions.
$AdjEmMaxFlow_{f,h}$	The maximum flow allowed on ***transmission facility f*** in hour ***h*** as determined by the ***security*** assessment for post-contingency conditions.

2.6.2.3 Other Inputs

Distribution of Load, Imports and Exports and Loop Flows

$LDF_{h,b}$	The proportion of forecast Ontario load at bus ***b*** in hour ***h***.
$ProxySFWt_{d,a}$	The proportion of scheduled imports from or exports to ***intertie zone a*** that shall be assigned to each bus ***d*** in the ***control area*** in which that ***intertie zone*** is located.
$ProxyUPIWt_{d,a}$	The proportion of inflows associated with unscheduled loop flows from ***intertie zone a*** that shall be assigned to each bus ***d*** in the ***control area*** in which that ***intertie zone*** is located.
$ProxyUPOWt_{d,a}$	The proportion of outflows associated with unscheduled loop flows from ***intertie zone a*** that shall be assigned to each bus ***d*** in the ***control area*** in which that ***intertie zone*** is located.

Operating Reserve Requirements:

$TOT10R_h$	Minimum requirement for the total amount of ***ten-minute operating reserve***.
$TOT10S_h$	The total amount of synchronized ***ten-minute operating reserve*** required in hour ***h***, which is a percentage of the total ***ten-minute operating reserve*** requirement.
$TOT30R_h$	Minimum requirement for the total amount of ***thirty-***

minute operating reserve.

$REGMin10R_{r,h}$	The minimum requirement for *ten-minute operating reserve* in region *r* in hour *h*.
$REGMax10R_{r,h}$	The maximum amount of *ten-minute operating reserve* that may be provided in region *r* in hour *h*.
$REGMin30R_{r,h}$	The minimum requirement for *thirty-minute operating reserve* in region *r* in hour *h*.
$REGMax30R_{r,h}$	The maximum amount of *thirty-minute operating reserve* that may be provided in region *r* in hour *h*.

Other Ancillary Service and Resource Initializing Assumptions:

$Reg_{h,b}$	The amount of *regulation* that the unit at bus *b* is contracted to provide in hour *h*, in terms of the aggregate amount that it is required to be able to move up or down in response to *automatic generation control* (*AGC*) signals.
$MinPRG_{h,b}$	The minimum output for a *generation facility* at bus *b* in hour *h*, required in order to provide *regulation* or voltage support.
$MaxPRG_{h,b}$	The maximum output for a *generation facility* at bus *b* in hour *h*, limited to this level in order to provide *regulation* or voltage support or as the result of *outages* or deratings.
$InitOperHrs_b$	The number of consecutive hours at the end of the previous day for which the *generation facility* or load at bus *b* was scheduled to operate.
$InitDownHrs_b$	The number of consecutive hours at the end of the previous day for which the *generation facility* or load at bus *b* was not scheduled to operate.

2.6.2.4 Constraint Violation Price Inputs

PLdViol	The value that the *DAM calculation engine* will assign to scheduling (forecast) load. If the cost of serving that load, as measured by the effect of serving that load on the value of the objective function exceeds *PLdViol*, then that load would not be scheduled. Not applicable to *pass 1* since *PLdViol* will exceed maximum *bid* price allowed and no *bid* load could be scheduled at this price.
PGenViol	The price at which additional load will be included above the scheduled amount when the amount of

	energy generation facilities produce at their *minimum generation level*s exceeds the amount of load scheduled on the system.
P10Sviol	The price at which the overall minimum synchronized *ten-minute operating reserve* requirement may be violated.
P10Rviol	The price at which the overall minimum *ten-minute operating reserve* requirement may be violated.
P30Rviol	The price at which the overall minimum *thirty-minute operating reserve* requirement may be violated.
PREG10Rviol	The price at which the regional minimum *ten-minute operating reserve* requirements may be violated.
PXREG10Rviol	The price at which the regional maximum *ten-minute operating reserve* requirements may be violated.
PREG30Rviol	The price at which the regional minimum *thirty-minute operating reserve* requirements may be violated.
PXREG30Rviol	The price at which the regional maximum *thirty-minute operating reserve* requirements may be violated.
PPreConITLViol	The price at which pre-contingency flows over internal transmission may exceed that *facility*'s limit.
PITLViol	The price at which flows over internal *facility* following a contingency may exceed that *facility*'s limit.
PPreConXTLViol	The price at which the pre-contingency *import* and *export intertie* limits may be violated.
PRmpXTLViol	The price at which the limit for hour to hour changes (up and down) of total net scheduled imports from *intertie zones* may be violated.

2.6.2.5 Output Schedule and Commitment Variables

$SPSL^{1}_{j,h}$	The amount of *price sensitive load* scheduled in hour *h* in *pass 1* in association with each *bid j*.
$OMPSL^{1}_{j}$	Represents whether multi-hour *price sensitive load bid* has been scheduled in *pass 1*.
$SVL^{1}_{j,h}$	The amount of *virtual* load scheduled in hour *h* in *pass 1* in association with each *bid j*.
$SHXL^{1}_{j,h,a}$	The amount of exports scheduled in hour *h* in *pass 1* from *intertie zone a* in association with each *bid j*.
$SX10N^{1}_{j,h,a}$	The amount of non-synchronized *ten-minute operating reserve* scheduled from the *export* in hour *h* in *pass 1*

	from *intertie zone a* in association of *bid j.*
$SX30R^{1}_{j,h,a}$	The amount of *thirty-minute operating reserve* scheduled from the *export* in hour *h* in *pass 1* from *intertie zone a* in association of *bid j.*
$OBXL^{1}_{a}$	Represents whether the multi-hour *export* has been scheduled at *intertie zone a* in *pass 1.*
$SPRL^{1}_{j,h,b}$	The amount of load reduction scheduled at bus *b* in hour *h* in *pass 1* in association with each *bid j* at that bus. This is addition to any $MinQPRL_{h,b}$, the *minimum load reduction*, which must also be committed.
$OPRL^{1}_{h,b}$	Represents whether load reduction has been scheduled at bus *b* in hour *h* in *pass 1.*
$IPRL^{1}_{h,b}$	Represents whether the initiation of load reduction at bus *b* has been scheduled in hour *h* in *pass 1.*
$10NSPRL^{1}_{j,h,b}$	The amount of *ten-minute operating reserve* that a qualified *price responsive load* is scheduled to provide at bus *b* in hour *h* in *pass 1* in association of *bid j* for this bus.
$30RSPRL^{1}_{j,h,b}$	The amount of *thirty-minute operating reserve* that a qualified *price responsive load* is scheduled to provide at bus *b* in hour *h* in *pass 1* in association of *bid j* for this bus.
$SVS^{1}_{k,h}$	The amount of *virtual* supply scheduled in hour *h* in *pass 1* in association with each *offer k*
$OBIG^{1}_{a}$	Represents whether the multi-hour *import* has been scheduled at *intertie zone a* in *pass 1.*
$SHIG^{1}_{k,h,a}$	The amount of hourly imports scheduled in hour *h* from *intertie zone a* in *pass 1* in association with each *offer k.*
$SI10N^{1}_{k,h,a}$	The amount of imported *ten-minute operating reserve* scheduled in hour *h* from *intertie zone a* in *pass 1* in association with each *offer k.*
$SI30R^{1}_{k,h,a}$	The amount of imported *thirty-minute operating reserve* scheduled in hour *h* from *intertie zone a* in *pass 1* in association with each *offer k.*
$SPRG^{1}_{k,h,b}$	The amount scheduled for the *generation facility* at bus *b* in hour *h* in *pass 1* in association with each *offer k* at that bus. This is addition to any $MinQPRG_{h,b}$, the *minimum generation level*, which must also be committed.
$OPRG^{1}_{h,b}$	Represents whether the *generation facility* at bus *b* has been scheduled in hour *h* in *pass 1.*
$IPRG^{1}_{h,b}$	Represents whether *generation facility* at bus *b* has

been scheduled to start in hour *h* in *pass 1*.

$10SSPRG^{1}_{k,h,b}$ — The amount of synchronized *ten-minute operating reserve* that a qualified *generation facility* at bus *b* is scheduled to provide in hour *h* in *pass 1* in association of *offer k* for this bus.

$10NSPRG^{1}_{k,h,b}$ — The amount of non-synchronized *ten-minute operating reserve* that a qualified *generation facility* at bus *b* is scheduled to provide in hour *h* in *pass 1* in association of *offer k* for this bus.

$30RSPRG^{1}_{k,h,b}$ — The amount of *thirty-minute operating reserve* that a qualified *generation facility* at bus *b* is scheduled to provide in hour *h* in *pass 1* in association of *offer k* for this bus.

2.6.2.6 Output Violation Variables

$ViolCost^{1}_{h}$ — The cost incurred in order to avoid having the *pass 1* schedules for hour *h* violate specified constraints.

$SLdViol^{1}_{h}$ — The amount of load that cannot be met using *offers* scheduled or committed in hour *h* in *pass 1*.[This quantity is zero in *pass 1* since no forecast load is included.]

$SGenViol^{1}_{h}$ — The amount of additional load that must be scheduled in hour *h* in *pass 1* to ensure that there is enough load on the system to offset the must run requirements of *generation facilities.*

$S10SViol^{1}_{h}$ — The amount by which the overall synchronized *ten-minute operating reserve* requirement is not met in hour *h* of *pass 1* because the cost of meeting that portion of the requirement was greater than or equal to *P10SViol.*

$S10RViol^{1}_{h}$ — The amount by which the overall *ten-minute operating reserve* requirement is not met in hour *h* of *pass 1* (above and beyond any failure to meet the synchronized *ten-minute operating reserve* requirement) because the cost of meeting that portion of the requirement was greater than or equal to *P10RViol.*

$S30RViol^{1}_{h}$ — The amount by which the overall *thirty-minute operating reserve* requirement is not met in hour *h* of *pass 1* (above and beyond any failure to meet the *ten-minute operating reserve* requirement) because the cost of meeting that portion of the requirement was greater than or equal to *P30RViol.*

$SREG10RViol^{1}_{r,h}$	The amount by which the overall *ten-minute operating reserve* requirement for region *r* is not met in hour *h* of *pass 1* because the cost of meeting that portion of the requirement was greater than or equal to *PREG10RViol*.
$SREG30RViol^{1}_{r,h}$	The amount by which the overall *thirty-minute operating reserve* requirement for region *r* is not met in hour *h* of *pass 1* because the cost of meeting that portion of the requirement was greater than or equal to *PREG30RViol*.
$SXREG10RViol^{1}_{r,h}$	The amount by which the overall *ten-minute operating operating reserve* requirement for region *r* is more than the maximum required in hour *h* of *pass 1* because the cost of meeting that the maximum requirement limit was greater than or equal to *PXREG10RViol*.
$SXREG30RViol^{1}_{r,h}$	The amount by which the overall *thirty-minute operating reserve* requirement for region *r* is more than the maximum required in hour *h* of *pass 1* because the cost of meeting the maximum requirement limit was greater than or equal to *PXREG30RViol*.
$SPreConITLViol^{1}_{f,h}$	The amount by which pre-contingency flows over *facility f* in hour *h* of *pass 1* exceed the normal limit for flows over that *facility*, because the cost of alternative solutions that would not result in such an overload was greater than or equal to *PPreConITLViol*.
$SITLViol^{1}_{f,c,h}$	The amount by which flows over *facility f* that would follow the occurrence of contingency *c* in hour *h* of *pass 1* exceed the emergency limit for flows over that *facility*, because the cost of alternative solutions that would not result in such an overload was greater than or equal to *PITLViol*.
$SPreConXTLViol^{1}_{z,h}$	The amount by which *intertie* flows over *facility z* in hour *h* of *pass 1* exceed the normal limit for flows over that *facility*, because the cost of alternative solutions that would not result in such an overload was greater than or equal to *PPreConXTLViol*.
$SURmpXTLViol^{1}_{h}$	The amount by which the total net scheduled *import* increase for hour *h* in *pass 1* exceeds the up ramp limits, because the cost of alternative solutions that would not result in violation was greater than or equal to *PRmpXTLViol*.
$SDRmpXTLViol^{1}_{h}$	The amount by which the total net scheduled *import* decrease in hour *h* of *pass 1* exceed the down ramp limits, because the cost of alternative solutions that would not result in violation was greater than or equal

to *PRmpXTLViol*.

2.6.2.7 Output Shadow Prices and Locational Marginal Prices for Energy

Shadow Prices of Constraints:

SPL^1_h	The *pass 1* shadow price measuring the the rate of change of the objective function for a change in load at the *reference bus* in hour *h*.
$SPNormT^1_{f,h}$	The *pass 1* shadow price measuring the the rate of change of the objective function for a change in the limit on flows over transmission *facilities* in normal conditions for *facility f* in hour *h*.
$SPEmT^1_{f,c,h}$	The *pass 1* shadow price measuring the the rate of change of the objective function for a change in the limit on flows over transmission *facilities* in emergency conditions for *facility f* in monitored contingency *c* in hour *h*.
$SPExtT^1_{z,h}$	The *pass 1* shadow price measuring the the rate of change of the objective function for a change in the limit on flows over transmission *facilities* on the boundary between Ontario and other *control areas* for each constraint z in hour *h*.
$SPRUExtT^1_h$	The *pass 1* shadow price measuring the the rate of change of the objective function for a change in the limit on the upward change of the sum of net imports over all *interties* from the previous hour to hour *h*.
$SPRDExtT^1_h$	The *pass 1* shadow price measuring the the rate of change of the objective function for a change in the limit on the downward change of the sum of net imports over all *interties* from the previous hour to hour *h*.
$SP10S^1_h$	The *pass 1* shadow price measuring the the rate of change of the objective function for a change in the total synchronized *ten-minute operating reserve* requirement in hour *h*.
$SP10R^1_h$	The *pass 1* shadow measuring the the rate of change of the objective function for a change in the total *ten-minute operating reserve* constraint in hour *h*.
$SP30R^1_h$	The *pass 1* shadow price measuring the the rate of change of the objective function for a change in the total *thirty-minute operating reserve* requirement in hour *h*.
$SPREGMin10R^1_{r,h}$	The *pass 1* shadow price measuring the the rate of change of the objective function for a change in the the

minimum *ten-minute operating reserve* requirement for region *r*in hour *h*.

$SPREGMin30R^{1}_{r,h}$ — The *pass 1* shadow price measuring the the rate of change of the objective function for a change in the minimum *thirty-minute operating reserve* requirement for region *r* in hour *h*.

$SPREGMax10R^{1}_{r,h}$ — The *pass 1* shadow price measuring the the rate of change of the objective function for a change in the maximum *ten-minute operating reserve* limit for region *r* in hour *h*.

$SPREGMax30R^{1}_{r,h}$ — The *pass 1* shadow price measuring the the rate of change of the objective function for a change in the maximum *thirty-minute operating reserve* limit for region *r* in hour *h*.

Locational Marginal Price for Energyat Internal Buses:

$LMP^{1}_{h,b}$ — The *pass 1 locational marginal price* for *energy* at each bus *b* in each hour *h*. It measures the *offered* cost of meeting an infinitesimal amount of load at that bus in that hour, or equivalently, measures the value of an incremental amount of supply at that bus in that hour in *pass 1*.

2.6.2.8 Step 2 Multiple Energy Ramp Rates

$RmpRngmaxPRL_{j,h,b}$ — The *maximum load reduction* to which the ramp rates $URRPRL_{j,h,b}$ and $DRRPRL_{j,h,b}$ apply for which a *price responsive load* at bus *b* in hour *h*. $RmpRngmaxPRL_{j,h,b}$ must be greater than or equal to *maximum load reduction bid*.

$RmpRngmaxPRL_{0,h,b}$ — Equivalent to the *minimum load reduction* for *price responsive load* at bus *b* in hour *h*.

$URRPRL_{j,h,b}$ — The maximum rate per minute at which a *price responsive load* at bus *b* can increase load reduction in hour *h* while operating in the range between $RmpRngMaxPRL_{j-1,h,b}$ and $RmpRngMaxRPRL_{j,h,b}$.

$DRRPRL_{j,h,b}$ — The maximum rate per minute at which a *price responsive load* at bus *b* can decrease load reduction in hour *h* while operating in the range between $RmpRngMaxPRL_{j-1,h,b}$ and $RmpRngMaxRPRL_{j,h,b}$.

$RmpRngmaxPRG_{k,h,b}$ — The maximum output level to which the ramp rates $URRPRG_{k,h,b}$ and $DRRPRG_{k,h,b}$ apply for a *generation facility* at bus *b* in hour *h*. $RmpRngmaxPRG_{k,h,b}$ must be greater than or equal to *maximum generation level*

	offered.
$RmpRngmaxPRG_{0,h,b}$	Equivalent to the minimum output for a *generation facility* at bus *b* in hour *h*.
$URRPRG_{k,h,b}$	The maximum rate per minute at which a *generation facility* at bus *b* can increase its output in hour *h* while operating in the range between $RmpRngMaxPRG_{k-1,h,b}$ and $RmpRngMaxRPRG_{k,h,b}$.
$DRRPRG_{k,h,b}$	The maximum rate per minute at which a *generation facility* at bus *b* can decrease its output in hour *h* while operating in the range between $RmpRngMaxPRG_{k-1,h,b}$ and $RmpRngMaxRPRG_{k,h,b}$.
$LowerPRG_{h,b}$	The highest of the lower production limits applicable to the *generation facility offer* at bus *b* in hour *h*, referred to as the minimum production limit. The value and meaning of the variable can change during the pre-processing for step 2.
$UpperPRG_{h,b}$	The lowest of the upper production limits applicable to the *generation facility offer* at bus *b* in hour *h*, referred to as the maximum production limit. The value and meaning of the variable can change during the pre-processing for step 2.
$FRmpUPRG_{h,b}$	The maximum output a *generation facility* at bus *b* in hour *h* can achieve if it ramps up (using the multiple ramp rates for *energy*) for one hour from the *energy* schedule calculated in step 2 for hour (*h-1*).
$FRmpDPRG_{h,b}$	The minimum output a *generation facility* at bus *b* in hour *h* can achieve if it ramps down (using the multiple ramp rates for *energy*) for one hour from the *energy* schedule calculated in step 2 for hour (*h-1*).
$BRmpUPRG_{h,b}$	The maximum output a *generation facility* at bus *b* in hour *h* from which if it ramps down (using the multiple ramp rates for *energy*) for one hour it will reach the *energy* schedule calculated in step 1 for hour (*h+1*). will be the output at hour *h* that the *generation facility* will ramp up from to reach the *energy* schedule calculated in step 1 for hour (*h+1*).
$BRmpDPRG_{h,b}$	The minimum output a *generation facility* at bus *b* in hour *h* from which if it ramps up (using the multiple ramp rates for *energy*) for one hour it will reach the *energy* schedule calculated in step 1 for hour (*h+1*).

2.7 Objective Function

2.7.1 The objective function for *pass 1* is to maximize gains from trade by maximizing the objective function below. The objective function attributes value to scheduled *bids*, costs to scheduled supply, and additional cost to any constraint violations.

2.7.1.1 Gains from trade as determined as:

$$\sum_{h=1,\ldots,24}\left\{\begin{array}{l}\left[\begin{array}{l}\sum_{j\in J}\left[\begin{array}{l}SPSL^{1}_{j,h}\cdot PPSL_{j,h}+SVL^{1}_{j,h}\cdot PVL_{j,h}\\+\sum_{a\in A}(SHXL^{1}_{j,h,a}\cdot PHXL_{j,h,a}-SX10N^{1}_{j,h,a}\cdot PX10N_{j,h,a}-SX30R^{1}_{j,h,a}\cdot PX30R_{j,h,a})\end{array}\right]\\-\sum_{b\in B}\left[\begin{array}{l}\sum_{j\in J_b}SPRL^{1}_{j,h,b}\cdot PPRL_{j,h,b}+OPRL^{1}_{h,b}\cdot MLBPRL_{h,b}+IPRL^{1}_{h,b}\cdot SUPRL_{h,b}\\+\sum_{j\in J}(10NSPRL^{1}_{j,h,b}\cdot 10NPPRL_{j,h,b}+30RSPRL^{1}_{j,h,b}\cdot 30RPPRL_{j,h,b})\end{array}\right]\end{array}\right]\\-\sum_{k\in K}\left[\begin{array}{l}SVS^{1}_{k,h}\cdot PVS_{k,h}\\+\sum_{a\in A}\left(SHIG^{1}_{k,h,a}\cdot PHIG_{k,h,a}+SI10N^{1}_{k,h,a}\cdot PI10N_{k,h,a}+SI30R^{1}_{k,h,a}\cdot PI30R_{k,h,a}\right)\end{array}\right]\\-\sum_{b\in B}\left[\begin{array}{l}\sum_{k\in K_b}(10SSPRG^{1}_{k,h,b}\cdot 10SPPRG_{k,h,b}+30RSPRG^{1}_{k,h,b}\cdot 30RPPRG_{k,h,b}\\+10NSPRG^{1}_{k,h,b}\cdot 10NPPRG_{k,h,b})\\+\sum_{k\in K_b}SPRG^{1}_{k,h,b}\cdot PPRG_{k,h,b}+OPRG^{1}_{h,b}\cdot MGOPRG_{h,b}+IPRG^{1}_{h,b}\cdot SUPRG_{h,b}\end{array}\right]\\-ViolCost^{1}_{h}\end{array}\right\}$$

$$+\sum_{a\in A}\sum_{j\in J}OBXL^{1}_{j,a}\cdot QBXL_{j,a}\cdot PBXL_{j,a}(ENXHR_{j,a}-STXHR_{j,a}+1)$$

$$-\sum_{a\in A}\sum_{k\in K}OBIG^{1}_{k,a}\cdot QBIG_{k,a}\cdot PBIG_{k,a}(ENIHR_{k,a}-STIHR_{k,a}+1)$$

$$+\sum_{j\in J}OMPSL^{1}_{j}\cdot QMPSL_{j}\cdot PMPSL_{j}(ENMPSHR_{j}-STMPSHR_{j}+1)$$

where B is the set of all buses in Ontario, and $ViolCost^{1}_{h}$ is calculated as:

$$
\begin{aligned}
ViolCost_h^1 = {} & SLdViol_h^1 \cdot PLdViol - SGenViol_h^1 \cdot PGenViol \\
& + S10SViol_h^1 \cdot P10SViol + S10RViol_h^1 \cdot P10RViol \\
& + S30RViol_h^1 \cdot P30RViol \\
& + \sum_{r \in ORREG} \begin{pmatrix} SREG10RViol_{r,h}^1 \cdot PREG10RViol \\ + SREG30RViol_{r,h}^1 \cdot PREG30RViol \\ + SXREG10RViol_{r,h}^1 \cdot PXREG10RViol \\ + SXREG30RViol_{r,h}^1 \cdot PXREG30RViol \end{pmatrix} \\
& + \sum_{f \in F} SPreConITLViol_{f,h,}^1 \cdot PPreConITLViol \\
& + \sum_{f \in F, c \in C} SITLViol_{f,c,h}^1 \cdot PITLViol \\
& + \sum_{z \in Z} SPreConXTLViol_{z,h}^1 \cdot PPreConXTLViol \\
& + SURmpXTLViol_h^1 \cdot PRmpXTLViol + SDRmpXTLViol_h^1 \cdot PRmpXTLViol;
\end{aligned}
$$

2.8 Constraints

2.8.1 The optimization for *pass 1* must incorporate constraints to ensure that:

2.8.1.1 the schedules determined in the optimization do not violate the parameters specified in the ***bids*** and ***offers*** submitted by ***registered market participants***, and

2.8.1.2 those schedules do not violate reliability criteria established by the *IMO*.

2.8.2 The optimization must not violate the parameters specified in the ***energy bids*** and ***offers*** which describe the capacity available for scheduling.

2.8.2.1 Boolean variables, $OPRL^1_{h,b}$,$OPRG^1_{h,b}$, $OBXL^1_a$ and $OBIG^1_a$, indicate whether a ***price responsive load*** and ***generation facility*** at bus ***b*** is committed in hour ***h*** and multi-hour ***export*** and multi-hour ***import*** at ***intertie zone a*** is committed, respectively. A value of zero indicates that a resource is not committed, while a value of one indicates that it is committed. Therefore:

$OPRL^1_{h,b}, OPRG^1_{h,b} = 0$ or 1, for all hours ***h*** and buses ***b.***

$OBXL^1_{j,a}, OBIG^1_{k,a} = 0$ or 1, for all ***intertie zones a.***

2.8.2.2 Boolean variables, $IPRL^{1}_{h,b}$ and $IPRG^{1}_{h,b}$, indicate whether ***price responsive loads*** are scheduled to initiate load reduction in a given hour, or whether ***generation facilities*** are scheduled to start up in that hour. A value of zero indicates that a resource is not scheduled to initiate load reduction or start up, while a value of one indicates that it is scheduled to initiate load reduction or start up. Therefore, for $h > 1$:

$$IPRL^{1}_{h,b} = \begin{cases} 1, \text{ if } OPRL^{1}_{h-1,b} = 0 \text{ and } OPRL^{1}_{h,b} = 1 \\ 0 \text{ otherwise,} \end{cases}$$

and

$$IPRG^{1}_{h,b} = \begin{cases} 1, \text{ if } OPRG^{1}_{h-1,b} = 0 \text{ and } OPRG^{1}_{h,b} = 1 \\ 0 \text{ otherwise.} \end{cases}$$

For $h = 1$, the determination of whether a resource was previously operating must make reference to the previous day's ***day-ahead market*** schedule:

$$IPRL^{1}_{h,b} = \begin{cases} 1, \text{ if } InitOperHrs_{b} = 0 \text{ and } OPRL^{1}_{h,b} = 1 \\ 0 \text{ otherwise,} \end{cases}$$

and

$$IPRG^{1}_{h,b} = \begin{cases} 1, \text{ if } InitOperHrs_{b} = 0 \text{ and } OPRG^{1}_{h,b} = 1 \\ 0 \text{ otherwise.} \end{cases}$$

2.8.2.3 ***Reliability must run resources*** will be considered committed for all must run hours. Regulating units providiing AGC will be considered committed for all the hours that they are regulating. ***Generation facilities*** and ***price responsive load*** which through their ***offers*** and ***bids*** elect to be committable hourly, as identified in sections 1.3.7 and 1.2.4 will be considered committed for all hours ***offerred*** or ***bid.*** Such commitments mean that $OPRL^{1}_{h,b}, OPRG^{1}_{h,b} = 1$, for these facilities.

2.8.2.4 No schedule can be negative, nor can any schedule exceed the amount of capacity ***offered*** for that service (***energy*** and ***operating reserve***). Therefore for ***price sensitive load, virtual bids, hourly*** exports, ***virtual offers,*** and ***hourly*** imports:

$$0 \le SPSL^{1}_{j,h} \le QPSL_{j,h};$$

$$0 \le SVL^{1}_{j,h} \le QVL_{j,h};$$

$$0 \le SHXL^{1}_{j,h,a} \le QHXL_{j,h,a};$$

$$0 \le SX10N^{1}_{j,h,a} \le QX10N_{j,h,a};$$

$$0 \le SX30R^{1}_{j,h,a} \le QX30R_{j,h,a};$$

$$0 \le SVS^{1}_{k,h} \le QVS_{k,h};$$

$$0 \le SHIG^{1}_{k,h,a} \le QHIG_{k,h,a};$$

$$0 \le SI10N^{1}_{k,h,a} \le QI10N_{k,h,a};$$ and

$$0 \le SI30R^{1}_{k,h,a} \le QI30R_{k,h,a};$$

for all *bids j*, *offers k*, hours *h*, buses *b* and *intertie zones a*.

2.8.2.5 In the case of *price responsive loads* and *generation facilities*, in addition to restrictions on the magnitude of their schedules similar to those above, their schedules must be consistent with their operating status as described above. *Generation facilities* cannot be scheduled to produce *energy* or *operating reserve* unless they are committed, nor can *price responsive loads* be scheduled to reduce consumption unless they are committed. Therefore:

$$0 \le SPRL^{1}_{j,h,b} \le OPRL^{1}_{h,b} QPRL_{j,h,b},$$

$$0 \le 10NSPRL^{1}_{j,h,b} \le OPRL^{1}_{h,b} 10NQPRL_{j,h,b},$$

$$0 \le 30RSPRL^{1}_{j,h,b} \le OPRL^{1}_{h,b} 30RQPRL_{j,h,b},$$

$$0 \le SPRG^{1}_{k,h,b} \le OPRG^{1}_{h,b} QPRG_{k,h,b},$$

$$0 \le 10SSPRG^{1}_{k,h,b} \le OPRG^{1}_{h,b} 10SQPRG_{k,h,b},$$

$$0 \le 10NSPRG^{1}_{k,h,b} \le OPRG^{1}_{h,b} 10NQPRG_{k,h,b},$$ and

$$0 \le 30RSPRG^{1}_{k,h,b} \le OPRG^{1}_{h,b} 30RQPRG_{k,h,b},$$ for all *bids j*, *offers k*, hours *h*, and buses *b*.

2.8.2.6 The hourly *energy* from the multi-hour imports and exports are not optimization variables. They are calculated using the commitment status, start hour and end hour of the associated multi-hour imports and exports as follows:

$SBXL^1_{j,h,a} = OBXL^1_{j,a} \cdot QBXL_{j,a}$, for all *bid* hours from $STXHR_{j,a}$ to $ENXHR_{j,a}$ and zero for all other hours.

$SBIG^1_{k,h,a} = OBIG^1_{k,a} \cdot QBIG_{k,a}$, for all *offer* hours from $STIHR_{k,a}$ to $ENIHR_{k,a}$ and zero for all other hours.

2.8.2.7 Boolean variable, $OMPSL^1_j$ indicates whether a multi-hour *price sensitive load bid* is committed. A value of zero indicates that a resource is not committed, while a value of one indicates that it is committed. Therefore:

$OMPSL^1_j = 0$ or 1, for *bid j.*

=

2.8.2.8 The hourly *energy* to be consumed by multi-hour *price sensitive load bids* are not optimization variables. They are calculated using the commitment status, start hour and end hour of the associated multi-hour *price sensitive loads* as follows:

$SMPSL^1_{h,j} = OMPSL^1_j QMPSL_j$, for all *bid* hours from $STMPSHR_j$ to $ENMPSHR_j$ and zero for all other hours.

2.8.2.9 The minimum and/or maximum output of *generating facilties* may be limited because of *outages* and/or deratings or in order for the units to provide *regulation* or voltage support. These constraints will take the form:

$$MinPRG_{h,b} \le MinQPRG_{h,b} + \sum_{k \in K_b} SPRG^1_{k,h,b} \le MaxPRG_{h,b}$$

where:

$MinPRG_{h,b}$ is the *minimum generation level* specified by the *IMO*, and

$MaxPRG_{h,b}$ is the maximum *generation* level specified by the *IMO*, or as indicated by *outage* or derating information.

2.8.2.10 Constraining the schedule quantities to be within the maximum capability rating for a resource, as represented by the registration data for the resource, is achieved through the constraints above since *bids* and *offers* may not exceed such maximum capability for the resource.

2.8.3 The optimization must not violate the parameters specified in the *offers* which describe the *operating reserve* available for scheduling.

2.8.3.1 The total *operating reserve* (non-synchronized ten-minute and thirty-minute) from committed *price responsive load* can not exceed its ramp capability over 30 minutes.

$$\sum_{j \in J} (10NSPRL^{1}_{j,h,b} + 30RSPRL^{1}_{j,h,b}) \leq 30 \cdot OPRL^{1}_{h,b} \cdot ORRPRL_{h,b},$$

2.8.3.2 The total *operating reserve* (non-synchronized ten-minute and thirty-minute) from committed *price responsive load* can not exceed the total scheduled load (maximum load *bid* minus the load reductions).

$$\sum_{j \in J} (10NSPRL^{1}_{j,h,b} + 30RSPRL^{1}_{j,h,b}) \leq \sum_{j \in J} (QPRL_{j,h,b} - SPRL^{1}_{j,h,b}).$$

2.8.3.3 The amount of non-synchronized *ten-minute operating reserve* that a *price responsive load* is scheduled to provide cannot exceed the amount by which it can decrease its load over 10 minutes, as limited by its *operating reserve ramp rate.*

$$\sum_{j \in J} 10NSPRL^{1}_{j,h,b} \leq 10 \cdot ORRPRL_{h,b}.$$

2.8.3.4 The total *operating reserve* (ten-minute synchronized,ten-minute non-synchronized and thirty-minute) from a committed *generation facility* can not exceed its ramp capability over 30 minutes.

$$\sum_{k \in K} (10SSPRG^{1}_{k,h,b} + 10NSPRG^{1}_{k,h,b} + 30RSPRG^{1}_{k,h,b}) \leq 30 \cdot OPRG^{1}_{h,b} \cdot ORRPRG_{h,b},$$

2.8.3.5 The total *operating reserve* (ten-minute synchronized,ten-minute non-synchronized and thirty-minute) from a committed *generation facility* can not exceed the remaining capacity (maximum *offered generation* minus the *energy* schedule).

$$\sum_{k \in K} (10SSPRG^{1}_{k,h,b} + 10NSPRG^{1}_{k,h,b} + 30RSPRG^{1}_{k,h,b}) \leq \sum_{k \in K} (QPRG_{k,h,b} - SPRG^{1}_{k,h,b}).$$

2.8.3.6 The amount of *ten-minute operating reserve* (both synchronized and non-synchronized) that a *generation facility* is scheduled to provide cannot exceed the amount by which it can increase its output over 10 minutes, as limited by its *operating reserve ramp rate.*

$$\sum_{k \in K} (10SSPRG^{1}_{k,h,b} + 10NSPRG^{1}_{k,h,b}) \leq 10 \cdot ORRPRG_{h,b}.$$

2.8.3.7 The total *operating reserve* (ten-minute non-synchronized and thirty-minute) from hourly exports can not exceed its ramp capability over 30 minutes.

$$\sum_{j \in J} (SX10N^{1}_{j,h,a} + SX30R^{1}_{j,h,a}) \leq 30 \cdot ORRHXL_{h,a},$$

2.8.3.8 The total *operating reserve* (ten-minute non-synchronized and thirty-minute) from hourly exports can not exceed the total scheduled *export.*

$$\sum_{j \in J} (SX10N^{1}_{j,h,a} + SX30R^{1}_{j,h,a}) \leq \sum_{j \in J} SHXL^{1}_{j,h,a}.$$

2.8.3.9 The amount of non-synchronized *ten-minute operating reserve* that hourly *export* is scheduled to provide cannot exceed the amount by which it can decrease its load over 10 minutes, as limited by its *operating reserve ramp rate.*

$$\sum_{j \in J} SX10N^{1}_{j,h,a} \leq 10 \cdot ORRHXL_{h,a}.$$

2.8.3.10 The total *operating reserve* (ten-minute non-synchronized and thirty-minute) from hourly imports can not exceed its ramp capability over 30 minutes.

$$\sum_{k \in K} (SI10N^{1}_{k,h,a} + SI30R^{1}_{k,h,a}) \leq 30 \cdot ORRHIG_{h,a},$$

2.8.3.11 The total *operating reserve* (ten-minute non-synchronized and thirty-minute) from hourly imports can not exceed the remaining capacity (maximum *import* minus scheduled *energy import*).

$$\sum_{k \in K} (SI10N^{1}_{k,h,a} + SI30R^{1}_{k,h,a}) \leq \sum_{k \in K} (QHIG_{k,h,a} - SHIG^{1}_{k,h,a}).$$

2.8.3.12 The amount of non-synchronized *ten-minute operating reserve* that hourly *import* is scheduled to provide cannot exceed the amount by

which it can increase the output over 10 minutes, as limited by its *operating reserve ramp rate*.

$$\sum_{k \in K} SI10N^{1}_{k,h,a} \leq 10 \cdot ORRHIG_{h,a}.$$

2.8.4 The optimization must not violate the effective uniform ramp rate parameters derived from the *bids* and *offers*.

2.8.4.1 *Energy* schedules for each resource cannot change in successive hours by more than the ramping up or down capacity achievable in one hour for that resource.

2.8.4.2 For one commited hour to another committed hour such schedule change is limited by 60 minutes of ramping at the effective uniform ramp derived from the rates specified in the *offer*.

2.8.4.3 The *energy* schedule change in the hour in which the unit is scheduled to start up or shut down is in part dependent on ramp rates in the *offer*. It must also be dependent on the time required for the *generation facility*to ramp up to or down from the *minimum generation level*.

2.8.4.4 As specified for registration data, *generation facilities* are assumed able to ramp up to and down from their *minimum generation level* in no more than one hour. This may allow some additional time within the start or end hour of the commitment period for ramping above the *minimum generation level*, at ramp rates specified in the *offer* associated with the incremental *energy* which may be scheduled.

2.8.4.5 The following constraint limits changes in schedules from one committed hour to the next commited hour to 60 minutes of ramping at the *effective uniform ramp rate* down or ramp rate up for the *generation facility*. The constraint also limits the hourly change in schedule for incremental *energy* in hours where there is a commitment status change for the resource, which occurs in hours where the resource starts up or shuts down.

$$\sum_{k \in K_b} SPRG^{1}_{k,h-1,b} - 60(YG(OPRG^{1}_{h,b} - OPRG^{1}_{h-1,b}) + 1)DRRPRG_{h,b} \leq \sum_{k \in K_b} SPRG^{1}_{k,h,b} \leq \sum_{k \in K_b} SPRG^{1}_{k,h-1,b} + 60(1 - XG(OPRG^{1}_{h,b} - OPRG^{1}_{h-1,b}))URRPPRG_{h,b},$$

2.8.4.6 Similar considerations apply to *price responsive loads* leading to the following constraint:

$$\sum_{j\in J_b} SPRL^1_{j,h-1,b} - 60(YL(OPRL^1_{h,b} - OPRL^1_{h-1,b}) + 1)DRRPRL_{h,b} \le \sum_{j\in J_b} SPRL^1_{j,h,b}$$
$$\le \sum_{j\in J_b} SPRL^1_{j,h-1,b} + 60(1 - XL(OPRL^1_{h,b} - OPRL^1_{h-1,b}))URRPPRL_{h,b},$$

2.8.4.7 These ramping constraints apply for all hours from 1 to 24. In the above two constraint equations for hour 1 the variables related to hour zero are schedule and commitment variable values from last hour of the previous day.

2.8.4.8 Changes to the maximum and minimum scheduling limits from one hour to the next may not be feasible for the specified ramping capability of the resource. Where this occurs, the ramping rates in the ramping constraints, must be adjusted to allow the resource to:

i) ramp down from its minimum *offer* or *bid* in hour (*h-1*) to its maximum *offer* or *bid* in hour *h*, or

ii) ramp up from its maximum *offer* or *bid* in hour (*h-1*) to its its minimum *offer* or *bid* in hour *h.*

2.8.5 The optimization must not violate the duration parameters specified in the *bids* and *offers*.

2.8.5.1 Schedules for *price responsive loads* and *generation facilities* must observe *minimum run times*, *minimum down times*, and the *maximum number of stops*.

2.8.5.2 At the beginning of the day, if the number of down-time hours at the end of the previous day (where there was no load reduction scheduled) is less than the minimum down time, then the *price responsive load* at bus *b* has not yet completed its minimum down time. Therefore, the resource may not be committed for the required number of hours at the beginning of the day.

If $\text{InitDownHrs}_b < \text{MDTPRL}_b$, then

$$OPRL^1_{1,b}, OPRL^1_{2,b}, ..., OPRL^1_{\min(24, MDTPRL_b - InitDownHrs_b), b} = 0,$$

2.8.5.3 At the beginning of the day, if the number of run-time hours at the end of the previous day (where load reduction was scheduled) is less than the minimum run time, then the *price responsive load* at bus *b* has not yet completed its minimum run time. Therefore, the resource may not be decommitted for the required number of hours at the beginning of the day.

If $\text{InitOperHrs}_b < \text{MRTPRL}_b$, then

$$OPRL^{1}_{1,b}, OPRL^{1}_{2,b}, ..., OPRL^{1}_{\min(24, MRTPRL_b - InitOperHrs_b), b} = 1.$$

2.8.5.4 At the beginning of the day, if the number of down-time hours at the end of the previous day (where there was no *generation* scheduled) is less than the minimum down time, then the *generation facility* at bus *b* has not yet completed its minimum down time. Therefore, the resource may not be committed for the required number of hours at the beginning of the day.

If $InitDownHrs_b < MDTPRG_b$, then

$$OPRG^{1}_{1,b}, OPRG^{1}_{2,b}, ..., OPRG^{1}_{\min(24, MDTPRG_b - InitDownHrs_b), b} = 0,$$

2.8.5.5 At the beginning of the day, if the number of run-time hours at the end of the previous day (where there was *generation* scheduled) is less than the minimum run time, then the *generation facility* at bus *b* has not yet completed its minimum run time. Therefore, the resource may not be decommitted for the required number of hours at the beginning of the day.

If $InitOperHrs_b < MRTPRG_b$, then

$$OPRG^{1}_{1,b}, OPRG^{1}_{2,b}, ..., OPRG^{1}_{\min(24, MRTPRG_b - InitOperHrs_b), b} = 1.$$

2.8.5.6 During the day, if the *price responsive load* at bus *b* has been scheduled to cease load reduction during hour h + 1, no further load reduction may be scheduled until it has completed its minimum time between load reductions, or for all remaining hours of the day, whichever occurs first.

If $OPRL^{1}_{h,b} = 1$, $OPRL^{1}_{h+1,b} = 0$, and $MDTPRL_b > 1$, then

$$OPRL^{1}_{h+2,b}, OPRL^{1}_{h+3,b}, ..., OPRL^{1}_{\min(24, h+MDTPRL_b), b} = 0.$$

2.8.5.7 During the day, if the *price responsive load* at bus *b* has been scheduled to initiate load reduction during hour h + 1, it must be scheduled to continue to provide load reduction until it has completed its *minimum load reduction time*, or for all remaining hours of the day, whichever occurs first.

If $OPRL^{1}_{h,b} = 0$, $OPRL^{1}_{h+1,b} = 1$, and $MRTPRL_b > 1$, then

$$OPRL^{1}_{h+2,b}, OPRL^{1}_{h+3,b}, ..., OPRL^{1}_{\min(24, h+MRTPRL_b), b} = 1.$$

2.8.5.8 During the day, if the genertation resource at bus *b* has been scheduled to shut down during hour h + 1, no further *generation*

may be scheduled until it has completed its minimum down time, or for all remaining hours of the day, whichever occurs first.

If $OPRG^{1}_{h,b} = 1$, $OPRG^{1}_{h+1,b} = 0$, and $MDTPRG_b > 1$, then

$$OPRG^{1}_{h+2,b}, OPRG^{1}_{h+3,b}, ..., OPRG^{1}_{\min(24, h+MDTPRL_b),b} = 0.$$

2.8.5.9 During the day, if the *generation facility* at bus *b* has been scheduled to start up during hour h + 1, it must be scheduled to remain in operation until it has completed its minimum run time, or for all remaining hours of the day, whichever occurs first.

If $OPRG^{1}_{h,b} = 0$, $OPRG^{1}_{h+1,b} = 1$, and $MRTPRG_b > 1$, then

$$OPRG^{1}_{h+2,b}, OPRG^{1}_{h+3,b}, ..., OPRG^{1}_{\min(24, h+MRTPRL_b),b} = 1.$$

2.8.5.10 To ensure that *generation facilities* and *price responsive load* are not scheduled to stop more than their specified *maximum number of stops* in a day, the following constraints are defined:

$$\sum_{h=1}^{24} IPRG^{1}_{h,b} \leq MaxStopsG_b,$$

$$\sum_{h=1}^{24} IPRL^{1}_{h,b} \leq MaxStopsRL_b.$$

2.8.6 The optimization must not violate the daily *energy* limit specified in an *offer*.

2.8.6.1 An *energy limited resource* may not be scheduled to provide more *energy* in total over the day than is indicated through its *offer* it is capable of providing. In addition, the application of the energy limit must also ensure that *facilities* are not scheduled to provide *energy* in amounts that would preclude them from providing *energy* for activated *operating reserve* in any given hour.

$$\sum_{h=1}^{1}\left(OPRG^{1}_{h,b}\cdot MinQPRG_{h,b}+\sum_{k\in K_b}SPRG^{1}_{k,h,b}\right)+\sum_{k\in K_b}10SSPRG^{1}_{k,1,b}+\sum_{k\in K_b}10NSPRG^{1}_{k,1,b}+\sum_{k\in K_b}30RSPRG^{1}_{k,1,b}\le EL_b,$$

$$\sum_{h=1}^{2}\left(OPRG^{1}_{h,b}\cdot MinQPRG_{h,b}+\sum_{k\in K_b}SPRG^{1}_{k,h,b}\right)+\sum_{k\in K_b}10SSPRG^{1}_{k,2,b}+\sum_{k\in K_b}10NSPRG^{1}_{k,2,b}+\sum_{k\in K_b}30RSPRG^{1}_{k,2,b}\le EL_b,\quad ,$$

$$\mathbb{M}$$

$$\sum_{h=1}^{24}\left(OPRG^{1}_{h,b}\cdot MinQPRG_{h,b}+\sum_{k\in K_b}SPRG^{1}_{k,h,b}\right)+\sum_{k\in K_b}10SSPRG^{1}_{k,24,b}+\sum_{k\in K_b}10NSPRG^{1}_{k,24,b}+\sum_{k\in K_b}30RSPRG^{1}_{k,24,b}\le EL_b,$$

for all buses ***b*** at which ***energy limited resources*** are located.

2.8.7 The optimization must satisfy load requirements, by balancing injections and withdrawals.

2.8.7.1 For each hour, the total amount of ***energy*** injected (scheduled supply from ***generation facilities*** plus scheduled imports and ***virtual offers***) must balance total ***energy*** withdrawn (scheduled purchases by loads, exports and ***virtual bids***) and transmission losses consistent with these supplies and purchases.

2.8.7.2 Withdrawals at bus ***b*** within Ontario and each bus d outside Ontario for hour ***h*** is the sum of:

i) the total scheduled ***price sensitive load*** and scheduled ***virtual bids*** allocated to the bus ***b***, using the load distribution factors used to distribute forecasted load;

ii) ***price responsive load*** at the bus ***b*** net of any scheduled load reduction;

iii) multi-hour and hourly exports from Ontario to each ***intertie zone***, allocated among the buses ***d*** in the ***intertie zone*** using the distribution factors developed for that purpose; and

iv) outflows from Ontario associated with unscheduled loop flows between Ontario and each ***intertie zone***, allocated among the buses ***d*** in the ***intertie zone*** using the distribution factors developed for that purpose.

For *pass 1* at each bus *b* within Ontario and each bus *d* outside Ontario in each hour *h*, withdrawals are defined as[1]:

$$With^1_{h,b} = LDF_{h,b}\left[\sum_{j\in J}\left(SPSL^1_{j,h} + SMPSL^1_{j,h} + SVL^1_{j,h}\right)\right] + (1 - OPRL^1_{h,b}) \cdot MinQPRL_{h,b} + \sum_{j\in J_b}\left(QPRL_{j,h,b} - SPRL^1_{j,h,b}\right)$$

$$With^1_{h,d} = \sum_{a\in A}\left(ProxySFWt_{d,a}\sum_{j\in J}(SHXL^1_{j,h,a} + SBXL^1_{j,h,a})\right) - \sum_{a\in A} ProxyUPOWt_{d,a}\min(0, PF_{h,a}).$$

2.8.7.3 Injections at bus *b* for hour *h* is the sum of:

i) *virtual offers* scheduled in that hour allocated to that bus *b*, using the load distribution factors used to distribute forecasted load;

ii) scheduled energy from a *generation facility* at that bus *b*;

iii) multi-hour and hourly imports into Ontario from each *intertie zone*, allocated among the buses *d* in the *intertie zone* using the distribution factors developed for that purpose; and

iv) inflows into Ontario associated with unscheduled loop flows between Ontario and each *intertie zone*, allocated among the buses *d* in the *intertie zone* using the distribution factors developed for that purpose.

For *pass 1* at each bus *b* within Ontario and each bus *d* outside Ontario in each hour *h*, injections are defined as[2]:

$$Inj^1_{h,b} = LDF_{h,b}\sum_{k\in K} SVS^1_{k,h} + OPRG^1_{h,b} \cdot MinQPRG_{h,b} + \sum_{k\in K_b} SPRG^1_{k,h,b}$$

$$Inj^1_{h,d} = \sum_{a\in A}\left(ProxySFWt_{d,a}\sum_{k\in K}(SHIG^1_{k,h,a} + SBIG^1_{k,h,a})\right) + \sum_{a\in A} ProxyUPIWt_{d,a}\max(0, PF_{h,a}).$$

2.8.7.4 To balance supply and purchases, losses must be taken into account. This is accomplished by adjusting injections and withdrawals at a bus for the marginal loss factor of that bus relative to the *reference bus*. Additional losses must be included as a loss adjustment, since total losses may be different from the sum of

[1] $PF_{h,a}$ uses the convention that a positive number denotes an inflow, so it is multiplied by negative one in the definition of $With^1_{h,b}$ so that it will correspond to an outflow. As in the current practice for the RTM, only the loop flows between New York and Michigan through Ontario will be considered for the *day-ahead market*.

[2] As in the current practice for the RTM, only the loop flows between New York and Michigan through Ontario will be considered for the *day-ahead market*.

marginal losses. Finally, load and *generation* violation variables must be included to avoid infeasible solutions.

$$\sum_{b\in B}(1+MglLoss_{h,b})With^{1}_{h,b}+\sum_{d\in D}(1+MglLoss_{h,d})With^{1}_{h,d}-SLDViol^{1}_{h}=$$
$$\sum_{b\in B}(1+MglLoss_{h,b})Inj^{1}_{h,b}+\sum_{d\in D}(1+MglLoss_{h,d})Inj^{1}_{h,d}-SGenViol^{1}_{h}+LossAdj_{h}.$$

2.8.8 The optimization must not violate *operating reserve* requirements.

2.8.8.1 Sufficient *operating reserve* must be scheduled to meet system wide requirements for *ten-minute operating* synchronized *reserve*, *ten-minute operating reserve* and *thirty-minute operating reserve*, as well as all applicable regional minimum and maximum requirements for *operating reserve*.

2.8.8.2 Violation variables ensure a feasible solution and allow relaxation of the requirements if the cost of meeting these becomes too high.

2.8.8.3 For synchronized *ten-minute operating reserve*, for all hours *h*:

$$\sum_{b\in B}\left(\sum_{k\in K}10SSPRG^{1}_{k,h,b}\right)+S10SViol^{1}_{h}\geq TOT10S_{h}$$

2.8.8.4 For total *ten-minute operating reserve*, for all hours *h*:

$$\sum_{b\in B}\left(\sum_{k\in K}10SSPRG^{1}_{k,h,b}\right)+S10RViol^{1}_{h}$$
$$+\sum_{b\in B}\left(\sum_{k\in K}10NSPRG^{1}_{k,h,b}\right)+\sum_{b\in B}\left(\sum_{j\in J}10NSPRL^{1}_{j,h,b}\right)$$
$$+\sum_{a\in A}\left(\sum_{k\in K}SI10N^{1}_{k,h,a}\right)+\sum_{a\in A}\left(\sum_{j\in J}SX10N^{1}_{j,h,a}\right)\geq TOT10R_{h}$$

2.8.8.5 For total *thirty-minute operating reserve*, for all hours *h*:

$$\sum_{b\in B}\left(\sum_{k\in K} 10SSPRG^{1}_{k,h,b}\right) + S30RViol^{1}_{h}$$
$$+\sum_{b\in B}\left(\sum_{k\in K} 10NSPRG^{1}_{k,h,b} + 30RSPRG^{1}_{k,h,b}\right)$$
$$+\sum_{b\in B}\left(\sum_{j\in J} 10NSPRL^{1}_{j,h,b} + 30RSPRL^{1}_{j,h,b}\right)$$
$$+\sum_{a\in A}\left(\sum_{k\in K} SI10N^{1}_{k,h,a} + SI30R^{1}_{k,h,a}\right)$$
$$+\sum_{a\in A}\left(\sum_{j\in J} SX10N^{1}_{j,h,a} + SX30R^{1}_{j,h,a}\right) \geq TOT30R_{h}$$

2.8.8.6 To satisfy the minimum regional requirement for ***ten-minute operating reserve***, for all hours ***h***, and for all regions ***r*** in the set *ORREG*:

$$\sum_{b\in r}\left(\sum_{k\in K} 10SSPRG^{1}_{k,h,b}\right) + SREG10RViol^{1}_{r,h}$$
$$+\sum_{b\in r}\left(\sum_{k\in K} 10NSPRG^{1}_{k,h,b}\right) + \sum_{b\in r}\left(\sum_{j\in J} 10NSPRL^{1}_{j,h,b}\right) \geq REGMin10R_{r,h}$$

2.8.8.7 To satisfy the maximum regional requierment for ***ten-minute operating reserve***, for all hours ***h***, and for all regions ***r***:

$$\sum_{b\in r}\left(\sum_{k\in K} 10SSPRG^{1}_{k,h,b}\right) - SXREG10RViol^{1}_{r,h}$$
$$+\sum_{b\in r}\left(\sum_{k\in K} 10NSPRG^{1}_{k,h,b}\right) + \sum_{b\in r}\left(\sum_{j\in J} 10NSPRL^{1}_{j,h,b}\right) \leq REGMax10R_{r,h}$$

2.8.8.8 To satisfy the minimum regional requierment for ***thirty-minute operating reserve***, for all hours ***h***, and for all regions ***r***:

$$\sum_{b\in r}\left(\sum_{k\in K} 10SSPRG^{1}_{k,h,b}\right) + SREG30RViol^{1}_{r,h}$$
$$+\sum_{b\in r}\left(\sum_{k\in K} 10NSPRG^{1}_{k,h,b} + 30RSPRG^{1}_{k,h,b}\right)$$
$$+\sum_{b\in r}\left(\sum_{j\in J} 10NSPRL^{1}_{j,h,b} + 30RSPRL^{1}_{j,h,b}\right) \geq REGMin30R_{r,h}$$

2.8.8.9 To satisfy the maximum regional requierment for ***thirty-minute operating reserve***, for all hours ***h***, and for all regions ***r***:

$$\sum_{b\in r}\left(\sum_{k\in K} 10SSPRG^{1}_{k,h,b}\right) - SXREG30RViol^{1}_{r,h}$$
$$+\sum_{b\in r}\left(\sum_{k\in K} 10NSPRG^{1}_{k,h,b} + 30RSPRG^{1}_{k,h,b}\right)$$
$$+\sum_{b\in r}\left(\sum_{j\in J} 10NSPRL^{1}_{j,h,b} + 30RSPRL^{1}_{j,h,b}\right) \le REGMax30R_{r,h}$$

2.8.9 The optimization must not violate internal transmission limits or ***security*** constraints.

2.8.9.1 ***Energy*** schedules produced by ***pass 1*** must not overload any internal transmission ***facility*** or exceed any ***security limits*** in either the pre-contingency state or in any contingency, except where this is not feasible.

2.8.9.2 ***Energy*** flows associated with a transmission or ***security limit*** are determined from the total scheduled ***energy*** at each bus, as injections or withdrawals, and the fraction of that ***energy*** which contributes to the transmission or ***security*** flow.

2.8.9.3 Total withdrawals scheduled in ***pass 1*** at each bus ***b*** in each hour ***h***, $WithT^{1}_{h,b}$, for buses within Ontario is:

$$WithT^{1}_{h,b} = LDF_{h,b}\left[\sum_{j\in J}\left(SPSL^{1}_{j,h} + SMPSL^{1}_{h,j} + SVL^{1}_{j,h}\right)\right]$$
$$+ (1 - OPRL^{1}_{h,b}) \cdot MinQPRL_{h,b} + \sum_{j\in J_b}\left(QPRL_{j,h,b} - SPRL^{1}_{j,h,b}\right) + \sum_{j\in J} SCMPRL^{1}_{j,h,b}$$

2.8.9.4 Total injections scheduled in ***pass 1*** at each bus ***b*** in each hour ***h***, $InjT^{1}_{h,b}$, for buses within Ontario is:

$$InjT^{1}_{h,b} = LDF_{h,b}\sum_{k\in K} SVS^{1}_{k,h} + OPRG^{1}_{h,b} \cdot MinQPRG_{h,b} + \sum_{k\in K_b} SPRG^{1}_{k,h,b}.$$

2.8.9.5 Total withdrawals scheduled in ***pass 1*** at each bus ***d*** in each hour ***h***, $WithX^{1}_{h,b}$, for buses outside Ontario in ***intertie zones*** associated with exports and unscheduled loop flows is:

$$WithX^{1}_{h,d} = \sum_{a \in A}\left[ProxySFWt_{d,a}(SBXL^{1}_{h,a} + \sum_{j \in J} SHXL^{1}_{j,h,a}) - ProxyUPOWt_{d,a} \min(0, PF_{h,a}) \right],$$

2.8.9.6 Total injections scheduled in *pass 1* at each bus *d* in each hour *h*, $InjX^{1}_{h,b}$, for buses outside Ontario associated with exports and unscheduled loop flows is:

$$InjX^{1}_{h,d} = \sum_{a \in A}\left[ProxySFWt_{d,a}(SBIG^{1}_{h,a} + \sum_{k \in K} SHIG^{1}_{k,h,a}) + ProxyUPIWt_{d,a} \max(0, PF_{h,a}) \right].$$

2.8.9.7 The *security* assessment function of the *DAM calculation engine* will identify binding (violated) pre-contingency limits on transmission *facilities* within Ontario. These will accounted for within the optimization as linearized constraints of the form:

$$\sum_{b \in B} PreConSF_{b,f,h}(InjT^{1}_{h,b} - WithT^{1}_{h,b}) + \sum_{d \in D} PreConSF_{d,f,h}(InjX^{1}_{h,d} - WithX^{1}_{h,d}) + \sum_{b \in B} PreOprgSF_{b,f,h} OPRG^{1}_{h,b} - SPreConITLViol^{1}_{f,h} \le AdjNormMaxFlow_{f,h},$$

where *D* is the set of buses outside Ontario, for all *facilities f* and hours *h*.

2.8.9.8 Similarly, linearized binding post-contingency limits will take the form:

$$\sum_{b \in B} SF_{b,f,c,h}(InjT^{1}_{h,b} - WithT^{1}_{h,b}) + \sum_{d \in D} SF_{d,f,c,h}(InjX^{1}_{h,d} - WithX^{1}_{h,d}) - SITLViol^{1}_{f,c,h} \le AdjEmMaxFlow_{f,c,h},$$

for all *facilities f*, hours *h*, and monitored contingencies *c*.

2.8.10 The optimization must not violate *intertie* limits.

2.8.10.1 Schedules produced by *pass 1* must not overload any *intertie facility* or exceed any *security limits*, except where this is not feasible.

2.8.10.2 Scheduled *import* and *export energy* plus *operating reserve* scheduled from control areas associated with an *intertie* should not exceed any limits associated with the *intertie*. A single constraint may represent a limit on schedules from more than one *intertie*.

2.8.10.3 The sum of the net scheduled *energy* and, in some cases, *operating reserve* from all *intertie zones* associated with an *intertie* constraint must be less than the constraint limit. *Operating reserve* is included for *interties* with a limit on injections, but not included for *interties* where there is a limit on withdrawals.

$$\sum_{a\in A}\left[\begin{array}{l} EnCoeff_{a,z}\left(\sum_{k\in K}(SHIG^{1}_{k,h,a}+SBIG^{1}_{k,h,a})+PF_{h,a}-\sum_{j\in J}(SHXL^{1}_{j,h,a}+SBXL^{1}_{j,h,a})\right)+ \\ 0.5(EnCoeff_{a,z}+1)\left[\sum_{k\in K}\left(SI10N^{1}_{k,h,a}+SI30R^{1}_{k,h,a}\right)+\sum_{j\in J}\left(SX10N^{1}_{j,h,a}+SX30R^{1}_{j,h,a}\right)\right] \end{array}\right] \le MaxExtSch_{z,h},$$

for all hours *h* and for all constraints z in the set Z_{sch}.

2.8.10.4 Changes in the net *energy* scheduled over all *interties* cannot exceed the limits set by the *IMO* for hour-to-hour changes in those total net schedules.

2.8.10.5 The net *import* schedule is the sum of imports less exports over all *interties* for a given hour. It cannot exceed the sum of net *import* schedule for all *intertie* for the previous hour plus the maximum permitted hourly increase. It can not be less than the sum of the net *import* schedule for all *interties* for the previous hour minus the maximum permitted hourly decrease. Violation variables are provided for both the up and down ramp limits to ensure that the *DAM calculation engine* will always find a solution. Therefore:

$$\begin{aligned} &\sum_{a\in A}\left(\sum_{k\in K}(SHIG^{1}_{k,h-1,a}+SBIG^{1}_{k,h-1,a})-\sum_{j\in J}(SHXL^{1}_{j,h-1,a}+SBXL^{1}_{j,h-1,a})\right)-ExtDSC_h-SDRmpXTLViol^{1}_{h} \\ &\le \sum_{a\in A}\left(\sum_{k\in K}(SHIG^{1}_{k,h,a}+SBIG^{1}_{k,h,a})-\sum_{j\in J}(SHXL^{1}_{j,h,a}+SBXL^{1}_{j,h,a})\right) \\ &\le \sum_{a\in A}\left(\sum_{k\in K}(SHIG^{1}_{k,h-1,a}+SBIG^{1}_{k,h-1,a})-\sum_{j\in J}(SHXL^{1}_{j,h-1,a}+SBXL^{1}_{j,h-1,a})\right)+ExtUSC_h+SURmpXTLViol^{1}_{h} \end{aligned}$$

for all hours *h*.

2.9 Locational Marginal Prices for Energy at Internal Buses

2.9.1 The *pass 1 locational marginal price* for energy at each bus *b* in each hour *h* measures the *offered* cost of meeting the marginal MWh of load at that bus in that hour, or equivalently, measures the value of the marginal MWh of *generation* at that bus in that hour in *pass 1*.

2.9.2 The *locational marginal price* must account for the cost of meeting load at bus *b*, incorporating the effect of marginal losses. It reflects the quantity of *energy* that must be injected at the *reference bus* to meet additional load at each bus *b*.

2.9.3 The *locational marginal price* must also account for the cost of additional transmission congestion at each internal transmission interface resulting from the increased withdrawal at bus *b*. This applies to both pre- and post-contingency internal transmission constraints. The cost of additional congestion at an interface is determined as the product of:

i) shadow price of the constraint, which equates to the cost of the marginal MW scheduled to flow acrooss the constraint;

ii) the shift factor for the bus and the constraint, which measures the actual impact of additional withdrawals at the bus on flows over the constraint; and

iii) negative one, since the shift factors for each bus are defined in terms of the impact on a *transmission facility* of an increment of *generation* at the bus offset by an increment of load at the *reference bus*.

2.9.4 The *pass 1 locational marginal price* for *energy* at each bus *b* in each hour *h*, given the inputs and constraints into *pass 1*, shall be calculated:

$$LMP^{1}_{h,b} = \left(1 + MglLoss_{h,b}\right) \cdot \left[SPL^{1}_{h} - \sum_{f} \left(\begin{array}{l} PreConSF_{b,f,h} \cdot SPNormT^{1}_{f,h} \\ + \sum_{c} SF_{b,f,c,h} \cdot SPEmT^{1}_{f,c,h} \end{array} \right) \right]$$

for each internal bus *b* for each hour *h*.

The variables SPL^{1}_{h}, $SPNormT^{1}_{f,h}$ and $SPEmT^{1}_{f,c,h}$ are the shadow prices associated with the load balancing constraint, and transmission *facility* limits during normal and emergency conditions, respectively.

2.9.5 The calculation engine is also capable of providing shadow values associated with:

2.9.5.1 flow limits on the *intertie facilities*;

2.9.5.2 the limit on changes, up or down, for net imports over all interties;

2.9.5.3 operating reserve requirements, representing the change in the objective function value for a small change in the requirements for each class of operating reserve; and

2.9.5.4 The maximum or minimum area reserve requirements for ten-minute and thirty-minute operating reserve.

Pass 1 results for these values are neither used in later passes nor published. However, comparable values for *pass 3* and *pass 5* are used. The specific variables and definitions are provided in the glossary, section 2.6.2.7.

2.10 Step 2: Treatment of Multiple Energy Ramp Rates

2.10.1 The full optimization for this *pass* requires two steps in which the treatment of ramp rates is fundamentally different.

2.10.1.1 In step 1, a single ramp rate is assumed to apply for all ranges of the *bid* and *offer*.

2.10.1.2 In step 2, multiple ramp rates are allowed, dependent on the quantity scheduled.

2.10.2 Step 1 of the optimization is described in detail in the previous sections.

2.10.2.1 Step 1 requires calculating a uniform ramp rate for *generation offers* and *price responsive load bids*. The maximum effective uniform ramp rate used would allow the resource to ramp up or down between its minimum and maximum levels, as specified in the *bid* or *offer*, in the same time it would take to ramp using its multiple ramp rates for *energy*.

2.10.2.2 As specified in the previous sections, step 1 of solves the multi-hour economic scheduling to produce *energy* and *operating reserve* schedules and commitments (for *pass 1* and *pass 2A*).

2.10.3 Step 2 of the optimization is based on the modification described in the next sections.

2.10.3.1. Step 2 solves a set of single hour economic scheduling problems, sequentially from hour 1 to hour 24.

2.10.3.2 In step 2 the multiple ramp rates specified in *energy bids* and *offers* constrain the schedules for *generation* and *price responsive load*.

2.10.4 The output from the two steps will consist of:

2.10.4.1 one set of *unit commitments* as determined by step 1 of *pass 1* (which are used as inputs to step 2 of *pass 1* and outputs from pass1;

2.10.4.2 one set of *energy limited resource* schedules as determined by step 1 and treated as the output of this *pass*;

2.10.4.3 two sets of schedules for all the other resources (steps 1 and 2). Schedules output from step 1 are input to step 2. The schedules from step 2 will be considered the output from this *pass*, for use by subsequent passes, because they reflect the correct ramping constraints for the resources.

2.10.4.4 two sets of shadow prices and *locational marginal prices* for *energy*. The results from step 1 are not required for subsequent purposes. Step 2 *locational marginal prices* for *energy* shall be used as the output of this *pass*.

2.10.5 The following changes to the step 1 description are necessary for the step 2 optimization:

2.10.5.1 Commitment variables will be removed from the optimization. They will be treated as constants. For *pass 1* their values will be those produced by the step 1.

2.10..5.2 The objective function will be modified such that the summation over 24 hours and any commitment costs will be removed. Only the terms applicable to the hour under consideration will be used.

2.10.5.3 Constraints applying to single hours will be used.

2.10.5.4 Inter hour constraints such as status variables, *minimum run time* and *minimum down time* will not be used.

2.10.5.5 Inter hour constraints such as ramping will apply only to internal *generation* and *price responsive loads*. In step 2 the multiple ramp rates in hour *h* constrain the schedule for a resource relative to:

i) the previous hour *(h-1)* schedule as calculated in step 2, and

ii) the subsequent hour (*h+1*) schedule as calculated in step 1.

2.10.5.6 Schedules for *energy limited resources* will be set at the values output from step 1.

2.10.6 Since the scheduled *generation* or load reductions are also constrained by other *offer* and capacity limits, such as those in section 2.8.2, additional logic is required to accommodate the multiple ramp rate constraints. This logic is defined for *generation* in the next sections, section 2.10.7 through 2.10.11. Similar logic would apply for a *price responsive load*.

2.10.7 Determine various minimum and maximum schedule levels related to the *offer* limits of section 2.8.2, and to various ramp limits.

2.10.7.1 Define the most restrictive *generation* limit from the *offer* and capacity limits in section 2.8.2, such that:

$$LowerPRG_{h,b} \leq MinQPRG_{h,b} + \sum_{k \in K_b} SPRG^{1}_{k,h,b} \leq UpperPRG_{h,b}$$

where

$LowerPRG_{h,b}$ is the highest of the lower limits, referred to as the minimum production limit and

$UpperPRG_{h,b}$ is the lowest of the upper limits, referred to as the maximum production limit.

2.10.7.2 Define schedule quantities for hour *h* which are achievable assuming ramping at the *bid* or *offered* ramp rates, starting with the limited schedule calculated in step 2 for hour (*h-1*):

i) $FRmpUPRG_{h,b}$ is the level achievable ramping up for one hour, and

ii) $FRmpDPRG_{h,b}$ is the level achievable ramping down for one hour.

$FRmpUPRG_{h,b}$ and $FRmpDPRG_{h,b}$ represent the upper and lower limits, respectively, of the schedule in hour *h* consistent with the step 2 schedule in hour *(h-1)*.

2.10.7.3 Define schedule quantities for hour *h* from which ramping at the *bid* or *offered* ramp rates will lead to the *energy* schedule calculated in step 1 for hour (*h+1*):

i) $BRmpUPRG_{h,b}$ is the starting level necessary in hour *h* assuming ramping down for one hour, and

ii) $BRmpDPRG_{h,b}$ is the starting level necessary in hour *h* assuming ramping up for one hour.

$BRmpUPRG_{h,b}$ and $BRmpDPRG_{h,b}$ represent the upper and lower limits, respectively, of the schedule in hour *h* consistent with the step 1 schedule in hour *(h+1)*.

2.10.8 Combine the *offer* limits with the ramp limits from hour (*h-1*):

2.10.8.1 If both ramp limits ($FRmpUPRG_{h,b}$ and $FRmpDPRG_{h,b.}$) are less than the minimum production limit ($LowerPRG_{h,b}$), set both the *generation facility* minimum and maximum production limits equal the initial minimum production limit, $LowerPRG_{h,b}$.

2.10.8.2 If both ramp limits ($FRmpUPRG_{h,b}$ and $FRmpDPRG_{h,b.}$) are greater than the maximum production limit ($UpperPRG_{h,b}$), set both *generation facility* minimum and maximum production limits equal the initial maximum *offer* limit, $UpperPRG_{h,b}$.

2.10.8.3 If the *offer* limits overlap with the ramp limits, which is equivalent to neither of the the above two conditions applying:

i) set the maximum production limit to the lower of ($FRmpUPRG_{h,b}$ and $UpperPRG_{h,b}$), and

ii) set the minimum production limits to the higher of ($FRmpDPRG_{h,b}$ and $LowerPRG_{h,b}$)

2.10.9 Combine the revised minimum and maximum production limits with the ramp limits from hour (*h+1*), ($BRmpUPRG_{h,b}$ and $BRmpDPRG_{h,b}$) using the same logic as in section 2.10.8, above.

2.10.10 In the case of conflicts between the *offer* limits, hour (h-1) ramp limits and the hour (h+1) ramp limits, the above logic will give precedence to:

2.10.10.1 the *offer* limits, then

2.10.10.2 the hour (*h-1*) ramp limits, and finally

2.10.10.3 the hour (*h+1*) ramp limits.

2.10.11 For *energy limited resources* the schedules (for both *energy* and *operating reserve*) will be fixed to the schedules produced in step 1. Scheduling of the *energy limited resources* requires optimization over 24 hours, as in step 1.

2.10.11.1 Consequently, where an *offer* for an *energy limited resource* includes multiple *energy* ramp rates, the effective equivalent uniform ramp rate calculated for step 1 will be used to determine the schedules for the resource.

3. Pass 2: Constrained Commitment to Meet Forecast Ontario Load

3.1 Pass 2 Overview

3.1.1 *Pass 2* performs a least cost *security* constrained *unit commitment* and constrained scheduling process that meets the commitment needs for *forecast Ontario load* and *operating reserve* to satisfy *IMO reliability* requirements.

3.1.2 The purpose of *pass 2* of the *DAM calculation engine* is to commit the timely operation of sufficient slow-ramping *generation units* to ensure that the *IMO* will be able to meet its expectations for load during the forthcoming day.

3.1.2.1 As a result a modified forecast of Ontario load is used in place of *bid* load (with the exception of *bids* by *price responsive loads* and exports), and *virtual bids* and *offers* are excluded from the *IMO's* evaluation.

3.1.2.2 *Pass 2* recognizes the commitments from *pass 1* and commits additional resources as necessary to satisfy the requirements associated with any additional forecast load.

3.1.3 The objective of *pass 2* is essentially to determine commitments rather than scheduling *energy*. Unlike *pass 1*, *pass 2* does not attempt to minimize all as-*offered* costs including *energy* costs, associated with meeting load. Instead, p*ass 2* minimizes only the commitment costs excluding *energy* costs, and *import* costs associated with any additional commitments.

3.1.4 To achieve this objective using submitted *bids* and *offers* and the same scheduling algorithm as *pass 1*, *bids* and *offers* representing *price responsive load* or *generation facilities* will be modified for input to *pass 2* only. With the exception of *energy limited resources*, discussed in sections 3.1.5 and 3.1.6, these *bids* and *offers* are modified to reflect only commitment costs, by setting *energy* related costs to a small nominal value. The resulting modified commitment cost, excluding *energy* costs, is the difference between:

3.1.4.1 the *offer* or *bid* startup or load reduction initiation costs and ongoing costs, associated with scheduling a resource at its minimum level, either the *minimum generation level* or *minimum load reduction* level; and,

3.1.4.2 the value of the *energy* produced (for *generation facilities*) or not consumed (for *price responsive loads*) in association with such minimum schedules.

3.1.5 The utilization of *energy limited resources* in *pass 2* allows rescheduling relative to *pass 1* but gives some preference to *pass 1* schedules through the modification to *offers* referred to in section 3.1.4.

3.1.5.1 Re-scheduling for such a resources will occur when the benefit of doing so in *pass 2* exceeds any reduction in the value of the *energy* schedules for the *facility* in *pass 1*.

3.1.5.2 *Pass 2* will also identify and set minimum levels for the schedules for these resources in each hour. Minimum levels are needed where the maximum supply from all committed resources which are not *energy* limited is insufficient by itself to meet reliability requirements. These become minimum schedules for the later passes of the *DAM calculation engine*

3.1.6 In order to accomplish these objectives for *energy limited resources, pass 2* is divided into two almost-identical iterations. The difference between the iterations pertains to the way *energy limited resources* are treated and the fact that the second iteration does not perform any additional resource commitment.

3.1.6.1 E*nergy-limited resource offers* in the first iteration will be modified to reflect the value of the resource in each hour, as represented by the *locational marginal prices* for *energy* from *pass 1*. This allows some rescheduling relative to *pass 1* when the benefit is sufficiently large. In the second iteration, very high prices will be used for these resources, which leads to identifying required minimum schedules.

3.1.6.2 The first iteration performs both *unit commitment* and constrained scheduling process. In the second iteration, the *facility* commitments calculated in the first iteration will be used. The second iteration will perform a constrained scheduling process but not a *unit commitment* in order to determine minimum schedules for *energy limited resources.*

3.1.7 *Pass 2* takes as inputs the commitments from *pass 1* and associated minimum schedule quantities.

3.1.7.1 Multi-hour imports and exports committed and scheduled in *pass 1* are taken as fixed in *pass 2* at the scheduled level. Additional commitment of multi-hour imports is allowed in *pass 2*.

3.1.7.2 *Bids* from *price responsive loads* and *offers* from *generation facilities* committed in *pass 1* are scheduled to at least their minimum levels in *pass 2*. Additional commitment and scheduling of other resources of these types is allowed.

3.1.7.3 Hourly imports scheduled in *pass 1* must be scheduled to at least that value in *pass 2*. Additional hourly imports for these and other resources may be scheduled in *pass 2*.

3.1.7.4 Hourly exports scheduled in *pass 1* are scheduled at that value in *pass 2*. No additional hourly exports for these or other resources may be scheduled in *pass 2*.

3.1.8 The *facility* commitments calculated in the first iteration of *pass 2* will be used in *passes* 3, 4 and 5. The exception to this is the additional commitment in *pass 2* of *hourly committable generation* of the type referred to in section 1.3.8.1 (excluding *energy limited resources)* which will be used only in *pass 4*.

3.1.9 In order to accommodate multiple ramp rates (up and down) in *bids* and *offers, pass 2A* performs two steps in the same manner as described for *pass 1* in section 2.10. Step 1 performs a 24-hour optimization using the *effective uniform ramp rates*. In step 2, commitments and schedules are used from step 1 to perform 24 independent hourly optimizations in which multiple ramp rates are recognized. Step 1 is described in detail in this section 3. The description for step 2 of *pass 2A* is analogous to the description in section 2.10 for step 2 of *pass 1*. *Pass 2B* does not require step 2 since the purpose of *pass 2B* is to determine minimum schedules for *energy limited resources,* which are calculated in step 1 and would be an input and therefore not modified if step 2 were performed.

3.2 Inputs for Pass 2A

3.2.1 Inputs to the *pass 2* process are required to represent:

3.2.1.1 the modified forecast of Ontario loads, net of forecast *price responsive load*, as identified in section 1.7.2,

3.2.1.2 *price responsive load* commitments from *pass 1*, and *bids* as may be modified for the purposes of *pass 2*;

3.2.1.3 *export* commitments and schedules for *energy* from *pass 1*,

3.2.1.4 *generation facility* commitments from *pass 1*, and *energy offers* as may be modified for the purposes of *pass 2*;

3.2.1.5 *import* commitments and schedules for *energy* from *pass 1*, to be used as minimum levels in *pass 2*, and *offers* as submitted,

3.2.1.6 *export* and *import* schedules for *operating reserve* from *pass 1*and *offers* from *price responsive load*s, *generation facilities* and imports to provide *operating reserve*, as may be modified for the purposes of *pass 2*; and

3.2.1.7 other inputs which are identical to *pass 1* inputs referred to in sections 2.2.1.4 to 2.2.1.7.

3.2.2 The modified forecast of Ontario load will be the hourly peak forecasts as described in section 1.7.2. The forecast load input to *pass 2* will include estimated *price sensitive load* but not *price responsive load* consumption.

3.2.3 *Pass 2A* shall accept as input data related to the following *bid*-based *energy* purchases:

3.2.3.1 for multi-part and block *price responsive loads,* commitments from *pass 1* and *bids,* with modifications to the ongoing commitment costs and the decremental *energy* prices *bid*, as specified in section 3.6;

3.2.3.2 for hourly exports, schedules from *pass 1;* and

3.2.3.3 for multi-hour exports, the commitments from *pass 1*and *bids*as submitted by the *market participants.*

exports *Pass 2A* will not include *price sensitive load bids* or *virtual bids* or any schedules for these determined in *pass 1*. *Price sensitive load* will be accounted for indirectly through the modified forecast of Ontario load.

3.2.4 *Pass 2A* shall accept as input data related to the following *offer*-based *energy* sales:

3.2.4.1 for *dispatchable generation facilities,* multi-part *generation facility* commitments from *pass 1* and *offers,* with modifications to the startup costs, ongoing commitment costs, incremental *energy* prices and incremental quantities *offered*, as specified in section 3.6;

3.2.4.2 for *non-dispatchable generators*, the *energy* schedules as determined in section 3.6;

3.2.4.3 for hourly imports, schedules from *pass 1* and *offers* for *energy,* as submitted by the *market participants*; and

3.2.4.4 for multi-hour imports, commitments from *pass 1* and *offers* for *energy*, as submitted by the *market participants.*

Pass 2A will not include *virtual offers* or any schedules for these determined in *pass 1*.

3.2.5 *Pass 2A* shall accept as input data related to *offers* to provide *operating reserve*:

3.2.5.1 for *dispatchable generating facilities*, *offers* with modifications to the *operating reserve* prices *offered*, as specified in section 3.6

3.2.5.2 for multi-part and block *price responsive load*, *offers* with modifications to the *operating reserve* prices *offered*, as specified in section 3.6;

3.2.5.3 for hourly imports and exports *operating reserve* schedules from *pass 1;* and

3.2.5.4 for hourly imports, *offers* as submitted by the *market participants*.

3.3 Optimization Objective for Pass 2A

3.3.1 The objective function of *pass 2A* is to maximize the gains from trade. (See section 3.7 for the complete statement of the objective function.) This is accomplished by maximizing the sum of the following hourly and daily quantities.:

For each hour of the trade day, the negative of the cost for:

- the foregone opportunity due to scheduled *price responsive load* reductions, incremental to any committed *minimum load reduction,* at the modified nominal price
- modified *ongoing hourly costs* at *minimum load reduction* for committed *price responsive load*
- initial costs to achieve the committed *minimum load reduction* for *price responsive load*
- scheduled *operating reserve* from *price responsive load*, at the modified nominal price
- scheduled hourly imports

- scheduled *operating reserve* from imports
- scheduled *generation facility offers*, incremental to any committed *minimum generation level*, for *dispatchable generation facilities* which are not *energy limited resources*, at the modified nominal price
- scheduled *generation facility offers*, incremental to any committed *minimum generation level*, for *energy limited resources*, at the modified negative price
- modified *ongoing hourly costs* at *minimum generation level* for committed *generation*
- modified startup cost for committed *generation*
- scheduled *operating reserve* from *generation facilities*, at the modified nominal price
- scheduled violation variables

One time quantities for the day, the negative of the cost for:

- multi-hour imports, over all scheduled hours

where:

the hourly cost associated with all violations variables is the sum of the individual hourly costs for:

- forecast load curtailment due to a supply deficit
- scheduling additional load to offset surplus must-run *generation* requirements (the minus sign is required since the violation price is negative)
- *operating reserve* requirement deficits
- all reserve area minimum *operating reserve*

requirement deficits

- all reserve area *operating reserve* excesses above maximum requirements
- pre-contingency limit violations for *import* or *export interties*
- exceeding the up or down ramp limits for the total net schedule change for imports and exports
- pre-contingency and post-contingency limit violations for internal *transmission facilities*.

3.4 Output from Pass 2A

3.4.1 Step 1 schedules and *facility* commitments are used as inputs to step 2.

3.4.2 *Pass 2A facility* commitments from step 1 are also used in all subsequent passes except any additional commitments derived in *pass 2A* for *hourly committable generation* of the type referred to in section 1.3.8.1, which are used only in *pass 4*. (*Pass 2A* commitments include those from *pass 1* and additional *facility* commitments derived in *pass 2A*.)

3.4.3 *Pass 2A* hourly *import* schedules for *energy* and *operating* as derived in step 2 are output from *pass 2A* for use in *pass 2B* and *pass 4* as fixed schedules.

3.5 Glossary of Sets, Indices, Variables and Parameters for Pass 2A

3.5.1 Fundamental Sets and Indices

B_{SC}	The set of buses *b* within Ontario, corresponding to *offers* for *non-dispatchable generation* at locations on the *IMO-controlled grid* .
B_{NSC}	The set of buses *b* within Ontario, corresponding to *bids* and *offers* excluding *offers* for *non-dispatchable generation* at locations on the *IMO-controlled grid* .
J'	The set of all modified *bids j* for *pass 2A* for a given *day-ahead market* day. Each P-Q pair of a *bid*

	submitted by a *market participant* would be represented by a unique element *j* in the set.
J'_b	The subset of those modified *bids j* for *pass 2A* consisting of *bids* for a *price responsive load resource* at a bus *b*
K'	The set of all modified *offers* for *pass 2A* for a given *day-ahead market.* Each P-Q pair of an *offer* submitted by a *market participant* would be represented by a unique element *k* in the set.
K'_b	The subset of those modified *offers* for *pass 2A* consisting of *offers* for a *generation facility* at a bus *b.*

3.5.2 Variables and Parameters

3.5.2.1 Bid and Offer Inputs

Price Responsive Load:

$SUCmtPRL_{h,b}$	The modified initial *load reduction cost* for *pass 2A* at bus *b* in hour *h* for the *minimum load reduction*.
$MLCmtPRL_{h,b}$	The modified *ongoing cost of minimum load reduction* to continue reducing consumption by *a price responsive load* for *pass 2A* at bus *b* in hour *h*.
$IncCmtPRL_{j,h,b}$	The modified lowest *energy* price for *pass 2A* at which the incremental quantity of reduction in *energy* consumption specified in *bid j* should be scheduled in hour *h* at bus *b.*
$10NCmtPRL_{j,h,b}$	The modified price of being scheduled for *pass 2A* to provide non-synchronized *ten-minute operating reserve* associated with *bid j* in hour *h* at bus *b*, for *price responsive loads* qualified to do so.
$30RQPRL_{j,h,b}$	The *thirty-minute operating reserve* quantity associated with *bid j*in hour *h* at bus *b*, for *price responsive loads* qualified to do so.
$30RCmtPRL_{j,h,b}$	The modified price of being scheduled for *pass 2A* to provide *thirty-minute operating reserve* associated with *bid j* in in hour *h* at bus *b*, for *price responsive loads* qualified to do so.

Internal Generation and Virtual Offers:

$ESC_{h,b}$	The anticipated output of *non-dispatchable generation* at each bus *b* in the set B_{SC} in each hour *h*. This is based on the forecast from the *generator* modified by

	any schedule determined in *pass 1* associated with *offers* submitted for the *facility*.
$SUCmtPRG_{h,b}$	Designates the modified *offered startup cost* for *pass 2A* that a *generation facility* at bus *b* incurs in order to start and synchronize in hour *h,*which may be a function of the time since last shut down..
$MGCmtPRG_{h,b}$	The modified *offered minimum generation cost* for *pass 2A* incurred by a *generation facility* at bus *b* in order to operate at its *minimum generation level* in hour *h.*
$Mod1QPRG_{k,h,b}$	An incremental quantity of *generation* (above and beyond the *minimum generation level*),other than for an *energy limited resource*, that may be scheduled at bus *b* in hour *h* in association with modified *offer k* for *pass 2A.*
$IncCmtPRG_{k,h,b}$	The lowest *energy* price at which incremental *generation* (other than for an *energy limited resource*) should be scheduled at bus *b* in hour *h* in association with modified *offer k* for *pass 2A.*
$ELSch1PRG_{k,h,b}$	An incremental quantity of *generation* (above and beyond the *minimum generation level*),other than for an *energy limited resource*, for *pass 2A* that may be scheduled at bus *b* in hour *h* in association with modified *offer k* for *pass 2A.*
$IncELCmt1PRG_{k,h,b}$	The lowest *energy* price for *pass 2A* at which incremental *generation* for an *energy limited resource* should be scheduled at bus *b* in hour *h* in association with modified *offer k* for *pass 2A.*
$10SCmtPRG_{k,h,b}$	The *offered* price of being scheduled to provide synchronized *ten-minute operating reserve* in the *day-ahead market* in hour *h* at bus *b* in association with modified *offer k* for *pass 2A.*
$10NCmtPRG_{k,h,b}$	The *offered* price of being scheduled to provide *ten-minute operating* non-synchronized *ten-minute operating reserve* in the *day-ahead market* in hour *h* at bus *b* in association with modified *offer k* for *pass 2A.*
$30RCmtPRG_{k,h,b}$	The *offered* price of being scheduled to provide *thirty-minute operating reserve* in the *day-ahead market* in hour *h* at bus *b* in association with modified *offer k* for *pass 2A.*

3.5.2.2 Transmission and Security Inputs and Intermediate Variables

$With^{2A}_{h,b}$	The total amount of withdrawals scheduled in *pass 2A*

at each bus *b* in each hour *h*, for scheduled *virtual offers* and *generation* for internal buses.

$With^{2A}_{h,d}$ — The total amount of withdrawals scheduled in *pass 2A* at each bus *d* in each hour *h*, for imports and inflows associated with unscheduled loop flows for buses in *intertie zones*.

$Inj^{2A}_{h,b}$ — The total amount of injections scheduled in *pass 2A* at each bus *b* in each hour *h*, for *scheduled price sensitive loads*, *virtual* loads and *price responsive loads* for internal buses.

Inj^{2A}_{hdb} — The total amount of injections scheduled in *pass 2A* at each bus *d* in each hour *h*, for exports and outflows associated with unscheduled loop flows for buses in *intertie zones*.

$WithT^{2A}_{h,b}$ — The total amount of withdrawals scheduled in *pass 2A* at each bus *b* in each hour *h*, similar to $With^{2A}_{h,b}$, defined for internal buses only.

$InjT^{2A}_{h,b}$ — The total amount of injections scheduled in *pass 2A* at each bus *b* in each hour *h*, similar to $Inj^{2A}_{h,b}$, defined for internal buses only.

$WithX^{2A}_{h,d}$ — The total amount of withdrawals scheduled in *pass 2A* at each bus *d* in each hour *h*, similar to $With^{2A}_{h,b}$, defined for buses in *intertie zones*.

$InjX^{2A}_{h,d}$ — The total amount of injections scheduled in *pass 2A* at each bus *d* in each hour *h*, similar to $Inj^{2A}_{h,b}$, defined for buses in *intertie zones*.

3.5.2.3 Other Inputs

FL_b — The modified forecast of Ontario load for the next day in hour *h* adjusted for *price responsive loads*.

m — A small positive number (e.g. 10 cents or some other nominal value) representing the modified price or value for *energy*, per MWh, or *operating reserve*, per MW.

n — A small negative number (e.g. -10 cents or some other nominal value) representing the modified price or value for *energy*, per MWh.

3.5.2.4 Output Schedule and Commitment Variables

$SPRL^{2A}_{j,h,b}$	The amount of load reduction scheduled at bus ***b*** in hour ***h*** in ***pass 2A*** in association with each ***bid j*** at that bus. This is addition to any $MinQPRL_{h,b}$, the ***minimum load reduction***, which must also be committed.
$OPRL^{2A}_{h,b}$	Represents whether load reduction has been scheduled at bus ***b*** in hour ***h*** in ***pass 2A***.
$IPRL^{2A}_{h,b}$	Represents whether the initiation of load reduction at bus ***b*** has been scheduled in hour ***h*** in ***pass 2A***.
$10NSPRL^{2A}_{j,h,b}$	The amount of ***ten-minute operating reserve*** that a qualified ***price responsive load*** is scheduled to provide at bus ***b*** in hour ***h*** in ***pass 2A*** in association with ***bid j*** for this bus.
$30RSPRL^{2A}_{j,h,b}$	The amount of ***thirty-minute operating reserve*** that a qualified ***price responsive load*** is scheduled to provide at bus ***b*** in hour ***h*** in ***pass 2A*** in association with ***bid j*** for this bus.
$OBIG^{2A}_{a}$	Represents whether the multi-hour ***import*** has been scheduled at ***intertie zone a*** in ***pass 2A***.
$SHIG^{2A}_{k,h,a}$	The amount of hourly imports scheduled in hour ***h*** from ***intertie zone a*** in ***pass 2A*** in association with each ***offer k***.
$SI10N^{2A}_{k,h,a}$	The amount of ***imported ten-minute operating reserve*** scheduled in hour ***h*** from ***intertie zone a*** in ***pass 2A*** in association with each ***offer k***.
$SI30R^{2A}_{k,h,a}$	The amount of ***imported thirty-minute operating reserve*** scheduled in hour ***h*** from ***intertie zone a*** in ***pass 2A*** in association with each ***offer k***.
$SPRG^{2A}_{k,h,b}$	The amount scheduled for the ***dispatchable generation facility*** at bus ***b*** in hour ***h*** in ***pass 2A*** in association with each ***offer k*** at that bus, excluding ***energy limited resources***. This is addition to any $MinQPRG_{h,b}$, the ***minimum generation level***, which must also be committed.
$SELPRG^{2A}_{k,h,b}$	The amount scheduled for the ***energy limited resource*** at bus ***b*** in hour ***h*** in ***pass 2A*** in association with each ***offer k*** at that bus.
$OPRG^{2A}_{h,b}$	Represents whether the ***dispatchable generation facility*** at bus ***b*** has been scheduled in hour ***h*** in ***pass 2A***.
$IPRG^{2A}_{h,b}$	Represents whether the ***dispatchable generation facility*** at bus ***b*** has been scheduled to start in hour ***h*** in ***pass 2A***.
$10SSPRG^{2A}_{k,h,b}$	The amount of synchronized ***ten-minute operating reserve*** that a qualified ***generation facility*** at bus ***b*** is

scheduled to provide in hour *h* in *pass 2A* in association with *offer k* for this bus.

$10NSPRG^{2A}_{k,h,b}$ — The amount of non-synchronized *ten-minute operating reserve* that a qualified *generation facility* at bus *b* is scheduled to provide in hour *h* in *pass 2A* in association with *offer k* for this bus.

$30RSPRG^{2A}_{k,h,b}$ — The amount of *thirty-minute operating reserve* that a qualified *generation facility* at bus *b* is scheduled to provide in hour *h* in *pass 2A* in association with *offer k* for this bus.

3.5.2.5 Output Violation Variables

$ViolCost^{2A}_{h}$ — The cost incurred in order to avoid having the *pass 2A* schedules for hour *h* violate specified constraints.

$SLdViol^{2A}_{h}$ — The amount of load that cannot be met using *offers* scheduled or committed in hour *h* in *pass 2A.*

$SGenViol^{2A}_{h}$ — The amount of additional load that must be scheduled in hour *h* in *pass 2A* to ensure that there is enough load on the system to offset the must run requirements of *generation facilities.*

$S10SViol^{2A}_{h}$ — The amount by which the overall synchronized *ten-minute operating reserve* requirement is not met in hour *h* of *pass 2A* because the cost of meeting that portion of the requirement was greater than or equal to *P10SViol.*

$S10RViol^{2A}_{h}$ — The amount by which the overall *ten-minute operating reserve* requirement is not met in hour *h* of *pass 2A* (above and beyond any failure to meet the synchronized *ten-minute operating reserve* requirement) because the cost of meeting that portion of the requirement was greater than or equal to *P10RViol.*

$S30RViol^{2A}_{h}$ — The amount by which the overall *thirty-minute operating reserve* requirement is not met in hour *h* of *pass 2A* (above and beyond any failure to meet the *ten-minute operating reserve* requirement) because the cost of meeting that portion of the requirement was greater than or equal to *P30RViol.*

$SREG10RViol^{2A}_{r,h}$ — The amount by which the overall *ten-minute operating reserve* requirement for region *r* is not met in hour *h* of *pass 2A* because the cost of meeting that portion of the requirement was greater than or equal to *PREG10RViol.*

$SREG30RViol^{2A}_{r,h}$ — The amount by which the overall *thirty-minute*

operating reserve requirement for region ***r*** is not met in hour ***h*** of *pass 2A* because the cost of meeting that portion of the requirement was greater than or equal to *PREG30RViol*.

$SXREG10RViol^{2A}_{r,h}$ — The amount by which the overall *ten-minute operating operating reserve* requirement for region ***r*** is more than the maximum required in hour ***h*** of *pass 2A* because the cost of meeting that the maximum requirement limit was greater than or equal to *PXREG10RViol*.

$SXREG30RViol^{2A}_{r,h}$ — The amount by which the overall *thirty-minute operating reserve* requirement for region ***r*** is more than the maximum required in hour ***h*** of *pass 2A* because the cost of meeting the maximum requirement limit was greater than or equal to *PXREG30RViol*.

$SPreConITLViol^{2A}_{f,h}$ — The amount by which pre-contingency flows over *facility f* in hour ***h*** of *pass 2A* exceed the normal limit for flows over that *facility*, because the cost of alternative solutions that would not result in such an overload was greater than or equal to *PPreConITLViol*.

$SITLViol^{2A}_{f,c,h}$ — The amount by which flows over *facility f* that would follow the occurrence of contingency ***c*** in hour ***h*** of *pass 2A* exceed the emergency limit for flows over that *facility*, because the cost of alternative solutions that would not result in such an overload was greater than or equal to *PITLViol*.

$SPreConXTLViol^{2A}_{z,h}$ — The amount by which *intertie* flows over *facility z* in hour ***h*** of *pass 2A* exceed the normal limit for flows over that *facility*, because the cost of alternative solutions that would not result in such an overload was greater than or equal to *PPreConXTLViol*.

$SURmpXTLViol^{2A}_{h}$ — The amount by which the total net scheduled *import* increase for hour ***h*** in *pass 2A* exceeds the up ramp limits, because the cost of alternative solutions that would not result in violation was greater than or equal to *PRmpXTLViol*.

3.6 Modifications to Bid and Offer Data for Pass 2

3.6.1 The focus of *pass 2A* on commitment rather than scheduling *energy*, and the subsequent focus in *pass 2B* on finding minimum schedules *for energy limited resources*, requires modifications to some of the *bid* and *offer* inputs to the calculation engine, as described in this section 3.6.

3.6.2 *Pass 2* does not require the following data as input to the calculation:

3.6.2.1 *virtual bids* and *virtual offers* which do not contribute to physical supply or demand; and

3.6.2.2 *price sensitive load bids* and multi-hour *price sensitive load bids*, which load is accounted for through the modified forecast of Ontario load used in *pass 2*.

3.6.3 *Bids* for *price responsive loads* are to be modified for *pass 2* to reflect nominal prices for *energy* and *operating reserve*. Only the following components of the *bids* are to be replaced by the modified values, for buses where a *price responsive load* is located:

3.6.3.1 $MLCmtPRL_{h,b}$, the ongoing commitment cost associated with scheduling a *price responsive load*, shall replace the submitted value $MLBPRL_{h,b}$. $MLCmtPRL_{h,b}$ is set to $\max\left(m, MLBPRL_{h,b} - \max\left(n, LMP^{1}_{h,b}\right)MinQPRL_{h,b}\right)$;

3.6.3.2 $IncCmtPRL_{j,h,b}$, the lowest *energy* price for scheduling incremental load reduction, replaces the submitted value $PPRL_{j,h,b}$. $IncCmtPRL_{j,h,b}$ is set to *m;*

3.6.3.3 $10NCmtPRL_{j,h,b}$, the price for being scheduled to provide non-synchronized *ten-minute operating reserve*, replaces the submitted value $10NPPRL_{j,h,b}$. $10NCmtPRL_{j,h,b}$ is set to *m;* and

3.6.3.4 $30RCmtPRL_{j,h,b}$, the price for being scheduled to provide *thirty-minute operating reserve*, replaces the submitted value $30RPPRL_{j,h,b}$. $30RCmtPRL_{j,h,b}$ is set to *m.*

3.6.4 *Offers* for *dispatchable generation* are to be modified for *pass 2A* to reflect nominal prices for *energy* and *operating reserve*. Only the following components of the *offers* are to be replaced by the modified values, for buses where a *dispatchable generation facility* is located:

3.6.4.1 $SUCmtPRG_{h,b}$, the startup cost associated with scheduling a *generation facility*, replaces the submitted value $SUPRG_{h,b}$. $SUCmtPRG_{h,b}$ is set to:

i) zero, for all buses where *hourly committable generation* of the type referred to in section 1.3.8, is located,

ii) $SUPRG_{h,b}$, for all other buses where *dispatchable generation* is located;

3.6.4.2 $MGCmtPRG_{h,b}$, the ongoing commitment cost associated with scheduling a *generation facility*, shall replace the submitted value $MGOPRG_{h,b}$. $MGCmtPRG_{h,b}$ is set to:

i) zero, for all buses where *hourly committable generation* of the type referred to in section 1.3.8, is located,

ii) $\max\left(m, MGOPRG_{h,b} - \max\left(n, LMP^{1}_{h,b}\right) MinQPRG_{h,b}\right)$, for all other buses where *dispatchable generation* is located;

3.6.4.3 $IncCmtPRG_{k,h,b}$, the lowest *energy* price for scheduling incremental *energy* at a *generation facility*, other than *energy* scheduled in *pass 1* for *energy limited resources*, replaces the submitted value $PPRG_{k,h,b}$. $IncCmtPRG_{k,h,b}$ is set to *m*.

3.6.4.4 $IncELCmt1PRG_{k,h,b}$, the lowest *energy price* for scheduling incremental *energy* which has been scheduled in *pass 1* at an *energy limited resource*, replaces the submitted value $PPRG_{k,h,b}$. $IncELCmt1PRG_{k,h,b}$ is set to the negative of max $(n, LMP^{1}_{h,b})$.

3.6.4.5 $Mod1QPRG_{k,h,b}$, the quantity of incremental *energy offered* at the modified price $IncCmtPRG_{k,h,b}$, replaces the submitted value $QPRG_{k,h,b}$. $Mod1QPRG_{k,h,b}$ is set to:

i) $\left(QPRG_{k,h,b} - SPRG^{1}_{k,h,b}\right)$, for buses where *energy limited resources* are located,

ii) $QPRG_{k,h,b}$, for all other buses;

3.6.4.6 $ELSch1PRG_{k,h,b}$, the quantity of incremental *energy offered* at the modified price $IncELCmt1PRG_{k,h,b}$, replaces the submitted value $QPRG_{k,h,b}$. $ELSch1PRG_{k,h,b}$ is set to:

i) $SPRG^{1}_{k,h,b}$, for buses where *energy limited resources* are located,

ii) *zero*, for all other buses;

3.6.4.7 $10SCmtPRG_{k,h,b}$, the price for being scheduled to provide synchronized *ten-minute operating reserve*, replaces the submitted value $10SPPRG_{k,h,b}$. $10SCmtPRG_{k,h,b}$ is set to *m*.

3.6.4.8 $10NCmtPRG_{k,h,b,}$, the price for being scheduled to provide non-synchronized *ten-minute operating reserve*, replaces the submitted value $10NPPRG_{k,h,b}$. $10NCmtPRG_{k,h,b}$ is set to *m*.

3.6.4.9 $30RCmtPRG_{k,h,b,}$, the price for being scheduled to provide *thirty-minute operating reserve*, replaces the submitted value $30RPPRG_{k,h,b}$. $30RCmtPRG_{k,h,b}$ is set to *m*.

The modifications to quantity *offers* in 3.6.4.5 and 3.6.4.7 lead to defining two sets of modified PQ pairs, for the purposes of *pass 2A.*

3.6.5 *Offers* for *dispatchable generation* are to be further modified for *pass 2B* to reflect high *energy* prices for *energy limited resources.* All *offer* components as specified in section 3.6.4 are to be modified, with the following to be used in place of the corresponding values indicated in sections 3.6.4.4 to 3.6.4.6:

3.6.4.4 $IncELCmt2PRG_{k,h,b}$, the incremental cost associated with having an *energy limited resource* generate *energy*, replaces the submitted value $PPRG_{k,h,b}$. $IncELCmt2PRG_{k,h,b}$ is set to $PPRG_{k,h,b} + 2 \cdot MMCP$.

3.6.4.5 $Mod2QPRG_{k,h,b}$, the quantity of incremental *energy offered* at the modified price $IncCmt2PRG_{k,h,b,}$ replaces the submitted value $QPRG_{k,h,b}$. $Mod2QPRG_{k,h,b}$ is set to:

i) *zero,* for buses where *energy limited resources* are located,

ii) $QPRG_{k,h,b}$, for all other buses; and

3.6.4.6 $ELSch2PRG_{k,h,b}$, the quantity of incremental *energy offered* at the modified price $IncELCmt2PRG_{k,h,b}$, replaces the submitted value $QPRG_{k,h,b}$. $ELSch2PRG_{k,h,b}$ is set to:

i) $QPRG_{k,h,b}$, for buses where *energy limited resources* are located,

ii) *zero,* for all other buses.

3.6.6 For *non-dispatchable generation* forecasts of expected production in each hour as a function of price are submitted by the *registered market participant* representing the *facility.* Using expected day-ahead prices from *pass 1*and the submitted data, the *IMO* determines $ESC_{h,b}$, the likely production from each such *facility.* In the event that *non-dispatchable generation* was represented by an *offer* and scheduled in *pass 1*, $ESC_{h,b}$ should not be set to less than

$$MinQPRG_{h,b} + \sum_{k \in K_{ib}} SPRG^{1}_{k,h,b},$$

since in that event, the *generator* may have undertaken a financial commitment (and may receive *production cost guarantee* payments) to provide *energy*.

3.7 Objective Function Pass 2A

$$\sum_{h=1,\ldots,24}\left\{\begin{array}{l}
-\sum_{b\in B}\left[\begin{array}{l}\sum_{j\in J'_b} SPRL^{2A}_{j,h,b}\cdot IncCmtPRL_{j,h,b}\\ +OPRL^{2A}_{h,b}\cdot MLCmtPRL_{h,b}+IPRL^{2A}_{h,b}\cdot SUCmtPRL_{h,b}\\ +\sum_{j\in J'_b} 10NSPRL^{2A}_{j,h,b}\cdot 10NCmtPRL_{j,h,b}+30RSPRL^{2A}_{j,h,b}\cdot 30RCmtPRL_{j,h,b}\end{array}\right]\\
-\sum_{k\in K',a\in A}\left(SHIG^{2A}_{k,h,a}\cdot PHIG_{k,h,a}+SI10N^{2A}_{k,h,a}\cdot PI10N_{k,h,a}+SI30R^{2A}_{k,h,a}\cdot PI30R_{k,h,a}\right)\\
-\sum_{b\in B_{NSC}}\left[\begin{array}{l}\sum_{k\in K'_b}\left(SPRG^{2A}_{k,h,b}\cdot IncCmtPRG_{k,h,b}+SELPRG^{2A}_{k,h,b}\cdot IncELCmt1PRG_{k,h,b}\right)\\ +OPRG^{2A}_{h,b}\cdot MGCmtPRG_{h,b}+IPRG^{2A}_{h,b}\cdot SUCmtPRG_{h,b}\\ +\sum_{k\in K'_b} 10SSPRG^{2A}_{k,h,b}\cdot 10SCmtPRG_{k,h,b}+10NSPRG^{2A}_{k,h,b}\cdot 10NCmtPRG_{k,h,b}\\ +30RSPRG^{2A}_{k,h,b}\cdot 30RCmtPRG_{k,h,b}\end{array}\right]\\
-ViolCost^{2A}_{h}
\end{array}\right\};$$

$$-\sum_{a\in A}\sum_{k\in K} OBIG^{2A}_{k,a}\cdot QBIG_{k,a}\cdot PBIG_{k,a}(ENIHR_{k,a}-STIHR_{k,a}+1)$$

where $ViolCost^{2A}_{h}$ is calculated as follows:

$$\begin{array}{l}
ViolCost^{2A}_{h}=SLdViol^{2A}_{h}\cdot PLdViol-SGenViol^{2A}_{h}\cdot PGenViol\\
\quad +S10SViol^{2A}_{h}\cdot P10SViol+S10RViol^{2A}_{h}\cdot P10RViol\\
\quad +S30RViol^{2A}_{h}\cdot P30RViol\\
\quad +\sum_{r\in ORREG}\left(\begin{array}{l}SREG10RViol^{2A}_{r,h}\cdot PREG10RViol\\ +SREG30RViol^{2A}_{r,h}\cdot PREG30RViol\\ +SXREG10RViol^{2A}_{r,h}\cdot PXREG10RViol\\ +SXREG30RViol^{2A}_{r,h}\cdot PXREG30RViol\end{array}\right)\\
\quad +\sum_{z\in Z}\left(SPreConXTLViol^{2A}_{z,h}\cdot PPreConXTLViol\right)\\
+SURmpXTLViol^{2A}\cdot PRmpXTLViol+SDRmpXTLViol^{2A}\cdot PRmpXTLViol\\
\quad +\sum_{f\in F} SPreConITLViol^{2A}_{f,h}\cdot PPreConITLViol\\
\quad +\sum_{f\in F,c\in C} SITLViol^{2A}_{f,c,h}\cdot PITLViol;
\end{array}$$

3.8 Constraints for Pass 2A

3.8.1 The optimization constraints for *pass 2A* are similar to those in *pass 1*. For *pass 2A* the constraints must be modified to ensure that they:

3.8.1.1 apply to variables associated with *pass 2A*;

3.8.1.2 reflect *bid*s and *offers* as modified for *pass 2A*;

3.8.1.3 reflect forecast load while eliminating *bids* and *offers* that are not used in *pass 2A*, such as *virtual bids* and *offers*;

3.8.1.4 reflect the special treatment of *energy-limited resources* appropriate for *pass 2A*;

3.8.1.5 account for the forecast output by *non-dispatchable generation facilities* and the *pass 1* schedules for those *facilitiess* (if any);

3.8.1.6 recognize fixed schedules from *pass 1* for *price sensitive load* and exports; and

3.8.1.7 do not allow the de-commitment *of price responsive load* or *generating facilities.*

3.8.2 The optimization must not violate the parameters specified in the *energy bids* and *offers* which describe the capacity available for scheduling.

3.8.2.1 Boolean variables, $OPRL^{2A}_{h,b}$,$OPRG^{2A}_{h,b}$, $OBXL^{2A}_{a}$ and $OBIG^{2A}_{a}$, indicate for *pass 2A* whether a *price responsive load* and *generation facility* at bus *b* is committed in hour *h* and multi-hour *import* at *intertie zone a* is committed, respectively. A value of zero indicates that a resource is not committed, while a value of one indicates that it is committed. Therefore:

$OPRL^{2A}_{h,b}, OPRG^{2A}_{h,b} = 0$ or 1, for all hours *h* and buses *b.*

$OBIG^{2A}_{k,a} = 0$ or 1, for all *intertie zones a.*

3.8.2.2 Boolean variables, $IPRL^{2A}_{h,b}$ and $IPRG^{1}_{h,b}$, indicate for *pass 2A* whether *price responsive loads* are scheduled to initiate load reduction in a given hour, or whether *generation facilities* are scheduled to start up in that hour. A value of zero indicates that a resource is not scheduled to initiate load reduction or start up, while a value of one indicates that it is scheduled to initiate load reduction or start up. Therefore, for $h > 1$:

$$IPRL^{2A}_{h,b} = \begin{cases} 1, \text{ if } OPRL^{2A}_{h-1,b} = 0 \text{ and } OPRL^{2A}_{h,b} = 1 \\ 0 \text{ otherwise,} \end{cases}$$

and

$$IPRG^{2A}_{h,b} = \begin{cases} 1, \text{ if } OPRG^{2A}_{h-1,b} = 0 \text{ and } OPRG^{2A}_{h,b} = 1 \\ 0 \text{ otherwise.} \end{cases}$$

For $h = 1$, the determination of whether a resource was previously operating must make reference to the previous day's ***day-ahead market*** schedule:

$$IPRL^{2A}_{h,b} = \begin{cases} 1, \text{ if } InitOperHrs_b = 0 \text{ and } OPRL^{2A}_{h,b} = 1 \\ 0 \text{ otherwise,} \end{cases}$$

and

$$IPRG^{2A}_{h,b} = \begin{cases} 1, \text{ if } InitOperHrs_b = 0 \text{ and } OPRG^{2A}_{h,b} = 1 \\ 0 \text{ otherwise.} \end{cases}$$

3.8.2.3 Regulating units providing AGC and ***reliability must run resources*** will continue to be considered committed for all must run hours.

3.8.2.4 No schedule being determined in ***pass 2A*** can be negative, nor can any schedule for hourly imports exceed the amount of capacity ***offered*** for that service (***energy*** and ***operating reserve***). Therefore:

$$0 \le SHIG^{2A}_{k,h,a} \le QHIG_{k,h,a};$$

$$0 \le SI10N^{2A}_{k,h,a} \le QI10N_{k,h,a}; \text{ and}$$

$$0 \le SI30R^{2A}_{k,h,a} \le QI30R_{k,h,a}; \text{ for all } \textit{offers } k, \text{ hours } h, \text{ and } \textit{intertie zones } a.$$

3.8.2.5 In the case of ***price responsive loads*** and ***generation facilities,*** for which ***bids*** and ***offers*** scheduled in ***pass 1*** are modified, in addition to restrictions on the magnitude of their schedules similar to those above, their schedules must be consistent with their operating status as described above. ***Generation facilities,*** including ***energy limited resources,*** cannot be scheduled to produce ***energy*** or ***operating reserve*** unless they are committed, nor can ***price responsive loads*** be scheduled to reduce consumption unless they are committed. Therefore for ***pass 2A***:

$$0 \le SPRL^{2A}_{j,h,b} \le OPRL^{2A}_{h,b} \cdot QPRL_{j,h,b},$$

$$0 \le 10NSPRL^{2A}_{j,h,b} \le OPRL^{2A}_{h,b} \cdot 10NQPRL_{j,h,b},$$

$$0 \le 30RSPRL^{2A}_{j,h,b} \le OPRL^{2A}_{h,b} \cdot 30RQPRL_{j,h,b},$$

$$0 \le SPRG^{2A}_{k,h,b} \le OPRG^{2A}_{h,b} \cdot Mod1QPRG_{k,h,b},$$

$$0 \le SELPRG^{2A}_{k,h,b} \le OPRG^{2A}_{h,b} \cdot ELSch1PRG_{k,h,b},$$

$$0 \le 10SSPRG^{2A}_{k,h,b} \le OPRG^{2A}_{h,b} \cdot 10SQPRG_{k,h,b},$$

$$0 \le 10NSPRG^{2A}_{k,h,b} \le OPRG^{2A}_{h,b} \cdot 10NQPRG_{k,h,b}, \text{ and}$$

$$0 \le 30RSPRG^{2A}_{k,h,b} \le OPRG^{2A}_{h,b} \cdot 30RQPRG_{k,h,b},$$ for all modified ***bids*** ***j***, modified ***offers*** ***k***, hours ***h***, and buses ***b***.

3.8.2.6 The hourly ***energy*** from multi-hour imports are not optimization variables. They are calculated using the commitment status, start hour and end hour of the associated multi-hour imports as follows:

$SBIG^{2A}_{k,h,a} = OBIG^{2A}_{k,h,a} \cdot QBIG_{k,a}$, for all ***offer*** hours from $STIHR_{k,a}$ to $ENIHR_{k,a}$ and zero for all other hours.

3.8.2.7 The minimum and/or maximum output of ***generating facilties,*** inclduing ***energy limited resources***, may be limited because of ***outages*** and/or deratings or in order for the units to provide ***regulation*** or voltage support. These constraints will take the form:

$$MinPRG_{h,b} \le MinQPRG_{h,b} + \sum_{k \in K_b} (SPRG^{2A}_{k,h,b} + SELPRG^{2A}_{k,h,b}) \le MaxPRG_{h,b},$$

where:

$MinPRG_{h,b}$ is the ***minimum generation level*** specified by the ***IMO***, and

$MaxPRG_{h,b}$ is the maximum ***generation*** level specified by the ***IMO***, or as indicated by ***outage*** or derating information.

3.8.3 The optimization must not violate the parameters specified in the ***offers*** which describe the ***operating reserve*** available for scheduling.

3.8.3.1 The total *operating reserve* (non-synchronized ten-minute and thirty-minute) from committed *price responsive load* can not exceed its ramp capability over 30 minutes.

$$\sum_{j \in J} (10NSPRL^{2A}_{j,h,b} + 30RSPRL^{2A}_{j,h,b}) \leq 30 \cdot OPRL^{2A}_{h,b} \cdot ORRPRL_{h,b}.$$

3.8.3.2 The total *operating reserve* (non-synchronized ten-minute and thirty-minute) from committed *price responsive load* can not exceed the total scheduled load (maximum load *bid* minus the load reductions).

$$\sum_{j \in J} (10NSPRL^{2A}_{j,h,b} + 30RSPRL^{2A}_{j,h,b}) \leq \sum_{j \in J} (QPRL_{j,h,b} - SPRL^{2A}_{j,h,b})$$

3.8.3.3 The amount of non-synchronized *ten-minute operating reserve* that a *price responsive load* is scheduled to provide cannot exceed the amount by which it can decrease its load over 10 minutes, as limited by its *operating reserve ramp rate.*

$$\sum_{j \in J} 10NSPRL^{2A}_{j,h,b} \leq 10 \cdot ORRPRL_{h,b}.$$

3.8.3.4 The total *operating reserve* (ten-minute synchronized,ten-minute non-synchronized and thirty-minute) from a committed *generation facility* can not exceed its ramp capability over 30 minutes.

$$\sum_{k \in K} (10SSPRG^{2A}_{k,h,b} + 10NSPRG^{2A}_{k,h,b} + 30RSPRG^{2A}_{k,h,b}) \leq 30 \cdot OPRG^{2A}_{h,b} \cdot ORRPRG_{h,b},$$

3.8.3.5 The total *operating reserve* (ten-minute synchronized,ten-minute non-synchronized and thirty-minute) from a committed *generation facility,* including *energy limited resources,* can not exceed the remaining capacity (the modified maximum *offered generation* minus the *energy* schedule).

$$\sum_{k \in K} (10SSPRG^{2A}_{k,h,b} + 10NSPRG^{2A}_{k,h,b} + 30RSPRG^{2A}_{k,h,b})$$
$$\leq \sum_{k \in K} (Mod1QPRG_{k,h,b} - SPRG^{2A}_{k,h,b} + ElSch1PRG_{k,h,b} - SELPRG^{2A}_{k,h,b}).$$

3.8.3.6 The amount of *ten-minute operating reserve* (both synchronized and non-synchronized) that a *generation facility* is scheduled to provide cannot exceed the amount by which it can increase its output over 10 minutes, as limited by its *operating reserve ramp rate.*

$$\sum_{k \in K} (10SSPRG^{2A}_{k,h,b} + 10NSPRG^{2A}_{k,h,b}) \leq 10 \cdot ORRPRG_{h,b}.$$

3.8.3.7 The total *operating reserve* (ten-minute non-synchronized and thirty-minute) from hourly imports can not exceed its ramp capability over 30 minutes.

$$\sum_{k \in K} (SI10N^{2A}_{k,h,a} + SI30R^{2A}_{k,h,a}) \leq 30 \cdot ORRHIG_{h,a},$$

3.8.3.8 The total *operating reserve* (ten-minute non-synchronized and thirty-minute) from hourly imports can not exceed the remaining capacity (maximum *import* minus scheduled *energy import*).

$$\sum_{k \in K} (SI10N^{2A}_{k,h,a} + SI30R^{2A}_{k,h,a}) \leq \sum_{k \in K} (QHIG_{k,h,a} - SHIG^{2A}_{k,h,a}).$$

3.8.3.9 The amount of non-synchronized *ten-minute operating reserve* that hourly *import* is scheduled to provide cannot exceed the amount by which it can increase the output over 10 minutes, as limited by its *operating reserve ramp rate*.

$$\sum_{k \in K} SI10N^{2A}_{k,h,a} \leq 10 \cdot ORRHIG_{h,a}.$$

3.8.4 The optimization in *pass 2A* must not violate the *effective uniform ramp rate* parameters derived from the *bids* and *offers*.

3.8.4.1 The constraints for hour-to-hour schedule changes for *generating facilities* and *price responsive load* as stated for *pass 1* in sections 2.8.4.1 to 2.8.4.4 and sections 2.8.4.7 and 2.8.4.8 apply to *pass 2A* as well.

3.8.4.2 The constraints on the hour-to-hour schedule changes for *generating facilities* are accomplished through the following equation, which applies to successive hours whether there is a change to the commitment status or not.

$$\begin{aligned}
&\sum_{k \in K'_b} \left(SPRG^{2A}_{k,h-1,b} + SELPRG^{2A}_{k,h-1,b}\right) - 60(YG(OPRG^{2A}_{h,b} - OPRG^{2A}_{h-1,b}) + 1)DRRPRG_{h,b} \\
&\quad \leq \sum_{k \in K'_b} \left(SPRG^{2A}_{k,h,b} + SELPRG^{2A}_{k,h,b}\right) \\
&\quad \leq \sum_{k \in K'_b} \left(SPRG^{2A}_{k,h-1,b} + SELPRG^{2A}_{k,h-1,b}\right) + 60(1 - XG(OPRG^{2A}_{h,b} - OPRG^{2A}_{h-1,b}))URRPRG_{h,b},
\end{aligned}$$

3.8.4.3 Similar considerations apply to *price responsive loads* leading to the following constraint:

$$\sum_{j\in J_b} SPRL^{2A}_{j,h-1,b} - 60(YL(OPRL^{2A}_{h,b} - OPRL^{2A}_{h-1,b}) + 1)DRRPRL_{h,b} \le \sum_{j\in J_b} SPRL^{2A}_{j,h,b}$$
$$\le \sum_{j\in J_b} SPRL^{2A}_{j,h-1,b} + 60(1 - XL(OPRL^{2A}_{h,b} - OPRL^{2A}_{h-1,b}))URRPPRL_{h,b},$$

3.8.5 The optimization must not violate the duration parameters specified in the *bids* and *offers*.

3.8.5.1 Constraints pertaining to *minimum run times*, *minimum down times*, and minimum transaction durations precisely mirror those used in *pass 1*in sections 2.8.5.2 to 2.8.5.9 (although other constraints on exports make these constraints superfluous for the purposes of *pass 2A*). The constraint for *pass 2A* for the *maximum number of stops* is similar to the *pass1* constraint in section 2.8.5.10.

3.8.5.2 If $InitDownHrs_b < MDTPRL_b$, then

$$OPRL^{2A}_{1,b}, OPRL^{2A}_{2,b}, ..., OPRL^{2A}_{\min(24, MDTPRL_b - InitDownHrs_b), b} = 0,$$

3.8.5.3 If $InitOperHrs_b < MRTPRL_b$, then

$$OPRL^{2A}_{1,b}, OPRL^{2A}_{2,b}, ..., OPRL^{2A}_{\min(24, MRTPRL_b - InitOperHrs_b), b} = 1.$$

3.8.5.4 If $InitDownHrs_b < MDTPRG_b$, then

$$OPRG^{1}_{1,b}, OPRG^{1}_{2,b}, ..., OPRG^{1}_{\min(24, MDTPRG_b - InitDownHrs_b), b} = 0,$$

3.8.5.5 If $InitOperHrs_b < MRTPRG_b$, then

$$OPRG^{2A}_{1,b}, OPRG^{2A}_{2,b}, ..., OPRG^{2A}_{\min(24, MDTPRG_b - InitDownHrs_b), b} = 0,$$

3.8.5.6 If $OPRL^{1}_{h,b} = 1$, $OPRL^{1}_{h+1,b} = 0$, and $MDTPRL_b > 1$, then

$$OPRL^{2A}_{h+2,b}, OPRL^{2A}_{h+3,b}, ..., OPRL^{2A}_{\min(24, h+MDTPRL_b), b} = 0;$$

3.8.5.7 If $OPRL^{1}_{h,b} = 0$, $OPRL^{1}_{h+1,b} = 1$, and $MRTPRL_b > 1$, then

$$OPRL^{2A}_{h+2,b}, OPRL^{2A}_{h+3,b}, ..., OPRL^{2A}_{\min(24, h+MRTPRL_b), b} = 1;$$

3.8.5.8 If $OPRG^{1}_{h,b} = 1$, $OPRG^{1}_{h+1,b} = 0$, and $MDTPRG_b > 1$, then

$$OPRG^{2A}_{h+2,b}, OPRG^{2A}_{h+3,b}, ..., OPRG^{2A}_{\min(24, h+MDTPRL_b), b} = 0;$$

3.8.5.9 If $OPRG^{1}_{h,b} = 0$, $OPRG^{1}_{h+1,b} = 1$, and $MRTPRG_b > 1$, then

$$OPRG^{2A}_{h+2,b}, OPRG^{2A}_{h+3,b}, \ldots, OPRG^{2A}_{\min(24, h+MRTPRL_b),b} = 1;$$

3.8.5.10 To ensure that *generation facilities* and and *price responsive loads* are not scheduled to stop more than their specified *maximum number of stops* in a day, the following constraint is defined:

$$\sum_{h=1}^{24} IPRG^{2A}_{h,b} \le MaxStopsG_b,$$

$$\sum_{h=1}^{24} IPRL^{2A}_{h,b} \le MaxStopsRL_b.$$

3.8.6 The optimization must not violate the daily *energy* limit specified in an *offer*.

3.8.6.1 An *energy limited resource* may not be scheduled to provide more *energy* in total over the day than is indicated through its *offer* it is capable of providing. In addition, the application of the *energy* limit must also ensure that *facilities* are not scheduled to provide *energy* in amounts that would preclude them from providing *energy* for activated *operating reserve* in any given hour.

$$\sum_{h=1}^{1}\left(OPRG^{2A}_{h,b} \cdot MinQPRG_{h,b} + \sum_{k\in K_b}(SPRG^{2A}_{k,h,b} + SELPRG^{2A}_{k,h,b})\right) + \sum_{k\in K_b} 10SSPRG^{2A}_{k,1,b} + \sum_{k\in K_b} 10NSPRG^{2A}_{k,1,b} + \sum_{k\in K_b} 30RSPRG^{2A}_{k,1,b} \le EL_b,$$

$$\sum_{h=1}^{2}\left(OPRG^{2A}_{h,b} \cdot MinQPRG_{h,b} + \sum_{k\in K_b}(SPRG^{2A}_{k,h,b} + SELPRG^{2A}_{k,h,b})\right) + \sum_{k\in K_b} 10SSPRG^{2A}_{k,2,b} + \sum_{k\in K_b} 10NSPRG^{2A}_{k,2,b} + \sum_{k\in K_b} 30RSPRG^{2A}_{k,2,b} \le EL_b, \quad ,$$

$$\mathbb{M}$$

$$\sum_{h=1}^{24}\left(OPRG^{2A}_{h,b} \cdot MinQPRG_{h,b} + \sum_{k\in K_b}(SPRG^{2A}_{k,h,b} + SELPRG^{2A}_{k,h,b})\right) + \sum_{k\in K_b} 10SSPRG^{2A}_{k,24,b} + \sum_{k\in K_b} 10NSPRG^{2A}_{k,24,b} + \sum_{k\in K_b} 30RSPRG^{2A}_{k,24,b} \le EL_b,$$

for all buses ***b*** at which *energy limited resources* are located.

3.8.7 The optimization for *pass 2A* must satisfy load requirements, by balancing injections and withdrawals.

3.8.7.1 For each hour, the total amount of *energy* injected (scheduled supply from *generation facilities* plus scheduled imports) must

balance total *energy* withdrawn (scheduled or forecast purchases by loads and scheduled exports) and transmission losses consistent with these supplies and purchases.

3.8.7.2 Withdrawals at bus *b* within Ontario and each bus d outside Ontario for hour *h* include:

i) the portion of the modified forecast of Ontario load for that hour allocated to the bus *b*, using the load distribution factors for Ontarioload;

ii) the *price responsive load* at the bus *b* net of any scheduled load reduction;

iii) multi-hour and hourly exports from Ontario to each *intertie zone*, allocated among the buses *d* in the *intertie zone* using the distribution factors developed for that purpose; and

iv) outflows from Ontario associated with unscheduled loop flows between Ontario and each *intertie zone*, allocated among the buses *d* in the *intertie zone* using the distribution factors developed for that purpose.

For *pass 2A* at each bus *b* within Ontario and each bus *d* outside Ontario in each hour *h*, withdrawals are defined as:

$$With_{h,b}^{2A} = LDF_{h,b}FL_h + \left[MinQPRL_{h,b} - OPRL_{h,b}^{2A} \cdot MinQPRL_{h,b} + \sum_{j \in J_b'} \left(QPRL_{j,h,b} - SPRL_{j,h,b}^{2A} \right) \right]$$

$$With_{h,d}^{2A} = \sum_{a \in A} \left(ProxySFWt_{d,a} \sum_{j \in J'} (SHXL_{j,h,a}^{1} + SBXL_{j,h,a}^{1}) \right) - \sum_{a \in A} ProxyUPOWt_{d,a} \min(0, PF_{h,a}).$$

3.8.7.3 Injections at bus *b* for hour *h* include:

i) scheduled *energy* from a *dispatchable generation facility* at that bus *b*;

iii) multi-hour and hourly imports into Ontario from each *intertie zone*, allocated among the buses *d* in the *intertie zone* using the distribution factors developed for that purpose; and

iv) inflows into Ontario associated with unscheduled loop flows between Ontario and each *intertie zone*, allocated among the buses *d* in the *intertie zone* using the distribution factors developed for that purpose.

For *pass 2A* at each bus *b* within Ontario with a *dispatchable generation facility* and each bus *d* outside Ontario in each hour *h*, injections are defined as[3]:

$$Inj_{h,b}^{2A} = OPRG_{h,b}^{2A} \cdot ModMinQPRG_{h,b} + \sum_{k \in K_b'} \left(SPRG_{k,h,b}^{2A} + SELPRG_{k,h,b}^{2A} \right)$$

$$Inj_{h,d}^{2A} = \sum_{a \in A} \left(ProxySFWt_{d,a} \sum_{k \in K'} (SHIG_{k,h,a}^{2A} + SBIG_{k,h,a}^{2A}) \right) + \sum_{a \in A} ProxyUPIWt_{d,a} \max(0, PF_{h,a});$$

3.8.7.4 For *non-dispatchable generation facilities* at buses in the set B_{SC}, modified *offers* from the *facilities* at these buses are excluded from the objective function in section 2.7, since the production from these is an input into *pass 2*. The forecast for the production at that location is used as the injection at these buses, yielding:

$$Inj_{h,b}^{2A} = ESC_{h,b}.$$

3.8.7.5 To balance supply and purchases, losses must be taken into account. This is accomplished by adjusting injections and withdrawals at a bus for the marginal loss factor of that bus relative to the *reference bus*. Additional losses must be included as a loss adjustment, since total losses may be different from the sum of marginal losses. Finally, load and *generation* violation variables must be included to avoid infeasible solutions.

$$\sum_{b \in B} (1 + MglLoss_{h,b}) With_{h,b}^{2A} + \sum_{d \in D} (1 + MglLoss_{h,b}) With_{h,d}^{2A} - SLDViol_h^{2A}$$
$$= \sum_{b \in B} (1 + MglLoss_{h,b}) Inj_{h,b}^{2A} + \sum_{d \in D} (1 + MglLoss_{h,b}) Inj_{d,b}^{2A} - SGenViol_h^{2A} + LossAdj_h.$$

3.8.8 The optimization must not violate *operating reserve* requirements.

3.8.8.1 Sufficient *operating reserve* must be scheduled to meet system wide requirements for *ten-minute operating* synchronized *reserve*, *ten-minute operating reserve* and *thirty-minute operating reserve*, as well as all applicable regional minimum and maximum requirements for *operating reserve*.

3.8.8.2 Violation variables ensure a feasible solution and allow relaxation of the requirements if the cost of meeting these becomes too high.

3.8.8.3 For synchronized *ten-minute operating reserve*, for all hours *h*:

[3] As in the current practice for the RTM, only the loop flows between New York and Michigan through Ontario will be considered for the *day-ahead market*.

$$\sum_{b \in B}\left(\sum_{k \in K} 10SSPRG^{2A}_{k,h,b}\right) + S10SViol^{2A}_{h} \geq TOT10S_{h},$$

3.8.8.4 For total *ten-minute operating reserve*, for all hours ***h***:

$$\sum_{b \in B}\left(\sum_{k \in K} 10SSPRG^{2A}_{k,h,b}\right) + S10RViol^{2A}_{h}$$
$$+ \sum_{b \in B}\left(\sum_{k \in K} 10NSPRG^{2A}_{k,h,b}\right) + \sum_{b \in B}\left(\sum_{j \in J} 10NSPRL^{2A}_{j,h,b}\right)$$
$$+ \sum_{a \in A}\left(\sum_{k \in K} SI10N^{2A}_{k,h,a}\right) + \sum_{a \in A}\left(\sum_{j \in J} SX10N^{1}_{j,h,a}\right) \geq TOT10R_{h},$$

3.8.8.5 For total *thirty-minute operating reserve*, for all hours ***h***:

$$\sum_{b \in B}\left(\sum_{k \in K} 10SSPRG^{2A}_{k,h,b}\right) + S30RViol^{2A}_{h}$$
$$+ \sum_{b \in B}\left(\sum_{k \in K} (10NSPRG^{2A}_{k,h,b} + 30RSPRG^{2A}_{k,h,b})\right)$$
$$+ \sum_{b \in B}\left(\sum_{j \in J} (10NSPRL^{2A}_{j,h,b} + 30RSPRL^{2A}_{j,h,b})\right)$$
$$+ \sum_{a \in A}\left(\sum_{k \in K} (SI10N^{2A}_{k,h,a} + SI30R^{2A}_{k,h,a})\right)$$
$$+ \sum_{a \in A}\left(\sum_{j \in J} (SX10N^{1}_{j,h,a} + SX30R^{1}_{j,h,a})\right) \geq TOT30R_{h},$$

3.8.8.6 To satisfy the minimum regional requirement for *ten-minute operating reserve*, for all hours ***h***, and for all regions ***r*** in the set *ORREG*:

$$\sum_{b \in r}\left(\sum_{k \in K} 10SSPRG^{2A}_{k,h,b}\right) + SREG10RViol^{2A}_{r,h}$$
$$+ \sum_{b \in r}\left(\sum_{k \in K} 10NSPRG^{2A}_{k,h,b}\right) + \sum_{b \in r}\left(\sum_{j \in J} 10NSPRL^{2A}_{j,h,b}\right) \geq REGMin10R_{r,h},$$

3.8.8.7 To satisfy the maximum regional requierment for *ten-minute operating reserve*, for all hours ***h***, and for all regions ***r***:

$$\sum_{b \in r}\left(\sum_{k \in K} 10SSPRG^{2A}_{k,h,b}\right) - SXREG10RViol^{2A}_{r,h}$$
$$+ \sum_{b \in r}\left(\sum_{k \in K} 10NSPRG^{2A}_{k,h,b}\right) + \sum_{b \in r}\left(\sum_{j \in J} 10NSPRL^{2A}_{j,h,b}\right) \leq REGMax10R_{r,h},$$

3.8.8.8 To satisfy the minimum regional requierment for *thirty-minute operating reserve*, for all hours *h*, and for all regions *r*:

$$\sum_{b \in r}\left(\sum_{k \in K} 10SSPRG^{2A}_{k,h,b}\right) + SREG30RViol^{2A}_{r,h}$$
$$+ \sum_{b \in r}\left(\sum_{k \in K}(10NSPRG^{2A}_{k,h,b} + 30RSPRG^{2A}_{k,h,b})\right)$$
$$+ \sum_{b \in r}\left(\sum_{j \in J}(10NSPRL^{2A}_{j,h,b} + 30RSPRL^{2A}_{j,h,b})\right) \geq REGMin30R_{r,h},$$

3.8.8.9 To satisfy the maximum regional requierment for *thirty-minute operating reserve*, for all hours *h*, and for all regions *r*:

$$\sum_{b \in r}\left(\sum_{k \in K} 10SSPRG^{2A}_{k,h,b}\right) - SXREG30RViol^{2A}_{r,h}$$
$$+ \sum_{b \in r}\left(\sum_{k \in K}(10NSPRG^{2A}_{k,h,b} + 30RSPRG^{2A}_{k,h,b})\right)$$
$$+ \sum_{b \in r}\left(\sum_{j \in J}(10NSPRL^{2A}_{j,h,b} + 30RSPRL^{2A}_{j,h,b})\right) \leq REGMax30R_{r,h},$$

3.8.9 The optimization must not violate internal transmission limits or *security* constraints.

3.8.9.1 *Energy* schedules produced by *pass 2A* must not overload any internal transmission *facility* or exceed any *security limits* in either the pre-contingency state or in any contingency, except where this is not feasible.

3.8.9.2 *Energy* flows associated with a transmission or *security limit* are determined from the total scheduled *energy* at each bus, as injections or withdrawals, and the fraction of that *energy* which contributes to the transmission or *security* flow.

3.8.9.3 Total withdrawals scheduled in *pass 2A* at each bus *b* in each hour *h*, $WithT^{2A}_{h,b}$, for buses within Ontario is:

$$WithT_{h,b}^{2A} = LDF_{h,b} \cdot FL_h + \left[MinQPRL_{h,b} - OPRL_{h,b}^{2A} \cdot MinQPRL_{h,b} + \sum_{j \in J'_b} \left(QPRL_{j,h,b} - SPRL_{j,h,b}^{2A} \right) \right].$$

3.8.9.4 Total injections scheduled in *pass 2A* at each bus *b* in each hour *h*, $InjT^{2A}_{h,b}$, for buses within Ontario where there is a *dispatchable generation facility*, is:

$$InjT_{h,b}^{2A} = OPRG_{h,b}^{2A} \cdot MinQPRG_{h,b} + \sum_{k \in K'_b} \left(SPRG_{k,h,b}^{2A} + SELPRG_{k,h,b}^{2A} \right)$$

3.8.9.5 Total injections scheduled in *pass 2A* at each bus *b* in each hour *h*, $InjT^{2A}_{h,b}$, for buses within Ontario where there is a *non-dispatchable generation facility*, is:

$$InjT_{h,b}^{2A} = ESC_{h,b}$$

3.8.9.6 Total withdrawals scheduled in *pass 2A* at each bus *d* in each hour *h*, $WithX^{1}_{h,b}$, for buses outside Ontario in *intertie zones* associated with exports and unscheduled loop flows is:

$$WithX_{h,d}^{2A} = \sum_{a \in A} \left[ProxySFWt_{d,a} \sum_{j \in J} (SHXL_{j,h,a}^{1} + SBXL_{j,h,a}^{1}) - ProxyUPOWt_{d,a} \min(0, PF_{h,a}) \right],$$

3.8.9.7 Total injections scheduled in *pass 2A* at each bus *d* in each hour *h*, $InjX^{1}_{h,b}$, for buses outside Ontario associated with exports and unscheduled loop flows is:

$$InjX_{h,d}^{2A} = \sum_{a \in A} \left[ProxySFWt_{d,a} \sum_{k \in K} SHIG_{k,h,a}^{2A} + SBIG_{k,h,a}^{2A}) + ProxyUPIWt_{d,a} \max(0, PF_{h,a}) \right].$$

3.8.9.8 The *security* assessment function of the *DAM calculation engine* will identify binding (violated) pre-contingency limits on transmission *facilities* within Ontario. These will accounted for within the optimization as linearized constraints of the form:

$$\sum_{b \in B} PreConSF_{b,f,h} (InjT_{h,b}^{2A} - WithT_{h,b}^{2A}) + \sum_{d \in D} PreConSF_{d,f,h} (InjX_{h,d}^{2A} - WithX_{h,d}^{2A})$$
$$+ \sum_{b \in B} PreOprgSF_{b,f,h} \cdot OPRG_{h,b}^{2A} - SPreConITLViol_{f,h}^{2A} \leq AdjNormMaxFlow_{f,h},$$

where *D* is the set of buses outside Ontario, for all *facilities f* and hours *h*.

3.8.9.9 Similarly, linearized binding post-contingency limits will take the form:

$$\sum_{b\in B} SF_{b,f,c,h}(InjT_{h,b}^{2A} - WithT_{h,b}^{2A}) + \sum_{d\in D} SF_{d,f,c,h}(InjX_{h,d}^{2A} - WithX_{h,d}^{2A}) - SITLViol_{f,h}^{2A} \le AdjEmMaxFlow_{f,h},$$

for all *facilities f*, hours *h*, and monitored contingencies *c*.

3.8.10 The optimization must not violate *intertie* limits.

3.8.10.1 Schedules produced by *pass 2A* must not overload any *intertie facility* or exceed any *security limits*, except where this is not feasible.

3.8.10.2 Scheduled *import* and *export energy* plus *operating reserve* scheduled from control areas associated with an *intertie* should not exceed any limits associated with the *intertie*. A single constraint may represent a limit on schedules from more than one *intertie*.

3.8.10.3 The sum of scheduled net *energy* and, in some cases, *operating reserve* from all *intertie zones* associated with an *intertie* constraint must be less than the constraint limit. and the sum of *operating reserve* provided at interties where there may be a limit on

$$\sum_{a\in A}\left[\begin{array}{l} EnCoeff_{a,z}\left(\sum_{k\in K}(SHIG_{k,h,a}^{2A} + SBIG_{k,h,a}^{2A}) + PF_{h,a} - \sum_{j\in J}\left(SHXL_{j,h,a}^{1} + SBXL_{j,h,a}^{1}\right)\right) + \\ 0.5(EnCoeff_{a,z}+1)\left[\sum_{k\in K}\left(SI10N_{k,h,a}^{2A} + SI30R_{k,h,a}^{2A}\right) + \sum_{j\in J}\left(SX10N_{j,h,a}^{1} + SX30R_{j,h,a}^{1}\right)\right] \end{array}\right] \le MaxExtSch_{z,h},$$

for all hours *h* and for all constraints z in the set Z_{sch}.

3.8.10.4 Changes in the net *energy* scheduled over all *interties* cannot exceed the limits set by the *IMO* for hour-to-hour changes in those total net schedules.

3.8.10.5 The net *import* schedule is the sum of imports less exports over all *interties* for a given hour. It cannot exceed the sum of net *import* schedule for all *intertie* for the previous hour plus the maximum permitted hourly increase. It can not be less than the sum of the net *import* schedule for all *interties* for the previous hour minus the maximum permitted hourly decrease. Violation variables are

provided for both the up and down ramp limits to ensure that the *DAM calculation engine* will always find a solution. Therefore:

$$\sum_{a\in A}\left(\sum_{k\in K}(SHIG^{2A}_{k,h-1,a}+SBIG^{2A}_{k,h-1,a})-\sum_{j\in J}(SHXL^{1}_{j,h-1,a}+SBXL^{1}_{j,h-1,a})\right)-ExtDSC_h-SDRmpXTLViol^{2A}_h$$
$$\leq\sum_{a\in A}\left(\sum_{k\in K}(SHIG^{2A}_{k,h,a}+SBIG^{2A}_{k,h,a})-\sum_{j\in J}(SHXL^{1}_{j,h,a}+SBXL^{1}_{j,h,a})\right)$$
$$\leq\sum_{a\in A}\left(\sum_{k\in K}(SHIG^{2A}_{k,h-1,a}+SBIG^{2A}_{k,h-1,a})-\sum_{j\in J}(SHXL^{1}_{j,h-1,a}+SBXL^{1}_{j,h-1,a})\right)+ExtUSC_h+SURmpXTLViol^{2A}_h$$

for all hours *h*.

3.8.11 *Pass 2A* must respect *import* schedules and commitments as well as commitments for *price responsive load* and *generation facilities* from *pass 1*.

3.8.11.1 *Pass 2A* will not reduce the amount of hourly *imported energy* or *operating reserve* scheduled from each intertie zone in any hour. Additional hourly imports of *energy* or *operating reserve* may be scheduled in *pass 2A*. Therefore:

$$\sum_{k\in K}SHIG^{2A}_{k,h,a}\geq\sum_{k\in K}SHIG^{1}_{k,h,a},$$

$$\sum_{k\in K}SI10N^{2A}_{k,h,a}\geq\sum_{k\in K}SI10N^{1}_{k,h,a},\text{ and}$$

$$\sum_{k\in K}SI30R^{2A}_{k,h,a}\geq\sum_{k\in K}SI30R^{1}_{k,h,a},$$

3.8.11.2 *Pass 2A* will continue to schedule multi-hour imports committed in *pass 1*, but may commit additional multi-hour imports. Therefore:

$$OBIG^{2A}_{k,a}\geq OBIG^{1}_{k,a}$$

3.8.11.3 *Pass 2A* must not de-commit *price responsive load* and *generation facilities* committed in *pass 1*, but may commit additional resources. Therefore:

$$OPRL^{2A}_{h,b}\geq OPRL^{1}_{h,b}\text{ and}$$

$$OPRG^{2A}_{h,b}\geq OPRG^{1}_{h,b},$$

for all hours *h* and buses *b*.

3.9 Inputs to Pass 2B

3.9.1 Inputs to the *pass 2B* process are identical to those for *pass 2A* as specified in section 3.2 except as described in this section 3.9.

3.9.2 *Pass 2B* shall accept as input the same data related to *bids* to purchase *energy* as specified in section 3.2.3 except that any additional commitments in *pass 2A* for *price responsive load* will also be input to *pass 2B*.

3.9.3 *Pass 2B* shall accept as input the same data related to *offers* to sell *energy* as specified in section 3.2.4 with the following exceptions:

3.9.1 commitments for *dispatchable generation* will include any additional commitments determined in *pass 2A*;

3.9.2 for *energy limited resources* the *offer* price for all *offered* quantities will be replaced by the submitted *offer* price plus two times *MMCP,* as indicated in section 3.6.5;

3.9.3 the modifications to *offer* quantities is as indicated in section 3.6.5; and

3.9.4 any commitments for multi-hour imports or schedules for hourly imports as output from *pass 2A* will be used to set the schedules in *pass 2B*.

3.9.4 *Pass 2B* shall accept as input the same data related to *offers* to provide *operating reserve* as specified in section 3.2.5, except that the resulting *import* schedules for *operating reserve* from *pass 2A* will be used to set the schedules in *pass 2B*.

3.10 Optimization Objective for Pass 2B

3.10.1 The objective function of *pass 2B* is to maximize the gains from trade. This is accomplished by maximizing the sum of the following hourly quantities. See section 3.12 for the complete statement of the objective function:

For each hour of the trade day, the negative of the cost for:

- the foregone opportunity due to scheduled *price responsive load* reductions, incremental to any committed *minimum load reduction,* at the modified nominal price
- scheduled *operating reserve* from *price*

responsive load, at the modified nominal price

- scheduled *dispatchable generation*, incremental to any committed *minimum generation level*, excluding *energy* scheduled in *pass 1* for *energy limited resources*, at the modified nominal price
- scheduled *dispatchable generation*, incremental to any committed *minimum generation level*, for *energy* scheduled in *pass 1* for *energy limited resources*, at the modified negative price
- scheduled *operating reserve* from *generation facilities*, at the modified nominal price
- scheduled violation variables

where:

the hourly cost associated with all violations variables is the sum of the individual hourly costs for:

- forecast load curtailment due to a supply deficit
- scheduling additional load to offset surplus must-run *generation* requirements (the minus sign is required since the violation price is negative)
- *operating reserve* requirement deficits
- all reserve area minimum *operating reserve* requirement deficits
- all reserve area *operating reserve* excesses above maximum requirements
- pre-contingency and post-contingency limit violations for internal *transmission facilities*.

3.11 Global Outputs from Pass 2

3.11.1 The primary outputs of *pass 2* which are used in subsequent passes or other *day-ahead market* processes include the following:

3.11.1.1 additional *facility* commitments; and

3.11.1.2 additional schedules for hourly imports.

3.11.2 As indicated in section 3.4.2, *pass 2A facility* commitments are generally used in all subsequent passes. The additional commitment (that is, availability for scheduling hourly) in *pass 2A* for *hourly committable generation* of the type referred to in section 1.3.8.1, which were not committed in *pass 1*, are used only in *pass 4*. The estimated production from *non-dispatchable generation*, determined as an input for *pass 2A*, is also used only in *pass 4*.

3.11.3 As indicated in section 3.4.3, hourly *import* schedules as determined in *pass 2A* become fixed schedules for *pass 4*.

3.11.4 The single output from *pass 2B* used in other *day-ahead market* processes is the minimum scheduled production required hourly from each *energy limited resource*. This is used in all subsequent passes.

3.11.5 Minimum levels and multi-hour uniform schedules may be associated with the output committments depending on the *bids* and *offers*.

3.11.6 Table 2 shows the products of *pass 2* and how these are used in later passes or the *day-ahead market settlement* process.

Table 2: Pass 2 Outputs and Target Processes

Output	Target Pass or Settlement - Application
Commitments (Pass 2A)	
Dispatchable generation facility commitments	P*ass 3, 5* –Input cumulative *pass 1* and *pass 2* commitments, except *hourly committable generation* as referred to in section 1.3.8.1. *Pass 4* –Input commitments used for *pass 3* and *pass 5*, plus the additional commitments (or availability) of *hourly committable generation*, as referred to in section 1.3.8.1. *Settlement* –Eligible for PCG (forecast load)
Price responsive load commitments	P*ass 3, 4, 5* – Input cumulative *pass 1* and *pass 2* commitments *Settlement* –Eligible for PCG (forecast load)

Output	Target Pass or Settlement - Application
Multi-hour *Import* commitments	P*ass 3, 4, 5* – Input cumulative *pass 1* and *pass 2* commitments for multi-hour imports (treated as must-take schedules) *Settlement* –Eligible for PCG (forecast load)
Constrained Schedules	
Energy limited resource constrained schedules – energy (pass 2B)	P*ass 3, 4, 5* – Input hourly minimum schedules *Settlement* –Eligible for PCG (forecast load)
Non-dispatchable generation estimated production	*Pass 4* – Input production as must-take schedules.
Hourly *import constrained schedules* (*pass 2A*)- *energy* and *operating reserve*	*Pass 4* – Input imports as must-take schedules *Settlement* –Eligible for PCG (forecast load)

3.12 Glossary of Sets, Indices, Variables and Parameters for Pass 2B

3.12.1 Fundamental Sets and Indices

J''	The set of all modified ***bids j*** for ***pass 2B*** for a given ***day-ahead market*** day. Each P-Q pair of a ***bid*** submitted by a ***market participant*** would be represented by a unique element ***j*** in the set.
J''_b	The subset of those modified ***bids j*** for ***pass 2B*** consisting of ***bids*** for a ***price responsive load resource*** at a bus ***b***
K''	The set of all modified ***offers*** for ***pass 2B*** for a given ***day-ahead market***. Each P-Q pair of an ***offer*** submitted by a ***market participant*** would be represented by a unique element ***k*** in the set.
K''_b	The subset of those modified ***offers*** for ***pass 2B*** consisting of ***offers*** for a ***generation facility*** at a bus ***b.***

3.12.2 Variables and Parameters

3.12.2.1 Bid and Offer Inputs

Internal Generation and Virtual Offers:

$Mod2QPRG_{k,h,b}$	The quantity of ***energy offered*** at the modified price $IncCmt2PRG_{k,h,b}$ in modified ***offer k.***

$ELSch2PRG_{k,h,b}$ The quantity of ***energy offered*** at the modified price $IncELCmt2PRG_{k,h,b}$ in modified ***offer k***.

$IncELCmt2PRG_{k,h,b}$ The ***incremental cost*** for ***pass 2B*** at which incremental ***generation*** for an ***energy limited resource*** should be scheduled at bus ***b*** in hour ***h*** in association with modified ***offer k*** for ***pass 2B***.

3.12.2.2 Transmission and Security Inputs and Intermediate Variables

$WithT^{2B}_{h,b}$ The total amount of withdrawals scheduled in ***pass 2B*** at each bus ***b*** in each hour ***h***, defined for internal buses only.

$InjT^{2B}_{h,b}$ The total amount of injections scheduled in ***pass 2B*** at each bus ***b*** in each hour ***h***, defined for internal buses only.

$WithX^{2B}_{h,d}$ The total amount of withdrawals scheduled in ***pass 2B*** at each bus ***d*** in each hour ***h***, defined for buses in ***intertie zones***.

$InjX^{2B}_{h,d}$ The total amount of injections scheduled in ***pass 2B*** at each bus ***d*** in each hour ***h***, defined for buses in ***intertie zones***.

3.12.2.4 Output Schedule and Commitment Variables

$SPRL^{2B}_{j,h,b}$ The amount of load reduction scheduled at bus ***b*** in hour ***h*** in ***pass 2B*** in association with each ***bid j*** at that bus. This is addition to any $MinQPRL_{h,b}$, the ***minimum load reduction***, which must also be committed.

$10NSPRL^{2B}_{j,h,b}$ The amount of ***ten-minute operating reserve*** that a qualified ***price responsive load*** is scheduled to provide at bus ***b*** in hour ***h*** in ***pass 2B*** in association with ***bid j*** for this bus.

$30RSPRL^{2B}_{j,h,b}$ The amount of ***thirty-minute operating reserve*** that a qualified ***price responsive load*** is scheduled to provide at bus ***b*** in hour ***h*** in ***pass 2B*** in association with ***bid j*** for this bus.

$SPRG^{2B}_{k,h,b}$ The amount scheduled for the ***dispatchable generation facility*** at bus ***b*** in hour ***h*** in ***pass 2B*** in association with each ***offer k*** at that bus, excluding ***energy limited resources***. This is addition to any $MinQPRG_{h,b}$, the ***minimum generation level***, which must also be committed.

$SELPRG^{2B}_{k,h,b}$ The amount scheduled for the ***energy limited resource*** at bus ***b*** in hour ***h*** in ***pass 2B*** in association with each

offer k at that bus.

$10SSPRG^{2B}_{k,h,b}$ The amount of synchronized *ten-minute operating reserve* that a qualified *generation facility* at bus *b* is scheduled to provide in hour *h* in *pass 2B* in association with *offer k* for this bus.

$10NSPRG^{2B}_{k,h,b}$ The amount of non-synchronized *ten-minute operating reserve* that a qualified *generation facility* at bus *b* is scheduled to provide in hour *h* in *pass 2B* in association with *offer k* for this bus.

$30RSPRG^{2B}_{k,h,b}$ The amount of *thirty-minute operating reserve* that a qualified *generation facility* at bus *b* is scheduled to provide in hour *h* in *pass 2B* in association with *offer k* for this bus.

3.12.2.5 Output Violation Variables

$ViolCost^{2B}_{h}$ The cost incurred in order to avoid having the *pass 2B* schedules for hour *h* violate constraints.

$SLdViol^{2B}_{h}$ The amount of load that cannot be met using *offers* scheduled in hour *h* in *pass 2B.*

$SGenViol^{2B}_{h}$ The amount of additional load that must be scheduled in hour *h* in *pass 2B* to ensure that there is enough load on the system to offset the must run requirements of *generation facilities.*

$S10SViol^{2B}_{h}$ The amount by which the overall synchronized *ten-minute operating reserve* requirement is not met in hour *h* of *pass 2B* because the cost of meeting that portion of the requirement was greater than or equal to *P10SViol.*

$S10RViol^{2B}_{h}$ The amount by which the overall *ten-minute operating reserve* requirement is not met in hour *h* of *pass 2B* (above and beyond any failure to meet the synchronized *ten-minute operating reserve* requirement) because the cost of meeting that portion of the requirement was greater than or equal to *P10RViol.*

$S30RViol^{2B}_{h}$ The amount by which the overall *thirty-minute operating reserve* requirement is not met in hour *h* of *pass 2B* (above and beyond any failure to meet the *ten-minute operating reserve* requirement) because the cost of meeting that portion of the requirement was greater than or equal to *P30RViol.*

$SREG10RViol^{2B}_{r,h}$ The amount by which the overall *ten-minute operating reserve* requirement for region *r* is not met in hour *h* of *pass 2B* because the cost of meeting that

portion of the requirement was greater than or equal to *PREG10RViol*.

$SREG30RViol^{2B}_{r,h}$ — The amount by which the overall *thirty-minute operating reserve* requirement for region *r* is not met in hour *h* of *pass 2B* because the cost of meeting that portion of the requirement was greater than or equal to *PREG30RViol*.

$SXREG10RViol^{2B}_{r,h}$ — The amount by which the overall *ten-minute operating operating reserve* requirement for region *r* is more than the maximum required in hour *h* of *pass 2B* because the cost of meeting that the maximum requirement limit was greater than or equal to *PXREG10RViol*.

$SXREG30RViol^{2B}_{r,h}$ — The amount by which the overall *thirty-minute operating reserve* requirement for region *r* is more than the maximum required in hour *h* of *pass 2B* because the cost of meeting the maximum requirement limit was greater than or equal to *PXREG30RViol*.

$SPreConITLViol^{2B}_{f,h}$ — The amount by which pre-contingency flows over *facility f* in hour *h* of *pass 2B* exceed the normal limit for flows over that *facility*, because the cost of alternative solutions that would not result in such an overload was greater than or equal to *PPreConITLViol*.

$SITLViol^{2B}_{f,c,h}$ — The amount by which flows over *facility f* that would follow the occurrence of contingency *c* in hour *h* of *pass 2B* exceed the emergency limit for flows over that *facility*, because the cost of alternative solutions that would not result in such an overload was greater than or equal to *PITLViol*.

3.13 Objective Function Pass 2B

$$\sum_{h=1,\ldots,24}\left\{\begin{array}{l} -\sum_{b\in B}\left[\begin{array}{l}\sum_{j\in J'_b} SPRL^{2B}_{j,h,b}\cdot IncCmtPRL_{j,h,b} \\ +\sum_{j\in j\in J'} 10NSPRL^{2B}_{j,h,b}\cdot 10NCmtPRL_{j,h,b}+30RSPRL^{2B}_{j,h,b}\cdot 30RCmtPRL_{j,h,b}\end{array}\right] \\ -\sum_{b\in B_{NSC}}\left[\begin{array}{l}\sum_{k\in K''_b}\left(SPRG^{2B}_{k,h,b}\cdot IncCmtPRG_{k,h,b}+SELPRG^{2B}_{k,h,b}\cdot IncELCmt2PRG_{k,h,b}\right) \\ +\sum_{k\in K'_b} 10SSPRG^{2B}_{k,h,b}\cdot 10SCmtPRG_{k,h,b}+10NSPRG^{2B}_{k,h,b}\cdot 10NCmtPRG_{k,h,b} \\ +30RSPRG^{2B}_{k,h,b}\cdot 30RCmtPRG_{k,h,b}\end{array}\right] \\ -ViolCost^{2B}_h \end{array}\right\};$$

where $ViolCost^{2B}_h$ is calculated as follows:

$$\begin{aligned} ViolCost^{2B}_h &= SLdViol^{2B}_h\cdot PLdViol - SGenViol^{2B}_h\cdot PGenViol \\ &+ S10SViol^{2B}_h\cdot P10SViol + S10RViol^{2B}_h\cdot P10RViol \\ &+ S30RViol^{2B}_h\cdot P30RViol \\ &+ \sum_{r\in ORREG}\left(\begin{array}{l} SREG10RViol^{2B}_{r,h}\cdot PREG10RViol \\ +SREG30RViol^{2B}_{r,h}\cdot PREG30RViol \\ +SXREG10RViol^{2B}_{r,h}\cdot PXREG10RViol \\ +SXREG30RViol^{2B}_{r,h}\cdot PXREG30RViol\end{array}\right) \\ &+ \sum_{f\in F} SPreConITLViol^{2B}_{f,h}\cdot PPreConITLViol \\ &+ \sum_{f\in F,c\in C} SITLViol^{2B}_{f,c,h}\cdot PITLViol; \end{aligned}$$

3.14 Constraints for Pass 2B

3.14.1 The constraints applied to this pass generally mirror those used in *pass 2A* related to scheduling *dispatchable generation* and *price responsive loads*. *Pass 2B* does not perform a commitment so constraints associated with commitments are redundant. Other constraints for which *offers* have been modified need to be restated for the new modified variables. Finally, since imports and exports are held constant constraints associated with the schedules for these and with intertie limits are omitted.

3.14.2 Variables representing schedules for *dispatchable generation* and *price responsive loads* in *pass 2B* replace the corresponding variables for *pass 2A*. This affects the constraints defined in sections 3.8.2.5, 3.8.2.7, 3.8.3.1 to

3.8.3.6, 3.8.4, and 3.8.6 to 3.8.9. Similarly, injection and withdrawal variables for *pass 2A* are replaced with the corresponding *pass 2B* variables, in sections 3.8.7 and 3.8.9.

3.14.3 The modification of *offers* for *dispatchable generation,* including *energy limited resources,* affect two constraints in section 3.8.2.5. The corresponding *pass 2A* constraints are replaced by the following:

$$0 \le SPRG^{2B}_{k,h,b} \le OPRG^{2B}_{h,b} \cdot Mod2QPRG_{k,h,b}, \text{ and}$$

$$0 \le SELPRG^{2B}_{k,h,b} \le OPRG^{2B}_{h,b} \cdot ELSch2PRG_{k,h,b}, \text{ for all modified } \textit{offers } k, \text{ hours } h, \text{ and buses } b$$

3.14.4 The constraints in section 3.8.9.8 and 3.8.9.9 related to constraints for transmission *facilities* within Ontario are are replaced by:

$$\sum_{b \in B} PreConSF_{b,f,h}(InjT^{2B}_{h,b} - WithT^{2B}_{h,b}) + \sum_{d \in D} PreConSF_{d,f,h}(InjX^{2B}_{h,d} - WithX^{2B}_{h,d})$$
$$\sum_{b \in B} PreOpregSF_{b,f,h} \cdot OPRG^{2A}_{h,b} - SPreConITLViol^{2B}_{f,h} \le AdjNormMaxFlow_{f,h},$$

for all *facilities f* and hours *h*, and

$$\sum_{b \in B} SF_{b,f,c,h}(InjT^{2B}_{h,b} - WithT^{2B}_{h,b}) + \sum_{d \in D} SF_{d,f,c,h}(InjX^{2B}_{h,d} - WithX^{2B}_{h,d})$$
$$- SITLViol^{2B}_{f,h} \le AdjEmMaxFlow_{f,h},$$

for all *facilities f*, hours *h*, and monitored contingencies *c*.

3.14.5 The other *pass 2A* constraints related to commitments, imports and exports are not required. These include constraints or definitions in sections 3.8.2.1 to 3.8.2.3, 3.8.2.6, 3.8.3.7 to 3.8.3.9, 3.8.5, 3.8.10 and 3.8.11.

4. Pass 3: Constrained Scheduling to Meet Bid Load

4.1 Pass 3 Overview

4.1.1 *Pass 3* conducts a least cost, *security* constrained scheduling process that meets the load as specified in *bids* and *operating reserve* requirements specified by the *IMO*. *Pass 3* uses *bids* and *offers* as submitted.

4.1.2 *Constrained schedules* for *price responsive load, generation facilities,* hourly imports and exports, *virtual bids* and *virtual offers* are determined from *pass 3.* For these resources there may be minimum schedules associated with the minimum levels specified in the *bids* and *offers,* or minimum schedule requirements for *energy limited resources,* as determined *in pass 2.*

4.1.3 The *pass 3* constrained scheduling process takes account of all transmission limitations including inter-tie transfer limits.

4.1.4 *Pass 3* performs two steps as described for *pass 1*. Step 1 is described in detail in this section 4. Step 2 for *pass 3* follows the same procedure as described in section 2.10, with references to *pass 3* replacing the references to *pass 1*, except where that section refers to commitments. *Pass 1* step 1 performs a *unit commitment,* while *pass 3* step 1 does not and takes commitments as inputs.

4.1.5 Output schedules for *pass 3* are those determined in step 2 except for e*nergy limited resources* for which schedules are determined in step 1. Consistent with this, results from *pass 3* step 2 are used determine *locational marginal prices* for *energy* and *operating reserve*, as well as losses which become an input to *pass 5.*

4.2 Inputs for Pass 3

4.2.1 The load, supply, transmission and other inputs into *pass 3* shall be the same inputs as used in *pass 1,* as described in section 2.2. Many of these inputs will be superfluous for the purposes of *pass 3,* as the constraints that require those inputs will be eliminated and related variables are omitted from the optimization objective since *pass 3* does not perform a *unit commitment.*

4.2.2 *Pass 3* does not perform a *unit commitment.* It takes as input the commitment variables from *pass 1* and *pass 2* as follows:

4.2.2.1 from *pass 1*, the commitments of multi-hour *price sensitive load*, multi-hour exports, *non-dispatchable generation and* some *hourly committable generation* as specified in section 1.3.8.1; and

4.2.2.2 from *pass 2A*, the cumulative *pass 1* and *pass 2A* commitments of multi-part and block *price responsive load*, *dispatchable generation facilities* other than those referred to in section 1.3.8.1, and multi-hour imports.

4.2.3 *Pass 3* will input the schedules from *pass 2B* for *energy limited* resources as minimum schedules for *pass 3*.

4.3 Optimization Objective for Pass 3

4.3.1 The objective function of *pass 3* is to maximize the gains from trade. (See section 4.6 for the complete statement of the objective function.) This is accomplished by maximizing the sum of the following hourly quantities:

For each hour of the trade day

the value of:
- scheduled *price sensitive load*
- scheduled *virtual bids*
- scheduled hourly exports

less the cost of:
- scheduled *operating reserve* from exports
- the foregone opportunity due to scheduled *price responsive load* reductions, incremental to any committed *minimum load reduction*
- scheduled *operating reserve* from *price responsive load*
- scheduled *virtual offers*
- scheduled hourly imports
- scheduled *operating reserve* from imports
- scheduled *generation facility offers*, incremental to any committed *minimum generation level*
- scheduled *operating reserve* from *generation*

facilities

- scheduled violation variables

where:

the hourly cost associated with all violations variables is the sum of the individual hourly costs for:

- load curtailment (= 0 for *pass 3*) due to a supply deficit
- scheduling additional load to offset surplus must-run *generation* requirements (the minus sign is required since the violation price is negative)
- *operating reserve* requirement deficits
- all reserve area minimum *operating reserve* requirement deficits
- all reserve area *operating reserve* excesses above maximum requirements
- pre-contingency limit violations for *import* or *export interties*
- exceeding the up or down ramp limits for the total net schedule change for imports and exports.
- pre-contingency and post-contingency limit violations for internal *transmission facilities*

4.4 Output from Pass 3

4.4.1 The primary outputs of *pass 3* which are used in other *day-ahead market* processes include the following:

4.4.1.1 *constrained schedules*;

4.4.1.2 *locational marginal prices* for *energy* and *operating reserve*; and

4.4.1.3 system transmission losses.

4.4.2 *Constrained schedules* for *energy* and *operating reserve* are calculated in *pass 3* for *generating facilities, price responsive load,* imports and exports. The calculated scheduled *energy* quantities determined by *pass 3* are incremental to any minimum levels required for the *generating facilities* or for load reduction. Combining minimum levels and the scheduled quantities determined in *pass 3* gives to the total scheduled *generation facility* production and the net scheduled *price responsive load* consumption.

4.4.3 *Constrained schedules* are also determined in *pass 3* for *price sensitive load, virtual bids* and *virtual offers,* although these are not used in subsequent passes or process and are not treated as financially binding. Financially binding values for these are determined in *pass 5*.

4.4.4 Step 1 schedules are used as inputs to step 2.

4.4.5 Output schedules for *pass 3* are those determined in step 2 except for e*nergy limited resources* for which schedules are determined in step 1.

4.4.6 Consistent with schedules being primarily determined in step 2, *pass 3* step 2 results are used determine *locational marginal prices* for *energy* and *operating reserve,* as well as transmission losses which become an input to *pass 5.*

4.4.7 Table 3 shows the products of *pass 3* and how these are used in later passes or the *day-ahead market settlement* process.

Table 3: Pass 3 Outputs and Target Processes

Output	**Target Pass or Settlement - Application**
Constrained schedules - energy and *operating reserve*: • *Generation facilities* - total schedules including minimum levels • *Price responsive loads* - total load reduction and net consumption • Imports – hourly and multi-hour • Exports – hourly and multi-hour	*Settlement* – financially binding *constrained schedules*
Locational marginal prices for *energy* and *operating reserve*	Publishing – for information only
System transmission losses	*Pass 5* – System losses for the load balancing

4.5 Glossary of Sets, Indices, Variables and Parameters for Pass 3

4.5.1 Transmission and Security Inputs and Intermediate Variables

$AvailPRL^{3}_{h,b}$	The *pass 3* input operating status in hour ***h*** at buses ***b*** where *price responsive loads* are located, which is the cumulative commitments at the end of *pass 2A*
$AvailPRG^{3}_{h,b}$	The *pass 3* input operating status in hour ***h*** at buses ***b*** where a *generation facility* is located.

4.5.2 Output Schedules

$SPSL^{3}_{j,h}$	The amount of *price sensitive load* scheduled in hour ***h*** in *pass 3* in association with each ***bid j***.
$SVL^{3}_{j,h}$	The amount of *virtual* load scheduled in hour ***h*** in *pass 3* in association with each ***bid j***.
$SHXL^{3}_{j,h,a}$	The amount of exports scheduled in hour ***h*** in *pass 3* from *intertie zone **a*** in association with each ***bid j***.
$SX10N^{3}_{j,h,a}$	The amount of non-synchronized *ten-minute operating reserve* scheduled from the *export* in hour ***h*** in *pass 3* from *intertie zone **a*** in association with ***bid j.***
$SX30R^{3}_{j,h,a}$	The amount of *thirty-minute operating reserve* scheduled from the *export* in hour ***h*** in *pass 3* from *intertie zone **a*** in association with ***bid j***.
$SPRL^{3}_{j,h,b}$	The amount of load reduction scheduled at bus ***b*** in hour ***h*** in *pass 3* in association with each ***bid j*** at that bus. This is addition to any $MinQPRL_{h,b}$, the *minimum load reduction*, which must also be committed.
$10NSPRL^{3}_{j,h,b}$	The amount of *ten-minute operating reserve* that a qualified *price responsive load* is scheduled to provide at bus ***b*** in hour ***h*** in *pass 3* in association with ***bid j*** for this bus.
$30RSPRL^{3}_{j,h,b}$	The amount of *thirty-minute operating reserve* that a qualified *price responsive load* is scheduled to provide at bus ***b*** in hour ***h*** in *pass 3* in association with ***bid j*** for this bus.
$SVS^{3}_{k,h}$	The amount of *virtual* supply scheduled in hour ***h*** in *pass 3* in association with each *offer **k***
$SHIG^{3}_{k,h,a}$	The amount of hourly imports scheduled in hour ***h*** from *intertie zone **a*** in *pass 3* in association with each *offer **k.***
$SI10N^{3}_{k,h,a}$	The amount of *imported ten-minute operating reserve*

scheduled in hour *h* from *intertie zone a* in *pass 3* in association with each *offer k.*

$SI30R^{3}_{k,h,a}$ The amount of *imported thirty-minute operating reserve* scheduled in hour *h* from *intertie zone a* in *pass 3* in association with each *offer k.*

$SPRG^{3}_{k,h,b}$ The amount scheduled for the *generation facility* at bus *b* in hour *h* in *pass 3* in association with each *offer k* at that bus. This is addition to any $MinQPRG_{h,b}$, the *minimum generation level*, which must also be committed.

$10SSPRG^{3}_{k,h,b}$ The amount of synchronized *ten-minute operating reserve* that a qualified *generation facility* at bus *b* is scheduled to provide in hour *h* in *pass 3* in association with *offer k* for this bus.

$10NSPRG^{3}_{k,h,b}$ The amount of non-synchronized *ten-minute operating reserve* that a qualified *generation facility* at bus *b* is scheduled to provide in hour *h* in *pass 3* in association with *offer k* for this bus.

$30RSPRG^{3}_{k,h,b}$ The amount of *thirty-minute operating reserve* that a qualified *generation facility* at bus *b* is scheduled to provide in hour *h* in *pass 3* in association with *offer k* for this bus.

4.5.3 Output Violation Variables

$ViolCost^{3}_{h}$ The cost incurred in order to avoid having the *pass 3* schedules for hour *h* violate specified constraints.

$SLdViol^{3}_{h}$ The amount of load that cannot be met using *offers* scheduled in hour *h* in *pass 3.*[This quantity is zero in *pass 3* since no forecast load is included.]

$SGenViol^{3}_{h}$ The amount of additional load that must be scheduled in hour *h* in *pass 3* to ensure that there is enough load on the system to offset the must run requirements of *generation facilities.*

$S10SViol^{3}_{h}$ The amount by which the overall synchronized *ten-minute operating reserve* requirement is not met in hour *h* of *pass 3* because the cost of meeting that portion of the requirement was greater than or equal to *P10SViol.*

$S10RViol^{3}_{h}$ The amount by which the overall *ten-minute operating reserve* requirement is not met in hour *h* of *pass 3* (above and beyond any failure to meet the synchronized *ten-minute operating reserve* requirement) because the cost of meeting that portion of the requirement was greater than or equal to

P10RViol.

$S30RViol^3_h$ — The amount by which the overall *thirty-minute operating reserve* requirement is not met in hour *h* of *pass 3* (above and beyond any failure to meet the *ten-minute operating reserve* requirement) because the cost of meeting that portion of the requirement was greater than or equal to *P30RViol*.

$SREG10RViol^3_{r,h}$ — The amount by which the overall *ten-minute operating reserve* requirement for region *r* is not met in hour *h* of *pass 3* because the cost of meeting that portion of the requirement was greater than or equal to *PREG10RViol*.

$SREG30RViol^3_{r,h}$ — The amount by which the overall *thirty-minute operating reserve* requirement for region *r* is not met in hour *h* of *pass 3* because the cost of meeting that portion of the requirement was greater than or equal to *PREG30RViol*.

$SXREG10RViol^3_{r,h}$ — The amount by which the overall *ten-minute operating operating reserve* requirement for region *r* is more than the maximum required in hour *h* of *pass 3* because the cost of meeting that the maximum requirement limit was greater than or equal to *PXREG10RViol*.

$SXREG30RViol^3_{r,h}$ — The amount by which the overall *thirty-minute operating reserve* requirement for region *r* is more than the maximum required in hour *h* of *pass 3* because the cost of meeting the maximum requirement limit was greater than or equal to *PXREG30RViol*.

$SPreConITLViol^3_{f,h}$ — The amount by which pre-contingency flows over *facility f* in hour *h* of *pass 3* exceed the normal limit for flows over that *facility*, because the cost of alternative solutions that would not result in such an overload was greater than or equal to *PPreConITLViol*.

$SITLViol^3_{f,c,h}$ — The amount by which flows over *facility f* that would follow the occurrence of contingency *c* in hour *h* of *pass 3* exceed the emergency limit for flows over that *facility*, because the cost of alternative solutions that would not result in such an overload was greater than or equal to *PITLViol*.

$SPreConXTLViol^3_{z,h}$ — The amount by which *intertie* flows over *facility z* in hour *h* of *pass 3* exceed the normal limit for flows over that *facility*, because the cost of alternative solutions that would not result in such an overload was greater than or equal to *PPreConXTLViol*.

$SURmpXTLViol^3_h$ — The amount by which the total net scheduled *import*

increase for hour ***h*** in ***pass 3*** exceeds the up ramp limits, because the cost of alternative solutions that would not result in violation was greater than or equal to ***PRmpXTLViol***.

$SDRmpXTLViol^{3}_{h}$ — The amount by which the total net scheduled ***import*** decrease in hour ***h*** of ***pass 3*** exceed the down ramp limits, because the cost of alternative solutions that would not result in violation was greater than or equal to ***PRmpXTLViol***.

4.5.4 Output Shadow Prices, Locational Marginal Prices and System Losses

4.5.4.1 Shadow Prices of Constraints:

SPL^{3}_{h} — The ***pass 3*** shadow price measuring the the rate of change of the objective function for a change in load at the ***reference bus*** in hour ***h***.

$SPNormT^{3}_{f,h}$ — The ***pass 3*** shadow price measuring the the rate of change of the objective function for a change in the limit on flows over transmission ***facilities*** in normal conditions for ***facility f*** in hour ***h***.

$SPEmT^{3}_{f,c,h}$ — The ***pass 3*** shadow price measuring the the rate of change of the objective function for a change in the limit on flows over transmission ***facilities*** in emergency conditions for ***facility f*** in monitored contingency ***c*** in hour ***h***.

$SPExtT^{3}_{z,h}$ — The ***pass 3*** shadow price measuring the the rate of change of the objective function for a change in the limit on flows over transmission ***facilities*** on the boundary between Ontario and other ***control areas*** for each constraint ***z*** in hour ***h***.

$SPRUExtT^{3}_{h}$ — The ***pass 3*** shadow price measuring the the rate of change of the objective function for a change in the limit on the upward change of the sum of net imports over all ***interties*** from the previous hour to hour ***h***.

$SPRDExtT^{3}_{h}$ — The ***pass 3*** shadow price measuring the the rate of change of the objective function for a change in the limit on the downward change of the sum of net imports over all ***interties*** from the previous hour to hour ***h***.

$SP10S^{3}_{h}$ — The ***pass 3*** shadow price measuring the the rate of change of the objective function for a change in the total synchronized ***ten-minute operating reserve*** requirement in hour ***h***.

$SP10R^{3}_{h}$ — The ***pass 3*** shadow measuring the the rate of change of the objective function for a change in the total ***ten-***

minute operating reserve requirement in hour ***h***.

$SP30R^{3}_{h}$ — The *pass 3* shadow price measuring the the rate of change of the objective function for a change in the total *thirty-minute operating reserve* requirement in hour ***h***.

$SPREGMin10R^{3}_{r,h}$ — The *pass 3* shadow price measuring the the rate of change of the objective function for a change in the the minimum *ten-minute operating reserve* requirement for region ***r***in hour ***h***.

$SPREGMin30R^{3}_{r,h}$ — The *pass 3* shadow price measuring the the rate of change of the objective function for a change in the minimum *thirty-minute operating reserve* requirement for region ***r*** in hour ***h***.

$SPREGMax10R^{3}_{r,h}$ — The *pass 3* shadow price measuring the the rate of change of the objective function for a change in the maximum *ten-minute operating reserve* limit for region ***r*** in hour ***h***.

$SPREGMax30R^{1}_{r,h}$ — The *pass 3* shadow price measuring the the rate of change of the objective function for a change in the maximum *thirty-minute operating reserve* limit for region ***r*** in hour ***h***.

4.5.4.2 Locational Marginal Prices at Internal Buses:

$LMP^{3}_{h,b}$ — The *pass 3 locational marginal price* for *energy* at each bus ***b*** in each hour ***h***. It measures the *offered* cost of meeting the marginal MWh of load at that bus in that hour, or equivalently, measures the value of the marginal MWh of supply at that bus in that hour in *pass 3*.

$ExtLMP^{3}_{h,a}$ — The *pass 3 locational marginal price* for *energy* at each *intertie zone* ***a*** in each hour ***h***. It measures the *offered* cost of meeting the marginal MWh of load at that *intertie* in that hour, or equivalently, measures the value of the marginal MWh of supply at that bus in that hour in *pass 3*.

$L10SP^{3}_{h,b}$ — The *pass 3 locational marginal price* for synchronized *ten-minute operating reserve,* which measures the value of the marginal MW of supply of synchronized *ten-minute operating reserve* at that bus ***b*** in hour ***h***.

$L10NP^{3}_{h,b}$ — The *pass 3 locational marginal price* for non-synchronized *ten-minute operating reserve,* which measures the value of the marginal MW of supply of non-synchronized *ten-minute operating reserve* at that bus ***b*** in hour ***h***.

$L30RP^{3}_{h,b}$	The *pass 3 locational marginal price* for *thirty-minute operating reserve,* which measures the value of the marginal MW of supply of *thirty-minute operating reserve* at that bus *b* in hour *h.*
$Ext10RP^{3}_{h,a}$	The *pass 3 locational marginal price* for *ten-minute operating reserve,* which measures the value of the marginal MW of supply of *ten-minute operating reserve* at that *intertie zone a* in hour *h.*
$Ext30RP^{3}_{h,a}$	The *pass 3 locational marginal price* for *thirty-minute operating reserve,* which measures the value of the marginal MW of supply of *ten-minute operating reserve* at that *intertie zone a* in hour *h.*

4.5.4.3 Transmission System Losses

$SysLoss^{3}_{h}$	The *pass 3* transmission system losses in each hour *h.*.

4.6 Objective Function Pass 3

4.6.1 The objective function for *pass 3* is to maximize gains from trade by maximizing the objective function below. The objective function attributes value to scheduled *bids*, costs to scheduled supply, and additional cost to any constraint violations.

4.6.1.1 Gains from trade as determined as:

$$\sum_{h=1,\ldots,24}\left\{\begin{array}{l}\sum_{j\in J}\left[\begin{array}{l}SPSL^{3}_{j,h}\cdot PPSL_{j,h}+SVL^{3}_{j,h}\cdot PVL_{j,h}\\+\sum_{a\in A}SHXL^{3}_{j,h,a}\cdot PHXL_{j,h,a}-SX10N^{3}_{j,h,a}\cdot PX10N_{j,h,a}-SX30R^{3}_{j,h,a}\cdot PX30R_{j,h,a}\end{array}\right]\\-\sum_{b\in B}\left[\begin{array}{l}\sum_{j\in J_b}SPRL^{3}_{j,h,b}\cdot PPRL_{j,h,b}\\+\sum_{j\in J}10NSPRL^{3}_{j,h,b}\cdot 10NPPRL_{j,h,b}+30RSPRL^{3}_{j,h,b}\cdot 30RPPRL_{j,h,b}\end{array}\right]\\-\sum_{k\in K}\left[\begin{array}{l}SVS^{3}_{k,h}\cdot PVS_{k,h}\\+\sum_{a\in A}\left(SHIG^{3}_{k,h,a}\cdot PHIG_{k,h,a}+SI10N^{3}_{k,h,a}\cdot PI10N_{k,h,a}+SI30R^{3}_{k,h,a}\cdot PI30R_{k,h,a}\right)\end{array}\right]\\-\sum_{b\in B}\left[\begin{array}{l}\sum_{k\in K_b}SPRG^{3}_{k,h,b}\cdot PPRG_{k,h,b}\\+\sum_{k\in K}10SSPRG^{3}_{k,h,b}\cdot 10SPPRG_{k,h,b}+10NSPRG^{3}_{k,h,b}\cdot 10NPPRG_{k,h,b}\\+30RSPRG^{3}_{k,h,b}\cdot 30RPPRG_{k,h,b}\end{array}\right]\\-ViolCost^{3}_{h}\end{array}\right\};$$

where $ViolCost^{3}_{h}$ is calculated as follows:

$$\begin{array}{l}ViolCost^{3}_{h}=SLdViol^{3}_{h}\cdot PLdViol-SGenViol^{3}_{h}\cdot PGenViol\\\quad+S10SViol^{3}_{h}\cdot P10SViol+S10RViol^{3}_{h}\cdot P10RViol\\\quad+S30RViol^{3}_{h}\cdot P30RViol\\\quad+\sum_{r\in ORREG}\left(\begin{array}{l}SREG10RViol^{3}_{r,h}\cdot PREG10RViol\\+SREG30RViol^{3}_{r,h}\cdot PREG30RViol\\+SXREG10RViol^{3}_{r,h}\cdot PXREG10RViol\\+SXREG30RViol^{3}_{r,h}\cdot PXREG30RViol\end{array}\right)\\\quad+\sum_{z\in Z}\left(SPreConXTLViol^{3}_{z,h}\cdot PPreConXTLViol\right)\\+SURmpXTLViol^{3}\cdot PRmpXTLViol+SDRmpXTLViol^{3}\cdot PRmpXTLViol\\\quad+\sum_{f\in F}SPreConITLViol^{3}_{f,h}\cdot PPreConITLViol\\\quad+\sum_{f\in F,c\in C}SITLViol^{3}_{f,c,h}\cdot PITLViol;\end{array}$$

4.7 Constraints for Pass 3

4.7.1 The constraints applied to this pass generally mirror those used in *pass 1* related to scheduling resources. Since *pass 3* and subsequent passes do not change commitments, constraints associated with determining commitments are redundant. and will not be used in these passes. Additional constraints are required for *energy limited resource* scheduling.

4.7.2 The optimization must not violate the parameters specified in the *energy bids* and *offers* which describe the capacity available for scheduling.

4.7.2.1 No schedule can be negative, nor can any schedule exceed the amount of capacity *offered* for that service (*energy* and *operating reserve*). Therefore for *price sensitive load, virtual bids, hourly* exports, *virtual offers,* and *hourly* imports:

$$0 \le SPSL^{3}_{j,h} \le QPSL_{j,h};$$

$$0 \le SVL^{3}_{j,h} \le QVL_{j,h};$$

$$0 \le SHXL^{3}_{j,h,a} \le QHXL_{j,h,a};$$

$$0 \le SX10N^{3}_{j,h,a} \le QX10N_{j,h,a};$$

$$0 \le SX30R^{3}_{j,h,a} \le QX30R_{j,h,a};$$

$$0 \le SVS^{3}_{k,h} \le QVS_{k,h};$$

$$0 \le SHIG^{3}_{k,h,a} \le QHIG_{k,h,a};$$

$$0 \le SI10N^{3}_{k,h,a} \le QI10N_{k,h,a};$$ and

$$0 \le SI30R^{3}_{k,h,a} \le QI30R_{k,h,a};$$

for all *bids j*, *offers k*, hours *h*, buses *b* and *intertie zones a*.

4.7.2.2 To simplify the translation of constraints for *pass 3* the following variables are introduced to represent the commitment status of *generation facilities* and *price responsive load* in *pass 3*:

i) for buses where *price responsive loads* are located:

$$AvailPRL^{3}_{h,b} = OPRL^{2A}_{h,b};$$ and

ii) for buses where *generation facilities* are located:

$AvailPRG^{3}_{h,b,} = OPRG^{2A}_{h,b}$, if the *dispatchable generation facility* at bus *b* is not *hourly committable generation* of the type referred to in section 1.3.8.1; or

$AvailPRG^{3}_{h,b,} = OPRG^{1}_{h,b}$, if the *generation facility* at bus *b is non-dispatchable generation*, or is *hourly committable generation* of the type referred to in section 1.3.8.1.

which will indicate whether a resource at bus *b* may be scheduled to operate in *pass 3* in hour *h*.

4.7.2.3 In the case of *price responsive loads* and *generation facilities*, in addition to restrictions on the magnitude of their schedules similar to those above, their schedules must be consistent with their operating status. The status is their commitment as indicated in section 4.7.3.2. *Generation facilities* cannot be scheduled to produce *energy* or *operating reserve* unless they are committed, nor can *price responsive loads* be scheduled to reduce consumption unless they are committed. Therefore:

$$0 \le SPRL^{3}_{j,h,b} \le AvailPRL^{3}_{h,b} \cdot QPRL_{j,h,b},$$

$$0 \le 10NSPRL^{3}_{j,h,b} \le AvailPRL^{3}_{h,b} \cdot 10NQPRL_{j,h,b},$$

$$0 \le 30RSPRL^{3}_{j,h,b} \le AvailPRL^{3}_{h,b} \cdot 30RQPRL_{j,h,b},$$

$$0 \le SPRG^{3}_{k,h,b} \le AvailPRG^{3}_{h,b} \cdot QPRG_{k,h,b},$$

$$0 \le 10SSPRG^{3}_{k,h,b} \le AvailPRG^{3}_{h,b} \cdot 10SQPRG_{k,h,b},$$

$$0 \le 10NSPRG^{3}_{k,h,b} \le AvailPRG^{3}_{h,b} \cdot 10NQPRG_{k,h,b}, \text{ and}$$

$0 \le 30RSPRG^{3}_{k,h,b} \le AvailPRG^{3}_{h,b} \cdot 30RQPRG_{k,h,b}$, for all *bids j*, *offers k*, hours *h*, and buses *b*.

4.7.2.4 The hourly *energy* from the multi-hour imports and exports are not optimization variables. They are calculated using the commitment status, start hour and end hour of the associated multi-hour imports and exports as follows:

$SBXL^{3}_{j,h,a} = OBXL^{1}_{j,a} \cdot QBXL_{j,a}$, for all *bid* hours from $STXHR_{j,a}$ to $ENXHR_{j,a}$ and zero for all other hours.

$SBIG^{3}_{k,h,a} = OBIG^{2A}_{k,a} QBIG_{k,a}$, for all *offer* hours from $STIHR_{k,a}$ to $ENIHR_{k,a}$ and zero for all other hours.

4.7.2.5 The hourly *energy* to be consumed by multi-hour *price sensitive load bids* are not optimization variables. They are calculated using the commitment status, start hour and end hour of the associated multi-hour *price sensitive loads* as follows:

$SMPSL^{3}_{h,j} = OMPSL^{1}_{j} \cdot QMPSL_{j}$, for all *bid* hours from $STMPSHR_{j}$ to $ENMPSHR_{j}$ and zero for all other hours.

4.7.2.6 The minimum and/or maximum output of *generating facilties* may be limited because of *outages* and/or deratings or in order for the units to provide *regulation* or voltage support. These constraints will take the form:

$$MinPRG_{h,b} \le MinQPRG_{h,b} + \sum_{k \in K_b} SPRG^{3}_{k,h,b} \le MaxPRG_{h,b},$$

4.7.3 The optimization must not violate the parameters specified in the *offers* which describe the *operating reserve* available for scheduling.

4.7.3.1 The total *operating reserve* (non-synchronized ten-minute and thirty-minute) from committed *price responsive load* can not exceed its ramp capability over 30 minutes.

$$\sum_{j \in J} (10NSPRL^{3}_{j,h,b} + 30RSPRL^{3}_{j,h,b}) \le 30 \cdot AvailPRL^{3}_{h,b} \cdot ORRPRL_{h,b}.$$

4.7.3.2 The total *operating reserve* (non-synchronized ten-minute and thirty-minute) from committed *price responsive load* can not exceed the total scheduled load (maximum load *bid* minus the load reductions).

$$\sum_{j \in J} (10NSPRL^{3}_{j,h,b} + 30RSPRL^{3}_{j,h,b}) \le \sum_{j \in J} (QPRL_{j,h,b} - SPRL^{3}_{j,h,b})$$

4.7.3.3 The amount of non-synchronized *ten-minute operating reserve* that a *price responsive load* is scheduled to provide cannot exceed the amount by which it can decrease its load over 10 minutes, as limited by its *operating reserve ramp rate.*

$$\sum_{j \in J} 10NSPRL^{3}_{j,h,b} \le 10 \cdot ORRPRL_{h,b}.$$

4.7.3.4 The total *operating reserve* (ten-minute synchronized,ten-minute non-synchronized and thirty-minute) from a committed *generation facility* can not exceed its ramp capability over 30 minutes.

$$\sum_{k \in K} (10SSPRG^{3}_{k,h,b} + 10NSPRG^{3}_{k,h,b} + 30RSPRG^{3}_{k,h,b}) \leq 30 \cdot AvailPRG^{3}_{h,b} \cdot ORRPRG_{h,b}.$$

4.7.3.5 The total *operating reserve* (ten-minute synchronized,ten-minute non-synchronized and thirty-minute) from a committed *generation facility* can not exceed the remaining capacity (maximum *offered generation* minus the *energy* schedule).

$$\sum_{k \in K} (10SSPRG^{3}_{k,h,b} + 10NSPRG^{3}_{k,h,b} + 30RSPRG^{3}_{k,h,b}) \leq \sum_{k \subset K} (QPRG_{k,h,b} - SPRG^{3}_{k,h,b})$$

4.7.3.6 The amount of *ten-minute operating reserve* (both synchronized and non-synchronized) that a *generation facility* is scheduled to provide cannot exceed the amount by which it can increase its output over 10 minutes, as limited by its *operating reserve ramp rate.*

$$\sum_{k \in K} (10SSPRG^{3}_{k,h,b} + 10NSPRG^{3}_{k,h,b}) \leq 10 \cdot ORRPRG_{h,b}.$$

4.7.3.7 The total *operating reserve* (ten-minute non-synchronized and thirty-minute) from hourly exports can not exceed its ramp capability over 30 minutes.

$$\sum_{j \in J} (SX10N^{3}_{j,h,a} + SX30R^{3}_{j,h,a}) \leq 30 \cdot ORRHXL_{h,a}.$$

4.7.3.8 The total *operating reserve* (ten-minute non-synchronized and thirty-minute) from hourly exports can not exceed the total scheduled *export.*

$$\sum_{j \in J} (SX10N^{3}_{j,h,a} + SX30R^{3}_{j,h,a}) \leq \sum_{j \in J} SHXL^{3}_{j,h,a}$$

4.7.3.9 The amount of non-synchronized *ten-minute operating reserve* that hourly *export* is scheduled to provide cannot exceed the amount by which it can decrease its load over 10 minutes, as limited by its *operating reserve ramp rate.*

$$\sum_{j \in J} SX10N^{3}_{j,h,a} \leq 10 \cdot ORRHXL_{h,a}.$$

4.7.3.10 The total *operating reserve* (ten-minute non-synchronized and thirty-minute) from hourly imports can not exceed its ramp capability over 30 minutes.

$$\sum_{k \in K} (SI10N^{3}_{k,h,a} + SI30R^{3}_{k,h,a}) \leq 30 \cdot ORRHIG_{h,a}$$

4.7.3.11 The total *operating reserve* (ten-minute non-synchronized and thirty-minute) from hourly imports can not exceed the remaining capacity (maximum *import* minus scheduled *energy import*).

$$\sum_{k \in K} (SI10N^{3}_{k,h,a} + SI30R^{3}_{k,h,a}) \leq \sum_{k \in K} (QHIG_{k,h,a} - SHIG^{3}_{k,h,a})$$

4.7.3.12 The amount of non-synchronized *ten-minute operating reserve* that hourly *import* is scheduled to provide cannot exceed the amount by which it can increase the output over 10 minutes, as limited by its *operating reserve ramp rate*.

$$\sum_{k \in K} SI10N^{3}_{k,h,a} \leq 10 \cdot ORRHIG_{h,a}.$$

4.7.4 The optimization must not violate the *effective uniform ramp rate* parameters derived from the *bids* and *offers*.

4.7.4.1 The following constraint limits changes in schedules from one committed hour to the next commited hour to 60 minutes of ramping at the down ramp rate or up ramp rate for the *generation facility*. The constraint also limits the hourly change in schedule for incremental *energy* in hours where there is a commitment status change for the resource, which occurs in hours where the resource starts up or shuts down.

$$\sum_{k \in K_b} SPRG^{3}_{k,h-1,b} - 60(YG(AvailPRG^{3}_{h,b} - AvailPRG^{3}_{h-1,b}) + 1)DRRPRG_{h,b} \leq \sum_{k \in K_b} SPRG^{3}_{k,h,b}$$
$$\leq \sum_{k \in K_b} SPRG^{3}_{k,h-1,b} + 60(1 - XG(AvailPRG^{3}_{h,b} - AvailPRG^{3}_{h-1,b}))URRPPRG_{h,b},$$

4.7.4.2 Similar considerations apply to *price responsive loads* leading to the following constraint:

$$\sum_{j \in J_b} SPRL^{3}_{j,h-1,b} - 60(YL(AvailPRL^{3}_{h,b} - AvailPRL^{3}_{h-1,b}) + 1)DRRPRL_{h,b} \leq \sum_{j \in J_b} SPRL^{3}_{j,h,b}$$
$$\leq \sum_{j \in J_b} SPRL^{3}_{j,h-1,b} + 60(1 - XL(AvailPRL^{3}_{h,b} - AvailPRL^{3}_{h-1,b}))URRPPRL_{h,b},$$

4.7.4.3 These ramping constraints apply for all hours from 1 to 24. In the above two constraint equations for hour 1 the variables related to hour zero are schedule and commitment variable values from last hour of the previous day.

4.7.4.4 Changes to the maximum and minimum scheduling limits from one hour to the next may not be feasible for the specified ramping capability of the resource. Where this occurs, the ramping rates in the ramping constraints must be adjusted to allow the resource to:

i) ramp down from its minimum *offer* or *bid* in hour (*h-1*) to its maximum *offer* or *bid* in hour *h*, or

ii) ramp up from its maximum *offer* or *bid* in hour (*h-1*) to its its minimum *offer* or *bid* in hour *h.*

4.7.5 The optimization must not violate the daily *energy* limit specified in an *offer* or the minimum schedule requirement from *pass 2*.

4.7.5.1 An *energy limited resource* may not be scheduled to provide more *energy* in total over the day than is indicated through its *offer* it is capable of providing. In addition, the application of the *energy* limit must also ensure that *facilities* are not scheduled to provide *energy* in amounts that would preclude them from providing *energy* for activated *operating reserve* in any given hour.

$$\sum_{h=1}^{1}\left(AvailPRG^{3}_{h,b}\cdot MinQPRG_{h,b}+\sum_{k\in K_b}SPRG^{3}_{k,h,b}\right)+\sum_{k\in K_b}10SSPRG^{3}_{k,1,b}+\sum_{k\in K_b}10NSPRG^{3}_{k,1,b}+\sum_{k\in K_b}30RSPRG^{3}_{k,1,b}\le EL_b,$$

$$\sum_{h=1}^{2}\left(AvailPRG^{3}_{h,b}\cdot MinQPRG_{h,b}+\sum_{k\in K_b}SPRG^{3}_{k,h,b}\right)+\sum_{k\in K_b}10SSPRG^{3}_{k,2,b}+\sum_{k\in K_b}10NSPRG^{3}_{k,2,b}+\sum_{k\in K_b}30RSPRG^{3}_{k,2,b}\le EL_b,\quad ,$$

$$\mathbb{M}$$

$$\sum_{h=1}^{24}\left(AvailPRG^{3}_{h,b}\cdot MinQPRG_{h,b}+\sum_{k\in K_b}SPRG^{3}_{k,h,b}\right)+\sum_{k\in K_b}10SSPRG^{3}_{k,24,b}+\sum_{k\in K_b}10NSPRG^{3}_{k,24,b}+\sum_{k\in K_b}30RSPRG^{3}_{k,24,b}\le EL_b,$$

for all buses *b* at which *energy limited resources* are located.

4.7.5.2 *Energy limited resources* may have a minimum schedule requirement placed on them for pass3 as the result of the forecast load commitment performed in *pass 2*. To respect this minimum schedule in *pass 3*:

$$SPRG^{3}_{k,h,b} \geq SPRG^{2B}_{k,h,b},$$

for all *offers k* and hours *h* at all buses *b* where *energy limited resources* are located.

4.7.6 Constraints to ensure that the resulting schedules do not violate other reliability requirements mirror those used in *pass 1* sections 2.8.7 to 2.8.10. Those constraints should be modified for *pass 3* by replacing *pass 1* schedule variables with the corresponding *pass 3* schedule variables. In addition, the variables identified in section 4.7.2.3 are to replace the corresponding *pass 1* commitment status variables in these constraints.

4.8 Locational Marginal Prices and Transmission Losses

4.8.1 Comparable to *pass 1 locational marginal prices* for *energy* for buses within Ontario as described in section 2.9, the *pass 3 locational marginal price* for *energy* at each bus *b* in each hour *h*, given the inputs and constraints into *pass 3*, shall be calculated:

$$LMP^{3}_{h,b} = \left(1 + MglLoss_{h,b}\right)\left[SPL^{3}_{h} - \sum_{f \in F}\left(\begin{array}{l} PreConSF_{b,f,h} \cdot SPNormT^{3}_{f,h} \\ + \sum_{c \in C} SF_{b,f,c,h} \cdot SPEmT^{3}_{f,c,h} \end{array}\right)\right].$$

for each internal bus *b* for each hour *h.*

4.8.2 The variables SPL^{3}_{h}, $SPNormT^{3}_{f,h}$ and $SPEmT^{3}_{f,c,h}$ are the shadow prices associated with the load balancing constraint, and transmission *facility* limits during normal and emergency conditions, respectively. The calculation engine is also capable of providing shadow values associated with those other constraints referred to in section 2.9.5, and which are used to derive the other quantities described in this section 4.8.

4.8.3 The p*ass 3 locational marginal price* for *energy* at each *intertie zone a* in each hour *h* is calculated as:

$$ExtLMP_{h,a}^{3} = \left(1 + \sum_{d \in D} ProxySFWt_{d,a} \cdot MglLoss_{h,d}\right) \cdot \left\{ \begin{array}{l} SPL_{h}^{3} - \sum_{d \in D}\left[ProxySFWt_{d,a} \sum_{f \in F}\left(PreConSF_{d,f,h} \cdot SPNormT_{f,h}^{3} + \sum_{c \in C}(SF_{d,f,c,h} \cdot SPEmT_{f,c,h}^{3}) \right)\right] \\ - \sum_{z \in Z_{sch}}(EnCoeff_{a,z} \cdot SPExtT_{z,h}^{3}) + SPRUExtT_{h}^{3} - SPRDExtT_{h}^{3} \end{array} \right\}.$$

where:

4.8.3.1 the first bracketted component of this calculation, comparable to section 2.9.2, is the cost of meeting load located at each *intertie zone,* including marginal losses incurred in transmitting *energy* from the *reference bus* to that *intertie zone.* The marginal loss factor is a weighted average of marginal loss factors for the buses in the *intertie zones* for which:

i) the buses are from the set *D* associated with intertie *a*, and

ii) that weighting is determined by the *security* assessment model for assessing the impact on flows over internal transmission *facilities*;

4.8.3.2 the second line of this expression calculates the effect of on the price at each bus for congestion on internal transmission *facilities.* This is similar to the congestion calculation for internal locations, described in section 2.9.3. The shift factor used for *intertie zone* prices is a weighted average of shift factors for external buses related to the *intertie zone* a; and

4.8.3.3 the last terms of this calculation reflect the impact of limits on imports or exports. Respectively, these terms are the marginal costs, or shadow prices, associated with:

i) limits for the amount of *energy* or *operating reserve* scheduled for the *intertie zone*;

ii) the limit for the increase in net scheduled imports from hour-to- hour; and

iii) the limit for the decrease in net scheduled imports from hour-to- hour.

4.8.4 *Locational marginal prices* for *operating reserve* shall be calculated for each bus within Ontario, as described in sections 4.8.5 to 4.8.7. These calculations will reflect the marginal contribution from each category of *operating reserve* to increasing the value of the objective function, or equivalently decreasing the cost, if an increment of that category of *operating reserve* were provided at that bus. The calculation shall recognize possible contributions to overall

operating reserve requirements as well as regional requirements. It shall aslo account for contributions:

4.8.4.1 from non-synchronized *ten-minute operating reserve* to satisfying the total *thirty-minute operating reserve* requirement, and

4.8.4.2 from synchronized *ten-minute operating reserve* to satisfying the total *ten-minute operating reserve* and *thirty-minute operating reserve* requirements.

4.8.5 The *pass 3 locational marginal price* for *thirty-minute operating reserve* at a given bus *b*, $L30RP^3_{h,b}$, is:

4.8.5.1 the shadow price of the total *thirty-minute operating reserve* constraint,

4.8.5.2 plus the shadow prices of all of the constraints requiring a minimum amount of *thirty-minute operating reserve* to be provided by resources in regions that include that bus,

4.8.5.3 minus the shadow prices of all the constraints limiting the amount of *thirty-minute operating reserve* that can be provided by resources in regions that include that bus

which leads to the definition:

$$L30RP^3_{h,b} = SP30R^3_h + \sum_{r \in ORREG_b} SPREGMin30R^3_{r,h} - \sum_{r \in ORREG_b} SPREGMax30R^3_{r,h}.$$

for each bus *b*, where the set $ORREG_b$ are all the potentially over-lapping regions *r* in which bus *b* is located.

4.8.6 The *pass 3 locational marginal price* for non-synchronized *ten-minute operating reserve* at a given bus *b*, $L10NP^3_{h,b}$, is:

4.8.6.1 the shadow price of the total *ten-minute* and *thirty-minute operating reserve* constraints,

4.8.6.2 plus the shadow prices of all of the constraints requiring a minimum amount of *ten-minute* or *thirty-minute operating reserve* to be provided by resources in regions that include that bus,

4.8.6.3 minus the shadow prices of all the constraints limiting the amount of *ten-minute* or *thirty-minute operating reserve* that can be provided by resources in regions that include that bus

which leads to the definition:

$$L10NP^{3}_{h,b} = SP10R^{3}_{h} + SP30R^{3}_{h} + \sum_{r \in ORREG_b} \left(SPREGMin10R^{3}_{r,h} + SPREGMin30R^{3}_{r,h} \right) - \sum_{r \in ORREG_b} \left(SPREGMax10R^{3}_{r,h} + SPREGMax30R^{3}_{r,h} \right).$$

for each bus *b*, where the set $ORREG_b$ are all the potentially over-lapping regions *r* in which bus *b* is located.

4.8.7 The *pass 3 locational marginal price* for synchronized *ten-minute operating reserve* at a given bus *b*, $L10SP^{3}_{h,b}$, is:

4.8.7.1 the shadow price for the synchronized *ten-minute*, total *ten-minute* and *thirty-minute operating reserve* constraints,

4.8.7.2 plus the shadow prices of all of the constraints requiring a minimum amount of *ten-minute* or *thirty-minute operating reserve* to be provided by resources in regions that include that bus**,**

4.8.7.3 minus the shadow prices of all the constraints limiting the amount of *ten-minute* or *thirty-minute operating reserve* that can be provided by resources in regions that include that bus

which leads to the definition:

$$L10SP^{3}_{h,b} = SP10S^{3}_{h} + SP10R^{3}_{h} + SP30R^{3}_{h} + \sum_{r \in ORREG_b} \left(SPREGMin10R^{3}_{r,h} + SPREGMin30R^{3}_{r,h} \right) - \sum_{r \in ORREG_b} \left(SPREGMax10R^{3}_{r,h} + SPREGMax30R^{3}_{r,h} \right).$$

for each bus *b*, where the set $ORREG_b$ are all the potentially over-lapping regions *r* in which bus *b* is located.

4.8.8 *Locational marginal prices* for *operating reserve* shall be calculated for each *intertie zone*, as described in sections 4.8.9 and 4.8.10. These calculation shall:

4.8.8.1 account for the impact of *intertie* constraints on scheduled net *energy* imports and *imported operating reserves*;

4.8.8.2 account for the contribution from non-synchronized *ten-minute operating reserve* to satsisfying the total *thirty-minute operating reserve* requirement, and

4.8.8.3 do not need to account for limits on the hour-to-hour changes in net *energy imported*, or for regional operating reserve requirements.

4.8.9 The *pass 3 locational marginal price* for *thirty-minute operating reserve* at a given *intertie zone a,* $Ext30RP^{3}_{h,a}$ is:

4.8.9.1 the shadow price of the total *thirty-minute operating reserve* constraint,

4.8.9.2 minus the sum for all *intertie* constraints related to zone a, of the product of :

i) the impact that imports of *operating reserve* from that *intertie zone* have on each constraint limiting the *import* of *operating reserve* from that *intertie zone*, and

ii) the shadow price of that constraint

which leads to the definition:

$$Ext30RP^{3}_{h,a} = SP30R^{3}_{h} - \sum_{z \in Z_{sch}} 0.5(ENCoeff_{a,z} + 1) SPExtT^{3}_{z,h}.$$

for each *intertie zone* a.

4.8.10 The *pass 3 locational marginal price* for *ten-minute operating reserve* at a given *intertie zone a,* $Ext10RP^{3}_{h,a}$ is:

4.8.10.1 the shadow price of the total *ten-minute* and total *thirty-minute operating reserve* constraints,

4.8.10.2 minus the sum for all *intertie* constraints related to zone a, of the product described in 4.8.9.2

which leads to the definition:

$$Ext10RP^{3}_{h,a} = SP10R^{3}_{h} + SP30R^{3}_{h} - \sum_{z \in Z_{sch}} 0.5(ENCoeff_{a,z} + 1) SPExtT^{3}_{z,h}.$$

for each *intertie zone* a.

4.8.11 The total transmission losses on the system corresponding to the schedules in *pass 3,* is equal to the sum in each hour *h* of all scheduled resources supplying *energy* in *pass 3* minus the sum of all internal load and exports scheduled in *pass 3.* Therefore:

$$SysLoss_h^3 = \left[\begin{array}{l} \sum_{k \in K} \left(SVS_{k,h}^3 + \sum_{a \in A} (SHIG_{k,h,a}^3 + SBIG_{k,h,a}^3) \right) \\ + \sum_{b \in B} \left(AvailPRG_{h,b}^3 \cdot MinQPRG_{h,b} + \sum_{k \in K_b} SPRG_{k,h,b}^3 \right) \end{array} \right]$$

$$- \sum_{j \in J} \left(SPSL_{j,h}^3 + SVL_{j,h}^3 + SMPSL_{j,h}^3 + \sum_{a \in A} (SHXL_{j,h,a}^3 + SBXL_{j,h,a}^3) \right)$$

$$+ SLdViol_h^3 - SGenViol_h^3 - \sum_{b \in B} \left[(1 - AvailPRL_{h,b}^3) \cdot MinQPRL_{h,b} + \sum_{j \in J_b} \left(QPRL_{j,h,b} - SPRL_{j,h,b}^3 \right) \right]$$

5. Pass 4: Constrained Scheduling to Meet Forecast Load

5.1 Pass 4 Overview

5.1.1 *Pass 4* performs a least cost *security* constrained scheduling process that meets the needs for *forecast Ontario load* and *operating reserve* to satisfy *IMO reliability* requirements.

5.1.2 The purpose of *pass 4* of the *DAM calculation engine* is to develop projected schedules for inputs to the *IMO security* assessment. The *constrained schedul*es for *energy* and *operating reserve* produced by *pass 4* will be consistent with the input modified forecast of Ontario load, previously determined commitments, and *bid* and *offer* prices submitted by *price responsive load* and *generation facilities*.

5.1.3 As for other passes, step 1 of *pass 4* performs a single optimization over 24 hours using the *effective uniform ramp rates*. Step 2 performs 24 separate one-hour optimizations using the actual submitted ramp rates. Step 1 is described in detail in this section 5. The description for step 2 of *pass 4* is analogous to the description in section 2.10 for step 2 of *pass 1*, except where that section refers to commitment variables.

5.2 Inputs for Pass 4

5.2.1 *Pass 4* will use as input the modified forecast of Ontario load as described in section 1.7.2 and as input to *pass 2*. This forecast will not include *responsive load* consumption.

5.2.2 *Pass 4* will use the *bids* for *price responsive load* as submitted by *market participants* and not as modified as in *pass 2.* The commitments to load reductions determined in *pass 1* or *pass 2* will be input to *pass 4.*

5.2.3 *Virtual offers, virtual bids* and *price sensitive load bids* will not be used in *pass 4.*

5.2.4 Both hourly and multi-hour exports will be fixed to the values scheduled in *pass 1.* The *pass 1* schedule for hourly exports and the commitments for multi-hour exports will be input to *pass 4.*

5.2.5 *Pass 4* will use the *offers* for *generation facilities* as submitted by *market participants* and not as modified as in *pass 2,* except that:

5.2.5.1 *offers* from *non-dispatchable generation* are not used. Instead, with the estimated production value as determined in section 3.6 for *pass 2* will also be input as the schedule for *pass 4*; and

5.2.5.2 the schedule for *energy limited resources* from *pass 2B* will be used as a minimum schedule for *pass 4*.

5.2.6 *Generation facility* commitments from *pass 1* and *pass 2* will be used for *pass 4.*

5.2.7 Both hourly and multi-hour imports will be fixed to the values scheduled in *pass 2A* by using as input to *pass 4* the *pass 1 or pass 2* commitments for multi-hour imports, *and the pass 2* schedules for hourly imports.

5.2.8 All transmission and other inputs described in sections 2.2.5 to 2.2.8 for *pass 1* will be used in *Pass 4* without modification. Since *pass 4* does not perform a *unit commitment* many of these inputs will be superfluous for the purposes of this *pass*

5.3 Optimization Objective for Pass 4

5.3.1 The objective function of *pass 4* is to maximize the gains from trade. (See section 5.6 for the complete statement of the objective function) This is accomplished by maximizing the sum of the following hourly quantities.:

For each hour of the trade day, the negative of the cost for:

- the foregone opportunity due to scheduled *price responsive load* reductions, incremental to any committed *minimum load reduction*
- scheduled *operating reserve* from *price*

responsive load

- scheduled *dispatchable generation*, incremental to any committed *minimum generation levels*
- scheduled *operating reserve* from *generation facilities*
- scheduled violation variables

where:

the hourly cost associated with all violations variables is the sum of the individual hourly costs for:

- forecast load curtailment due to a supply deficit
- scheduling additional load to offset surplus must-run *generation* requirements (the minus sign is required since the violation price is negative)
- *operating reserve* requirement deficits
- all reserve area minimum *operating reserve* requirement deficits
- all reserve area *operating reserve* excesses above maximum requirements
- pre-contingency and post-contingency limit violations for internal *transmission facilities*.

5.4 Output from Pass 4

5.4.1 *Pass 4* produces advisory information about the day-ahead schedules and prices.

5.4.2 The output consists of schedules for injections and withdrawals by *generation facilities,* imports, *price responsive load* and exports.

5.4.3 *Pass 4* output also includes advisory *locational marginal prices* for *energy* and *operating reserve.*

5.4.4 Table 4 shows the products of *pass 3* and how these are used in later passes or the *day-ahead market settlement* process

Table 4: Pass 4 Outputs and Target Processes

Output	Target Pass or Settlement - Application
Constrained schedules - energy and *operating reserve*: • *Generation facilities* - total schedules including minimum levels • *Price responsive loads* – total load reduction and net consumption • Imports – hourly and multi-hour • Exports – hourly and multi-hour	For information only
Locational marginal prices for *energy* and operating reserve	For information only

5.5 Glossary of Sets, Indices, Variables and Parameters for Pass 4

5.5.1 Fundamental Sets and Indices

J'''	The set of all *bids j* for *pass 4* for a given *day-ahead market* day. Each P-Q pair of a *bid* submitted by a *market participant* would be represented by a unique element *j* in the set.
J'''_b	The subset of those *bids j* for *pass 4* consisting of *bids* for a *price responsive load resource* at a bus *b.*
K'''	The set of all *offers* for *pass 4* for a given *day-ahead market*. Each P-Q pair of an *offer* submitted by a *market participant* would be represented by a unique element *k* in the set.
K'''_b	The subset of those *offers* for *pass 4* consisting of *offers* for a *generation facility* at a bus *b.*

5.5.2 Transmission and Security Inputs and Intermediate Variables

$AvailPRL^4_{h,b}$	The *pass 4* input operating status in hour *h* at buses *b*

where *price responsive loads* are located, which is the cumulative commitments at the end of *pass 2A*

$AvailPRG^4_{h,b}$ — The *pass 4* input operating status in hour *h* at buses *b* where *dispatchable generation* is located, which is the cumulative commitments at the end of *pass 2A*

$With^4_{h,b}$ — The total amount of withdrawals scheduled in *pass 4* at each bus *b* in each hour *h*, for scheduled *virtual offers* and *generation* for internal buses.

$With^4_{h,d}$ — The total amount of withdrawals scheduled in *pass 4* at each bus *d* in each hour *h*, for imports and inflows associated with unscheduled loop flows for buses in *intertie zones*.

$Inj^4_{h,b}$ — The total amount of injections scheduled in *pass 4* at each bus *b* in each hour *h*, for forecast load and *price responsive loads* for internal buses.

Inj^4_{hdb} — The total amount of injections scheduled in *pass 4* at each bus *d* in each hour *h*, for exports and outflows associated with unscheduled loop flows for buses in *intertie zones*.

$WithT^4_{h,b}$ — The total amount of withdrawals scheduled in *pass 4* at each bus *b* in each hour *h*, similar to $With^4_{h,b}$, defined for internal buses only.

$InjT^4_{h,b}$ — The total amount of injections scheduled in *pass 4* at each bus *b* in each hour *h*, similar to $Inj^4_{h,b}$, defined for internal buses only.

$WithX^4_{h,d}$ — The total amount of withdrawals scheduled in *pass 4* at each bus *d* in each hour *h*, similar to $With^4_{h,b}$, defined for buses in *intertie zones*.

$InjX^4_{h,d}$ — The total amount of injections scheduled in *pass 4* at each bus *d* in each hour *h*, similar to $Inj^4_{h,b}$, defined for buses in *intertie zones*.

5.5.3 Output Schedules

$SPRL^4_{j,h,b}$ — The amount of load reduction scheduled at bus *b* in hour *h* in *pass 4* in association with each *bid j* at that bus. This is addition to any $MinQPRL_{h,b}$, the *minimum load reduction*, which must also be committed.

$10NSPRL^4_{j,h,b}$ — The amount of *ten-minute operating reserve* that a qualified *price responsive load* is scheduled to provide at bus *b* in hour *h* in *pass 4* in association with *bid j* for this bus.

$30RSPRL^4_{j,h,b}$ — The amount of *thirty-minute operating reserve* that a qualified *price responsive load* is scheduled to provide

at bus *b* in hour *h* in *pass 4* in association with *bid j* for this bus.

$SPRG^{4}_{k,h,b}$ — The amount scheduled for the *generation facility* at bus *b* in hour *h* in *pass 4* in association with each *offer k* at that bus. This is addition to any $MinQPRG_{h,b}$, the *minimum generation level*, which must also be committed.

$10SSPRG^{4}_{k,h,b}$ — The amount of synchronized *ten-minute operating reserve* that a qualified *generation facility* at bus *b* is scheduled to provide in hour *h* in *pass 4* in association with *offer k* for this bus.

$10NSPRG^{4}_{k,h,b}$ — The amount of non-synchronized *ten-minute operating reserve* that a qualified *generation facility* at bus *b* is scheduled to provide in hour *h* in *pass 4* in association with *offer k* for this bus.

$30RSPRG^{4}_{k,h,b}$ — The amount of *thirty-minute operating reserve* that a qualified *generation facility* at bus *b* is scheduled to provide in hour *h* in *pass 4* in association with *offer k* for this bus.

5.5.4 Output Violation Variables

$ViolCost^{4}_{h}$ — The cost incurred in order to avoid having the *pass 4* schedules for hour *h* violate specified constraints.

$SLdViol^{4}_{h}$ — The amount of load that cannot be met using *offers* scheduled in hour *h* in *pass 4*.

$SGenViol^{4}_{h}$ — The amount of additional load that must be scheduled in hour *h* in *pass 4* to ensure that there is enough load on the system to offset the must-run requirements of *generation facilities.*

$S10SViol^{4}_{h}$ — The amount by which the overall synchronized *ten-minute operating reserve* requirement is not met in hour *h* of *pass 4* because the cost of meeting that portion of the requirement was greater than or equal to *P10SViol.*

$S10RViol^{4}_{h}$ — The amount by which the overall *ten-minute operating reserve* requirement is not met in hour *h* of *pass 4* (above and beyond any failure to meet the synchronized *ten-minute operating reserve* requirement) because the cost of meeting that portion of the requirement was greater than or equal to *P10RViol.*

$S30RViol^{4}_{h}$ — The amount by which the overall *thirty-minute operating reserve* requirement is not met in hour *h* of *pass 4* (above and beyond any failure to meet the *ten-*

	minute operating reserve requirement) because the cost of meeting that portion of the requirement was greater than or equal to *P30RViol.*
$SREG10RViol^4_{r,h}$	The amount by which the overall *ten-minute operating reserve* requirement for region *r* is not met in hour *h* of *pass 4* because the cost of meeting that portion of the requirement was greater than or equal to *PREG10RViol.*
$SREG30RViol^4_{r,h}$	The amount by which the overall *thirty-minute operating reserve* requirement for region *r* is not met in hour *h* of *pass 4* because the cost of meeting that portion of the requirement was greater than or equal to *PREG30RViol.*
$SXREG10RViol^4_{r,h}$	The amount by which the overall *ten-minute operating operating reserve* requirement for region *r* is more than the maximum required in hour *h* of *pass 4* because the cost of meeting that the maximum requirement limit was greater than or equal to *PXREG10RViol.*
$SXREG30RViol^4_{r,h}$	The amount by which the overall *thirty-minute operating reserve* requirement for region *r* is more than the maximum required in hour *h* of *pass 4* because the cost of meeting the maximum requirement limit was greater than or equal to *PXREG30RViol.*
$SPreConITLViol^4_{f,h}$	The amount by which pre-contingency flows over *facility f* in hour *h* of *pass 4* exceed the normal limit for flows over that *facility*, because the cost of alternative solutions that would not result in such an overload was greater than or equal to *PPreConITLViol.*
$SITLViol^4_{f,c,h}$	The amount by which flows over *facility f* that would follow the occurrence of contingency *c* in hour *h* of *pass 4* exceed the emergency limit for flows over that *facility*, because the cost of alternative solutions that would not result in such an overload was greater than or equal to *PITLViol.*

5.6 Objective Function Pass 4

5.6.1 The objective function for *pass 4* is to maximize gains from trade by maximizing the objective function below. The objective function attributes value to scheduled *bids*, costs to scheduled supply, and additional cost to any constraint violations.

5.6.1.1 Gains from trade as determined as:

$$\sum_{h=1,\ldots,24}\left\{\begin{array}{l}-\sum_{b\in B}\left[\begin{array}{l}\sum_{j\in J'''_b} SPRL^4_{j,h,b}\cdot PPRL_{j,h,b}\\ \sum_{j\in J'''} 10NSPRL^4_{j,h,b}\cdot 10NPPRL_{j,h,b}+30RSPRL^4_{h,b}\cdot 30RPPRL_{j,h,b}\end{array}\right]\\ -\sum_{b\in B_{NSC}}\left[\begin{array}{l}\sum_{k\in K'''_b} SPRG^4_{k,h,b}PPRG_{k,h,b}\\ +\sum_{k\in K'''_b} 10SSPRG^4_{k,h,b}\cdot 10SPPRG_{k,h,b}+10NSPRG^4_{k,h,b}\cdot 10NPPRG_{k,h,b}\\ +30RSPRG^4_{k,h,b}\cdot 30RPPRG_{k,h,b}\end{array}\right]\\ -ViolCost^4_h\end{array}\right\};$$

where $ViolCost^4_h$ is calculated as follows:

$$\begin{aligned}ViolCost^4_h &= SLdViol^4_h\cdot PLdViol - SGenViol^4_h\cdot PGenViol\\ &+ S10SViol^4_h\cdot P10SViol + S10RViol^4_h\cdot P10RViol\\ &+ S30RViol^4_h\cdot P30RViol\\ &+\sum_{r\in ORREG}\left(\begin{array}{l}SREG10RViol^4_{r,h}\cdot PREG10RViol\\ +SREG30RViol^4_{r,h}\cdot PREG30RViol\\ +SXREG10RViol^4_{r,h}\cdot PXREG10RViol\\ +SXREG30RViol^4_{r,h}\cdot PXREG30RViol\end{array}\right)\\ &+\sum_{f\in F} SPreConITLViol^4_{f,h}\cdot PPreConITLViol\\ &+\sum_{f\in F,c\in C} SITLViol^4_{f,c,h}\cdot PITLViol;\end{aligned}$$

5.7 Constraints for Pass 4

5.7.1 The constraints applied to this pass generally mirror those used in *pass 3*, since both perform scheduling of resources but not commitment. The constraints below reflect the use of forecast load, and the fixed levels for exports and imports.

5.7.2 The optimization must not violate the parameters specified in the *energy bids* and *offers* which describe the capacity available for scheduling.

5.7.2.1 To simplify the translation of constraints for *pass 4* the following variables are introduced to represent the commitment status of *generation facilities* and *price responsive load* in *pass 4*:

i) $\text{AvailPRL}^{4}_{h,b} = \text{OPRL}^{2A}_{h,b}$, for buses where *price responsive load* is located; and

ii) $\text{AvailPRG}^{4}_{h,b} = \text{OPRG}^{2A}_{h,b}$, for buses where *dispatchable generation* is located:

which will indicate whether a resource at bus *b* may be scheduled to operate in *pass 4* in hour *h*.

5.7.2.2 In the case of *price responsive loads* and *generation facilities*, in addition to restrictions on the magnitude of their schedules, their schedules must be consistent with their operating status. For *pass 4* the status is their commitment at the end of *pass 2*. *Generation facilities* cannot be scheduled to produce *energy* or *operating reserve* unless they are committed, nor can *price responsive loads* be scheduled to reduce consumption unless they are committed. Therefore:

$$0 \le SPRL^{4}_{j,h,b} \le AvailPRL^{4}_{h,b} \cdot QPRL_{j,h,b},$$

$$0 \le 10NSPRL^{4}_{j,h,b} \le AvailPRL^{4}_{h,b} \cdot 10NQPRL_{j,h,b},$$

$$0 \le 30RSPRL^{4}_{j,h,b} \le AvailPRL^{4}_{h,b} \cdot 30RQPRL_{j,h,b},$$

$$0 \le SPRG^{4}_{k,h,b} \le AvailPRG^{4}_{h,b} \cdot QPRG_{k,h,b},$$

$$0 \le 10SSPRG^{4}_{k,h,b} \le AvailPRG^{4}_{h,b} \cdot 10SQPRG_{k,h,b},$$

$$0 \le 10NSPRG^{4}_{k,h,b} \le AvailPRG^{4}_{h,b} \cdot 10NQPRG_{k,h,b}, \text{ and}$$

$$0 \le 30RSPRG^{4}_{k,h,b} \le AvailPRG^{4}_{h,b} \cdot 30RQPRG_{k,h,b},$$ for all *bids j*, *offers k*, hours *h*, and buses *b*.

5.7.2.3 The hourly *energy* from the multi-hour imports and exports are not optimization variables. They are calculated using the commitment status, start hour and end hour of the associated multi-hour imports and exports as follows:

$SBXL^{4}_{j,h,a} = OBXL^{1}_{j,a} QBXL_{j,a}$, for all *bid* hours from $STXHR_{j,a}$ to $ENXHR_{j,a}$ and zero for all other hours.

$SBIG^{4}_{k,h,a} = OBIG^{2A}_{k,a} QBIG_{k,a}$, for all *offer* hours from $STIHR_{k,a}$ to $ENIHR_{k,a}$ and zero for all other hours.

5.7.2.4 The minimum and/or maximum output of *generating facilties* may be limited because of *outages* and/or deratings or in order for the units to provide *regulation* or voltage support. These constraints will take the form:

$$MinPRG_{h,b} \le MinQPRG_{h,b} + \sum_{k \in K_b} SPRG^{4}_{k,h,b} \le MaxPRG_{h,b},$$

5.7.3 The optimization must not violate the parameters specified in the *offers* which describe the *operating reserve* available for scheduling.

5.7.3.1 The total *operating reserve* (non-synchronized ten-minute and thirty-minute) from committed *price responsive load* can not exceed its ramp capability over 30 minutes.

$$\sum_{j \in J} (10NSPRL^{4}_{j,h,b} + 30RSPRL^{4}_{j,h,b}) \le 30 \cdot AvailPRL^{4}_{h,b} \cdot ORRPRL_{h,b}.$$

5.7.3.2 The total *operating reserve* (non-synchronized ten-minute and thirty-minute) from committed *price responsive load* can not exceed the total scheduled load (maximum load *bid* minus the load reductions).

$$\sum_{j \in J} (10NSPRL^{4}_{j,h,b} + 30RSPRL^{4}_{j,h,b}) \le \sum_{j \in J} (QPRL_{j,h,b} - SPRL^{4}_{j,h,b})$$

5.7.3.3 The amount of non-synchronized *ten-minute operating reserve* that a *price responsive load* is scheduled to provide cannot exceed the amount by which it can decrease its load over 10 minutes, as limited by its *operating reserve ramp rate.*

$$\sum_{j \in J} 10NSPRL^{4}_{j,h,b} \le 10 \cdot ORRPRL_{h,b}.$$

5.7.3.4 The total *operating reserve* (ten-minute synchronized,ten-minute non-synchronized and thirty-minute) from a committed *generation facility* can not exceed its ramp capability over 30 minutes.

$$\sum_{k \in K} (10SSPRG^{4}_{k,h,b} + 10NSPRG^{4}_{k,h,b} + 30RSPRG^{4}_{k,h,b}) \le 30 \cdot AvailPRG^{4}_{h,b} \cdot ORRPRG_{h,b}.$$

5.7.3.5 The total *operating reserve* (ten-minute synchronized,ten-minute non-synchronized and thirty-minute) from a committed *generation*

facility can not exceed the remaining capacity (maximum *offered generation* minus the *energy* schedule).

$$\sum_{k\in K}(10SSPRG^4_{k,h,b} + 10NSPRG^4_{k,h,b} + 30RSPRG^4_{k,h,b}) \le \sum_{k\in K}(QPRG_{k,h,b} - SPRG^4_{k,h,b})$$

5.7.3.6 The amount of *ten-minute operating reserve* (both synchronized and non-synchronized) that a *generation facility* is scheduled to provide cannot exceed the amount by which it can increase its output over 10 minutes, as limited by its *operating reserve ramp rate.*

$$\sum_{k\in K}(10SSPRG^4_{k,h,b} + 10NSPRG^4_{k,h,b}) \le 10 \cdot ORRPRG_{h,b}.$$

5.7.4 The optimization must not violate the *effective uniform ramp rate* parameters derived from the *bids* and *offers.*

5.7.4.1 The following constraint limits changes in schedules from one committed hour to the next commited hour to 60 minutes of ramping at the down ramp rate or up ramp rate for the *generation facility.* The constraint also limits the hourly change in schedule for incremental *energy* in hours where there is a commitment status change for the resource, which occurs in hours where the resource starts up or shuts down.

$$\sum_{k\in K_b} SPRG^4_{k,h-1,b} - 60(YG(AvailPRG^4_{h,b} - AvailPRG^4_{h-1,b}) + 1)DRRPRG_{h,b} \le \sum_{k\in K_b} SPRG^4_{k,h,b}$$
$$\le \sum_{k\in K_b} SPRG^4_{k,h-1,b} + 60(1 - XG(AvailPRG^4_{h,b} - AvailPRG^4_{h-1,b}))URRPPRG_{h,b},$$

5.7.4.2 Similar considerations apply to *price responsive loads* leading to the following constraint:

$$\sum_{j\in J_b} SPRL^4_{j,h-1,b} - 60.(YL(AvailPRL^4_{h,b} - AvailPRL^4_{h-1,b}) + 1)DRRPRL_{h,b} \le \sum_{j\in J_b} SPRL^4_{j,h,b}$$
$$\le \sum_{j\in J_b} SPRL^4_{j,h-1,b} + 60(1 - XL(AvailPRL^4_{h,b} - AvailPRL^4_{h-1,b}))URRPPRL_{h,b},$$

5.7.4.3 These ramping constraints apply for all hours from 1 to 24. In the above two constraint equations for hour 1 the variables related to hour zero are schedule and commitment variable values from the last hour of the previous day.

5.7.4.4 Changes to the maximum and minimum scheduling limits from one hour to the next may not be feasible for the specified ramping capability of the resource. Where this occurs, the ramping rates in the ramping constraints must be adjusted to allow the resource to:

i) ramp down from its minimum *offer* or *bid* in hour (*h-1*) to its maximum *offer* or *bid* in hour *h*, or

ii) ramp up from its maximum *offer* or *bid* in hour (*h-1*) to its its minimum *offer* or *bid* in hour *h*.

5.7.5 The optimization must not violate the daily *energy* limit specified in an *offer* or the minimum schedule requirement from *pass 2*.

5.7.5.1 An *energy limited resource* may not be scheduled to provide more *energy* in total over the day than is indicated through its *offer* it is capable of providing. In addition, the application of the *energy* limit must also ensure that *facilities* are not scheduled to provide *energy* in amounts that would preclude them from providing *energy* for activated *operating reserve* in any given hour.

$$\sum_{h=1}^{1}\left(AvailPRG^{4}_{h,b} \cdot MinQPRG_{h,b} + \sum_{k\in K_b} SPRG^{4}_{k,h,b} \right) + \sum_{k\in K_b} 10SSPRG^{4}_{k,1,b} + \sum_{k\in K_b} 10NSPRG^{4}_{k,1,b} + \sum_{k\in K_b} 30RSPRG^{4}_{k,1,b} \le EL_b,$$

$$\sum_{h=1}^{2}\left(AvailPRG^{4}_{h,b} \cdot MinQPRG_{h,b} + \sum_{k\in K_b} SPRG^{4}_{k,h,b} \right) + \sum_{k\in K_b} 10SSPRG^{4}_{k,2,b} + \sum_{k\in K_b} 10NSPRG^{4}_{k,2,b} + \sum_{k\in K_b} 30RSPRG^{4}_{k,2,b} \le EL_b, \quad ,$$

$$\mathbb{M}$$

$$\sum_{h=1}^{24}\left(AvailPRG^{4}_{h,b} \cdot MinQPRG_{h,b} + \sum_{k\in K_b} SPRG^{4}_{k,h,b} \right) + \sum_{k\in K_b} 10SSPRG^{4}_{k,24,b} + \sum_{k\in K_b} 10NSPRG^{4}_{k,24,b} + \sum_{k\in K_b} 30RSPRG^{4}_{k,24,b} \le EL_b,$$

for all buses *b* at which *energy limited resources* are located.

5.7.5.2 *Energy limited resources* may have a minimum schedule requirement placed on them for *pass 4* as the result of the forecast load commitment performed in *pass 2*. To respect this minimum schedule in *pass 3*:

$$SPRG^{4}_{k,h,b} \ge SPRG^{2B}_{k,h,b},$$

for all *offers k* and hours *h* at all buses *b* where *energy limited resources* are located.

5.7.6 The optimization for *pass 4* must satisfy load requirements, by balancing injections and withdrawals.

5.7.6.1 For each hour, the total amount of *energy* injected (scheduled supply from *generation facilities* plus scheduled imports) must balance total *energy* withdrawn (scheduled or forecast purchases by loads and scheduled exports) and transmission losses consistent with these supplies and purchases.

5.7.6.2 Withdrawals at bus *b* within Ontario and each bus d outside Ontario for hour *h* are calculated as:

$$With^4_{h,b} = LDF_{h,b} \cdot FL_h + \left[MinQPRL_{h,b} - AvailPRL^4_{h,b} \cdot MinQPRL_{h,b} + \sum_{j \in J'''_b} \left(QPRL_{j,h,b} - SPRL^4_{j,h,b} \right) \right]$$

$$With^4_{h,d} = \sum_{a \in A} \left(ProxySFWt_{d,a} \sum_{j \in J'''} (SHXL^1_{j,h,a} + SBXL^4_{j,h,a}) \right) - \sum_{a \in A} ProxyUPOWt_{d,a} \min(0, PF_{h,a}).$$

5.7.6.3 Injections at bus *b* within Ontario, excluding buses *where non-dispatchable generation* is located, and each bus d outside Ontario for hour *h* are calculated as:

$$Inj^4_{h,b} = AvailPRG^4_{h,b} \cdot MinQPRG_{h,b} + \sum_{k \in K'''_b} SPRG^4_{k,h,b}$$

$$Inj^4_{h,d} = \sum_{a \in A} \left(ProxySFWt_{d,a} \sum_{k \in K'''} (SHIG^{2A}_{k,h,a} + SBIG^4_{k,h,a}) \right) + \sum_{a \in A} ProxyUPIWt_{d,a} \max(0, PF_{h,a});$$

5.7.6.4 For *non-dispatchable generation facilities* at buses in the set B_{SC}, *offers* from the *facilities* at these buses are excluded from the objective function in section 2.7, since the production from these is an input into *pass 4*. The forecast for the production at that location is used as the injection at these buses, yielding:

$$Inj^4_{h,b} = ESC_{h,b}.$$

5.7.6.5 To balance supply and purchases:

$$\sum_{b \in B} (1 + MglLoss_{h,b}) With^4_{h,b} + \sum_{d \in D} (1 + MglLoss_{h,d}) With^4_{h,d} - SLDViol^4_h$$
$$= \sum_{b \in B} (1 + MglLoss_{h,b}) Inj^4_{h,b} + \sum_{d \in D} (1 + MglLoss_{h,d}) Inj^4_{h,d} - SGenViol^4_h + LossAdj_h.$$

5.7.7 The optimization must not violate *operating reserve* requirements.

5.7.7.1 Sufficient *operating reserve* must be scheduled to meet system wide requirements for *ten-minute operating* synchronized *reserve*, *ten-minute operating reserve* and *thirty-minute operating reserve*, as well as all applicable regional minimum and maximum requirements for *operating reserve*. These are similar to the constraints of *pass 2*.

5.7.7.2 Violation variables ensure a feasible solution and allow relaxation of the requirements if the cost of meeting these becomes too high.

5.7.7.3 For synchronized *ten-minute operating reserve*, for all hours *h*:

$$\sum_{b\in B}\left(\sum_{k\in K} 10SSPRG^{4}_{k,h,b}\right)+S10SViol^{4}_{h} \geq TOT10S_{h},$$

5.7.7.4 For total *ten-minute operating reserve*, for all hours *h*:

$$\begin{aligned}&\sum_{b\in B}\left(\sum_{k\in K} 10SSPRG^{4}_{k,h,b}\right)+S10RViol^{4}_{h}\\&+\sum_{b\in B}\left(\sum_{k\in K} 10NSPRG^{4}_{k,h,b}\right)+\sum_{b\in B}\left(\sum_{j\in J} 10NSPRL^{4}_{j,h,b}\right)\\&+\sum_{a\in A}\left(\sum_{k\in K} SI10N^{2A}_{k,h,a}\right)+\sum_{a\in A}\left(\sum_{j\in J} SX10N^{1}_{j,h,a}\right)\geq TOT10R_{h},\end{aligned}$$

5.7.7.5 For total *thirty-minute operating reserve*, for all hours *h*:

$$\begin{aligned}&\sum_{b\in B}\left(\sum_{k\in K} 10SSPRG^{4}_{k,h,b}\right)+S30RViol^{4}_{h}\\&+\sum_{b\in B}\left(\sum_{k\in K}(10NSPRG^{4}_{k,h,b}+30RSPRG^{4}_{k,h,b})\right)\\&+\sum_{b\in B}\left(\sum_{j\in J}(10NSPRL^{4}_{j,h,b}+30RSPRL^{4}_{j,h,b})\right)\\&+\sum_{a\in A}\left(\sum_{k\in K}(SI10N^{2A}_{k,h,a}+SI30R^{2A}_{k,h,a})\right)\\&+\sum_{a\in A}\left(\sum_{j\in J}(SX10N^{1}_{j,h,a}+SX30R^{1}_{j,h,a})\right)\geq TOT30R_{h},\end{aligned}$$

5.7.7.6 To satisfy the minimum regional requirement for ***ten-minute operating reserve***, for all hours ***h***, and for all regions ***r*** in the set *ORREG*:

$$\sum_{b \in r}\left(\sum_{k \in K} 10SSPRG^{4}_{k,h,b}\right) + SREG10RViol^{4}_{r,h}$$
$$+ \sum_{b \in r}\left(\sum_{k \in K} 10NSPRG^{4}_{k,h,b}\right) + \sum_{b \in r}\left(\sum_{j \in J} 10NSPRL^{4}_{j,h,b}\right) \geq REGMin10R_{r,h},$$

5.7.7.7 To satisfy the maximum regional requierment for ***ten-minute operating reserve***, for all hours ***h***, and for all regions ***r***:

$$\sum_{b \in r}\left(\sum_{k \in K} 10SSPRG^{4}_{k,h,b}\right) - SXREG10RViol^{4}_{r,h}$$
$$+ \sum_{b \in r}\left(\sum_{k \in K} 10NSPRG^{4}_{k,h,b}\right) + \sum_{b \in r}\left(\sum_{j \in J} 10NSPRL^{4}_{j,h,b}\right) \leq REGMax10R_{r,h},$$

5.7.7.8 To satisfy the minimum regional requierment for ***thirty-minute operating reserve***, for all hours ***h***, and for all regions ***r***:

$$\sum_{b \in r}\left(\sum_{k \in K} 10SSPRG^{4}_{k,h,b}\right) + SREG30RViol^{4}_{r,h}$$
$$+ \sum_{b \in r}\left(\sum_{k \in K} (10NSPRG^{4}_{k,h,b} + 30RSPRG^{4}_{k,h,b})\right)$$
$$+ \sum_{b \in r}\left(\sum_{j \in J} (10NSPRL^{4}_{j,h,b} + 30RSPRL^{4}_{j,h,b})\right) \geq REGMin30R_{r,h},$$

5.7.6.9 To satisfy the maximum regional requierment for ***thirty-minute operating reserve***, for all hours ***h***, and for all regions ***r***:

$$\sum_{b \in r}\left(\sum_{k \in K} 10SSPRG^{4}_{k,h,b}\right) - SXREG30RViol^{4}_{r,h}$$
$$+ \sum_{b \in r}\left(\sum_{k \in K} (10NSPRG^{4}_{k,h,b} + 30RSPRG^{4}_{k,h,b})\right)$$
$$+ \sum_{b \in r}\left(\sum_{j \in J} (10NSPRL^{4}_{j,h,b} + 30RSPRL^{4}_{j,h,b})\right) \leq REGMax30R_{r,h},$$

5.7.8 The optimization must not violate internal transmission limits or ***security*** constraints.

5.7.8.1 *Energy* schedules produced by *pass 2A* must not overload any internal transmission *facility* or exceed any *security limits* in either the pre-contingency state or in any contingency, except where this is not feasible.

5.7.8.2 *Energy* flows associated with a transmission or *security limit* are determined from the total scheduled *energy* at each bus, as injections or withdrawals, and the fraction of that *energy* which contributes to the transmission or *security* flow.

5.7.8.3 Total withdrawals scheduled in *pass 4* at each bus *b* in each hour *h*, $WithT^{4}_{h,b}$, for buses within Ontario is:

$$WithT^{4}_{h,b} = LDF_{h,b} FL_{h} + \left[MinQPRL_{h,b} - AvailPRL^{4}_{h,b} \cdot MinQPRL_{h,b} + \sum_{j \in J''_{b}} \left(QPRL_{j,h,b} - SPRL^{4}_{j,h,b} \right) \right].$$

5.7.8.4 Total injections scheduled in *pass 4* at each bus *b* in each hour *h*, $InjT^{4}_{h,b}$, for buses within Ontario where there is a *dispatchable generation facility*, is:

$$InjT^{4}_{h,b} = AvailPRG^{4}_{h,b} \cdot MinQPRG_{h,b} + \sum_{k \in K''_{b}} SPRG^{4}_{k,h,b}.$$

5.7.8.5 Total injections scheduled in *pass 4* at each bus *b* in each hour *h*, $InjT^{4}_{h,b}$, for buses within Ontario where there is a *non-dispatchable generation facility*, is:

$$InjT^{4}_{h,b} = ESC_{h,b}$$

5.7.8.6 Total withdrawals scheduled in *pass 4* at each bus *d* in each hour *h*, $WithX^{1}_{h,b}$, for buses outside Ontario in *intertie zones* associated with exports and unscheduled loop flows is:

$$WithX^{4}_{h,d} = \sum_{a \in A} \left[ProxySFWt_{d,a} \sum_{j \in J'''} (SHXL^{1}_{j,h,a} + SBXL^{4}_{j,h,a}) - ProxyUPOWt_{d,a} \min(0, PF_{h,a}) \right],$$

5.7.8.7 Total injections scheduled in *pass 4* at each bus *d* in each hour *h*, $InjX^{1}_{h,b}$, for buses outside Ontario associated with exports and unscheduled loop flows is:

$$InjX^{4}_{h,d} = \sum_{a \in A} \left[ProxySFWt_{d,a} \sum_{k \in K'''} SHIG^{2A}_{k,h,a} + SBIG^{4}_{k,h,a}) + ProxyUPIWt_{d,a} \max(0, PF_{h,a}) \right].$$

5.7.8.8 The *security* assessment function of the *DAM calculation engine* will identify binding (violated) pre-contingency limits on transmission *facilities* within Ontario. These will accounted for within the optimization as linearized constraints of the form:

$$\sum_{b \in B} PreConSF_{b,f,h}(InjT^{4}_{h,b} - WithT^{4}_{h,b}) + \sum_{d \in D} PreConSF_{d,f,h}(InjX^{4}_{h,d} - WithX^{4}_{h,d}) + \sum_{b \in B} PreOprgSF_{b,f,h}(OPRG^{4}_{h,b}) - SPreConITLViol^{4}_{f,h} \leq AdjNormMaxFlow_{f,h},$$

where *D* is the set of buses outside Ontario, for all *facilities f* and hours *h*.

5.7.6.9 Similarly, linearized binding post-contingency limits will take the form:

$$\sum_{b \in B} SF_{b,f,c,h}(InjT^{4}_{h,b} - WithT^{4}_{h,b}) + \sum_{d \in D} SF_{d,f,c,h}(InjX^{4}_{h,d} - WithX^{4}_{h,d}) - SITLViol^{4}_{f,h} \leq AdjEmMaxFlow_{f,h},$$

for all *facilities f*, hours *h*, and monitored contingencies *c*.

5.7.7 To ensure the amount of *energy* each *energy limited resource* generates in each hour is consistent with the minimum output required for *reliability*, as determined in of *pass 2B*:

$$SPRG^{4}_{k,h,b} \geq SPRG^{2B}_{k,h,b},$$

for all *offers k* and hours *h* at all buses *b*, where *energy limited resources* are located.

5.8 Locational Marginal Prices and Transmission Losses

5.8.1 *Locational marginal prices* for *energy* and *operating reserve* at internal locations will be calculated and used for advisory purposes by the *IMO*, using the calculations described in *pass 3* modified to reflect *pass 4* variables and inputs.

5.8.2 Meaningful prices for external locations cannot be calculated in *pass 4* since schedules for *energy* imports and exports and *operating reserve* imports are fixed.

6. Pass 5: Unconstrained Scheduling to Meet Bid Load

6.1 Pass 5 Overview

6.1.1 *Pass 5* conducts a least cost, unconstrained scheduling process that meets the load as specified in *bids* and *IMO*-specified *operating reserve* requirements. *Pass 5* uses *bids* and *offers* as submitted.

6.1.2 Internal transmission constraints are not considered in this *pass*. The prices calculated in this *pass,* which are described in section 6.8*,* are the *day-ahead market* prices and used in *settlements.*

6.1.3 Schedules determined in this *pass* are also used in the *settlement* process. *Pass 5* schedules, where these differ from the schedules of *pass 3*, may lead to the calculation of congestion management *settlement* credits.

6.1.4 The *unconstrained schedules* for *price responsive load, generation facilities,* hourly imports and exports, *virtual bids* and *virtual offers* are determined from *pass 5.* For these resources there may be minimum schedules associated with the committed minimum levels specified in the *bids* and *offers,* or minimum schedule requirements for *energy limited resources*, as determined *in pass 2.*

6.1.5 The *pass 5* unconstrained scheduling process does not take account of internal transmission limitations but does account for intertie flow limits. The description for the *unconstrained IMO-grid model* is indicated in section 1.6.3

6.1.6 *Pass 5* performs two steps as described for *pass 1*. Step 1, is described in detail in this section 6. Step 2 for *pass 5* follows the same procedure as described in section 2.10, with references to *pass 5* replacing the references to *pass 1*, except where that section refers to commitments. *Pass 1* step 1 performs a *unit commitment*, while *pass 5* step 1 does not and takes commitments as inputs.

6.1.7 Output schedules for *pass 5* are those determined in step 2 except for e*nergy limited resources* for which schedules are determined in step 1. Consistent with this, results from *pass 5* step 2 are used to determine *locational marginal prices* for *energy* and *operating reserve.*

6.2 Inputs for Pass 5

6.2.1 The load, *generation facility*, transmission and other inputs into *pass 5* shall be the same inputs as were used in *pass 1* and *pass 3,* as indicated in section 4.2.1. Many of these inputs will be superfluous for the purposes of *pass 5*.

6.2.2 *Pass 5* does not perform a *unit commitment. Pass 5* takes as input the same commitment variables as specified for input to *pass 3* in section 4.2.2.

6.2.3 *Pass 3* will input the schedules from *pass 2B* for *energy limited* resources as minimum schedules for *pass 3.*

6.2.4 The total transmission losses incurred on the system in *pass 3*, $SysLoss^{3}_{h}$, will also be used.

6.3 Optimization Objective for Pass 5

6.3.1 The objective function of *pass 3* is to maximize the gains from trade. (See section 6.6 for the complete statement of the objective function.) This is accomplished by maximizing the sum of the following hourly quantities.:

For each hour of the trade day

the value of:

- scheduled *price sensitive load*
- scheduled *virtual bids*
- scheduled hourly exports

less the cost of:

- scheduled *operating reserve* from exports
- the foregone opportunity due to scheduled *price responsive load* reductions, incremental to any committed *minimum load reduction*
- scheduled *operating reserve* from *price responsive load*
- scheduled *virtual offers*
- scheduled hourly imports
- scheduled *operating reserve* from imports

- scheduled *generation facility offers*, incremental to any committed *minimum generation level*
- scheduled *operating reserve* from *generation facilities*
- scheduled violation variables

where:

the hourly cost associated with all violations variables is the sum of the individual hourly costs for:

- load curtailment (= 0 for *pass 5*) due to a supply deficit
- scheduling additional load to offset surplus must-run *generation* requirements (the minus sign is required since the violation price is negative)
- *operating reserve* requirement deficits
- pre-contingency limit violations for *import* or *export interties*
- exceeding the up or down ramp limits for the total net schedule change for imports and exports.
- pre-contingency and post-contingency limit violations for internal *transmission facilities*

6.4 Output from Pass 5

6.4.1 The primary outputs of *pass 5* which are used in other *day-ahead market* processes include the following:

6.4.1.1 *unconstrained schedules*; and

6.4.1.2 the *day-ahead market* prices for *energy a*nd *operating reserve*.

6.4.2 *Unconstrained schedules* for *energy* and *operating reserve* are calculated in *pass 5* for *generating facilities, price responsive load,* imports and exports. The calculated scheduled *energy* quantities determined by *pass 5* are incremental to any minimum levels required for the *generating facilities* or for load reduction. Combining minimum levels and the scheduled quantities determined in *pass 5* gives to the total scheduled *generation facility* production and the net scheduled *price responsive load* consumption. *Pass 5* also produces *unconstrained schedules* for *energy* for *pricesensitive load* and *virtual transactions.*

6.4.4 Step 1 schedules are used as inputs to step 2.

6.4.5 Output schedules for *pass 5* are those determined in step 2 except for e*nergy limited resources* for which schedules are determined in step 1.

6.4.6 Consistent with schedules being primarily determined in step 2, *pass 5* step 2 results are used to determine *day-ahead market* prices for *energy* and *operating reserve.*

6.4.7 Table 5 shows the products of *pass 5* and how these are used.

Table 5: Pass 5 Outputs and Target Processes

Output	**Target Pass or Settlement - Application**
Unconstrained schedules - energy and *operating reserve*: • *Generation facilities* - total schedules including minimum levels • *Price responsive loads* - total load reduction and net consumption • Imports – hourly and multi-hour • Exports – hourly and multi-hour	*Settlement* – Eligible for CMSC
Unconstrained schedules - energy • *Price sensitive load* • *Virtual transactions* to buy • *Virtual transactions* to sell	*Settlement* – financially binding *unconstrained schedules*
Prices for *energy* and *operating reserve*	*Settlements* – Prices for all *settlements*.

6.5 Glossary of Sets, Indices, Variables and Parameters for Pass 5

6.5.1 Transmission and Security Inputs and Intermediate Variables

$AvailPRL^{5}_{h,b}$	The *pass 5* input operating status in hour *h* at buses *b* where *price responsive loads* are located, which is the same as the commitment used by *pass 3*
$AvailPRG^{5}_{h,b}$	The *pass 5* input operating status in hour *h* at buses *b* where a *generation facility* is located,. This is the same as the commitment used by *pass 3*.

6.5.2 Output Schedules

$SPSL^{5}_{j,h}$	The amount of *price sensitive load* scheduled in hour *h* in *pass 5* in association with each *bid j*.
$SVL^{5}_{j,h}$	The amount of *virtual* load scheduled in hour *h* in *pass 5* in association with each *bid j*.
$SHXL^{5}_{j,h,a}$	The amount of exports scheduled in hour *h* in *pass 5* from *intertie zone a* in association with each *bid j*.
$SX10R^{5}_{j,h,a}$	The amount of non-synchronized *ten-minute operating reserve* scheduled from the *export* in hour *h* in *pass 5* from *intertie zone a* in association with *bid j.*
$SX30R^{5}_{j,h,a}$	The amount of *thirty-minute operating reserve* scheduled from the *export* in hour *h* in *pass 5* from *intertie zone a* in association with *bid j*.
$SPRL^{5}_{j,h,b}$	The amount of load reduction scheduled at bus *b* in hour *h* in *pass 5* in association with each *bid j* at that bus. This is addition to any $MinQPRL_{h,b}$, the *minimum load reduction*, which must also be committed.
$10NSPRL^{5}_{j,h,b}$	The amount of *ten-minute operating reserve* that a qualified *price responsive load* is scheduled to provide at bus *b* in hour *h* in *pass 5* in association with *bid j* for this bus.
$30RSPRL^{5}_{j,h,b}$	The amount of *thirty-minute operating reserve* that a qualified *price responsive load* is scheduled to provide at bus *b* in hour *h* in *pass 5* in association with *bid j* for this bus.
$SVS^{5}_{k,h}$	The amount of *virtual* supply scheduled in hour *h* in *pass 5* in association with each *offer k*
$SHIG^{5}_{k,h,a}$	The amount of hourly imports scheduled in hour *h* from *intertie zone a* in *pass 5* in association with each *offer k.*

$SI10R^5_{k,h,a}$	The amount of *imported ten-minute operating reserve* scheduled in hour *h* from *intertie zone a* in *pass 5* in association with each *offer k.*
$SI30R^5_{k,h,a}$	The amount of *imported thirty-minute operating reserve* scheduled in hour *h* from *intertie zone a* in *pass 5* in association with each *offer k.*
$SPRG^5_{k,h,b}$	The amount scheduled for the *generation facility* at bus *b* in hour *h* in *pass 5* in association with each *offer k* at that bus. This is addition to any $MinQPRG_{h,b}$, the *minimum generation level*, which must also be committed.
$10SSPRG^5_{k,h,b}$	The amount of synchronized *ten-minute operating reserve* that a qualified *generation facility* at bus *b* is scheduled to provide in hour *h* in *pass 5* in association with *offer k* for this bus.
$10NSPRG^5_{k,h,b}$	The amount of non-synchronized *ten-minute operating reserve* that a qualified *generation facility* at bus *b* is scheduled to provide in hour *h* in *pass 5* in association with *offer k* for this bus.
$30RSPRG^5_{k,h,b}$	The amount of *thirty-minute operating reserve* that a qualified *generation facility* at bus *b* is scheduled to provide in hour *h* in *pass 5* in association with *offer k* for this bus.

6.5.3 Output Violation Variables

$ViolCost^5_h$	The cost incurred in order to avoid having the *pass 5* schedules for hour *h* violate specified constraints.
$SLdViol^5_h$	The amount of load that cannot be met using *offers* scheduled in hour *h* in *pass 5*.[This quantity is zero in *pass 5* since no forecast load is included.]
$SGenViol^5_h$	The amount of additional load that must be scheduled in hour *h* in *pass 5* to ensure that there is enough load on the system to offset the must run requirements of *generation facilities.*
$S10SViol^5_h$	The amount by which the overall synchronized *ten-minute operating reserve* requirement is not met in hour *h* of *pass 5* because the cost of meeting that portion of the requirement was greater than or equal to *P10SViol.*
$S10RViol^5_h$	The amount by which the overall *ten-minute operating reserve* requirement is not met in hour *h* of *pass 5* (above and beyond any failure to meet the synchronized *ten-minute operating reserve* requirement) because the cost of meeting that portion

of the requirement was greater than or equal to *P10RViol*.

$S30RViol^5_h$ — The amount by which the overall *thirty-minute operating reserve* requirement is not met in hour *h* of *pass 5* (above and beyond any failure to meet the *ten-minute operating reserve* requirement) because the cost of meeting that portion of the requirement was greater than or equal to *P30RViol*.

$SPreConXTLViol^5_{z,h}$ — The amount by which *intertie* flows over *facility z* in hour *h* of *pass 5* exceed the normal limit for flows over that *facility*, because the cost of alternative solutions that would not result in such an overload was greater than or equal to *PPreConXTLViol*.

$SURmpXTLViol^5_h$ — The amount by which the total net scheduled *import* increase for hour *h* in *pass 5* exceeds the up ramp limits, because the cost of alternative solutions that would not result in violation was greater than or equal to *PRmpXTLViol*.

$SDRmpXTLViol^5_h$ — The amount by which the total net scheduled *import* decrease in hour *h* of *pass 5* exceed the down ramp limits, because the cost of alternative solutions that would not result in violation was greater than or equal to *PRmpXTLViol*.

6.5.4 Output Shadow Prices and Locational Marginal Prices

6.5.4.1 Shadow Prices of Constraints:

SPL^5_h — The *pass 5* shadow price measuring the the rate of change of the objective function for a change in load at the *reference bus* in hour *h*.

$SPExtT^5_{z,h}$ — The *pass 5* shadow price measuring the the rate of change of the objective function for a change in the limit on flows over transmission *facilities* on the boundary between Ontario and other *control areas* for each constraint z in hour *h*.

$SPRUExtT^5_h$ — The *pass 5* shadow price measuring the the rate of change of the objective function for a change in the limit on the upward change of the sum of net imports over all *interties* from the previous hour to hour *h*.

$SPRDExtT^5_h$ — The *pass 5* shadow price measuring the the rate of change of the objective function for a change in the limit on the downward change of the sum of net imports over all *interties* from the previous hour to hour *h*.

$SP10S^5_h$ — The *pass 5* shadow price measuring the the rate of

	change of the objective function for a change in the total synchronized *ten-minute operating reserve* requirement in hour *h*.
$SP10R^5_h$	The *pass 5* shadow price measuring the the rate of change of the objective function for a change in the total *ten-minute operating reserve* requirement in hour *h*.
$SP30R^5_h$	The *pass 5* shadow price measuring the the rate of change of the objective function for a change in the total *thirty-minute operating reserve* requirement in hour *h*.

6.5.4.2 *Locational marginal prices*:

$IntEP^5_h$	The *pass 5* internal *day-ahead market* price for *energy* in each hour *h.*
$ExtEP^5_{h,a}$	The *pass 5 day-ahead market* price for *energy* in each hour *h* for *intertie zone a.*
$Int10SP^5_{h,b}$	The *pass 5* internal *day-ahead market* price for synchronized *ten-minute operating reserve* in each hour *h*
$Int10RP^5_{h,b}$	The *pass 5* internal *day-ahead market* price for non-synchronized *ten-minute operating reserve* in each hour *h.*
$Int30RP^5_{h,b}$	The *pass 5* internal *day-ahead market* price for *thirty-minute operating reserve* in each hour *h.*
$Ext10RP^5_{h,a}$	The *pass 5 day-ahead market* price for non-synchronized *ten-minute operating reserve* in each hour *h* for *intertie zone a.*
$Ext30RP^5_{h,a}$	The *pass 5 day-ahead market* price for *thirty-minute operating reserve* in each hour *h* for *intertie zone a.*

6.6 Objective Function Pass 5

6.6.1 The objective function for *pass 5* is to maximize gains from trade by maximizing the objective function below. The objective function attributes value to scheduled *bids*, costs to scheduled supply, and additional cost to any constraint violations.

6.6.1.1 Gains from trade as determined as:

$$\sum_{h=1,\ldots,24}\left\{\begin{array}{l}\sum_{j\in J}\left[\begin{array}{l}SPSL^{5}_{j,h}\cdot PPSL_{j,h}+SVL^{5}_{j,h}\cdot PVL_{j,h}\\+\sum_{a\in A}(SHXL^{5}_{j,h,a}\cdot PXL_{j,h,a}-SX10R^{5}_{j,h,a}\cdot PX10R_{j,h,a}-SX30R^{5}_{j,h,a}\cdot PX30R_{j,h,a})\end{array}\right]\\-\sum_{b\in B}\left[\begin{array}{l}\sum_{j\in J_b}SPRL^{5}_{j,h,b}\cdot PPRL_{j,h,b}\\+\sum_{j\in J_b}(30RSPRL^{5}_{j,h,b}\cdot 30RPPRL_{j,h,b}+10NSPRL^{5}_{j,h,b}\cdot 10NPPRL_{j,h,b})\end{array}\right]\\-\sum_{k\in K}\left[\begin{array}{l}SVS^{5}_{k,h}\cdot PVS_{k,h}\\+\sum_{a\in A}\left(SHIG^{5}_{k,h,a}\cdot PHIG_{k,h,a}+SI10R^{5}_{k,h,a}\cdot PI10R_{k,h,a}+SI30R^{5}_{k,h,a}\cdot PI30R_{k,h,a}\right)\end{array}\right]\\-\sum_{b\in B}\left[\begin{array}{l}\sum_{k\in K_b}SPRG^{5}_{k,h,b}\cdot PPRG_{k,h,b}\\+\sum_{k\in K_b}(10SSPRG^{5}_{k,h,b}\cdot 10SPPRG_{k,h,b}+10NSPRG^{5}_{k,h,b}\cdot 10NPPRG_{k,h,b}\\+30RSPRG^{5}_{k,h,b}\cdot 30RPPRG_{k,h,b})\end{array}\right]\\-ViolCost^{5}_{h}\end{array}\right\};$$

where $ViolCost^{5}_{h}$ is calculated as follows:

$$\begin{array}{l}ViolCost^{5}_{h}=SLdViol^{5}_{h}\cdot PLdViol-SGenViol^{5}_{h}\cdot PGenViol\\\quad+S10SViol^{5}_{h}\cdot P10SViol+S10RViol^{5}_{h}\cdot P10RViol\\\quad+S30RViol^{5}_{h}\cdot P30RViol\\\quad+\sum_{z\in Z}\left(S\,\mathrm{Pr}\,eConXTLViol^{5}_{z,h}\cdot P\,\mathrm{Pr}\,eConXTLViol\right)\\+SURmpXTLViol^{5}\cdot PRmpXTLViol+SDRmpXTLViol^{5}\cdot PRmpXTLViol;\end{array}$$

6.7 Constraints for Pass 5

6.7.1 The constraints applied to this pass generally mirror those used in *pass 3* related to scheduling resources, with the exceptions as noted in sections 6.7.2 to 6.7.4 related to using the *unconstrained IMO-grid model*. To apply for *pass 5*, constraint variables used in section 4.7 must be modified to reflect *pass 5*, by replacing the variable superscript.

6.7.2 Marginal losses are not included in the *unconstrained IMO-grid model.* Consequently the load constraint in section 2.8.7.5 (as modified for *pass 3* by virtue of section 4.7.6) must be further modified to:

6.7.2.1 remove the marginal loss factors; and

6.7.2.2 apply a modified loss value representing total losses on the transmission system, $SysLoss^3_h$, as determined in *pass 3*,

Thus the load and generation balance requirement for *pass 5* is expressed as constraining the *pass 5* injections less *pass 5* withdrawals to be equal to system losses, estimated by the *pass 3* value for losses:

$$\left[\sum_{k\in K}\left(SVS^5_{k,h}+\sum_{a\in A}(SHIG^5_{k,h,a}+SBIG^5_{k,h,a})\right)\right.$$
$$\left.+\sum_{b\in B}\left(AvailPRG^5_{h,b}\cdot MinQPRG_{h,b}+\sum_{k\in K_b}SPRG^5_{k,h,b}\right)\right]$$

$$-\sum_{j\in J}\left(SMPSL^5_{j,h}+SPSL^5_{j,h}+SVL^5_{j,h}+\sum_{a\in A}(SHXL^5_{j,h,a}+SBXL^5_{j,h,a})\right)-SLdViol^5_h+SGenViol^5_h$$
$$-\sum_{b\in B}\left[(1-AvailPRL^5_{h,b})\cdot MinQPRL_{h,b}+\sum_{j\in J_b}\left(QPRL_{j,h,b}-SPRL^5_{j,h,b}\right)\right]$$
$$=SysLoss^3_h.$$

6.7.3 Limits requiring minimum amounts of *operating reserve* to be provided within a region, as well as upper limits on the scheduled amount within a region, will be ignored in *pass 5*. Therefore, the constraints similar to those in sections 2.8.8.6 to 2.8.8.9 are not used in *pass 5.*

6.7.4 Since internal transmission limits are also ignored, constraints similar to those in section 2.8.9 for *pass 1*, do not apply for *pass 5*.

6.8 Day-Ahead Market Prices

6.8.1 The *DAM calculation engine* will generate *pass 5* shadow prices corresponding to SPL^1_h, $SPExtT^1_{z,h}$, $SPRUExtT^1_{h,}$ $SPRDExtT^1_{h,}$ $SP10S^1_h$, $SP10R^1_h$, $SP30R^1_h$, as described in *pass 1*. (Values corresponding to the other shadow prices appearing in the glossary for *pass 1* section 2.6.2.7 will not be produced in *pass 5* since the constraints included for *pass 1* from which these shadow prices are derived do not apply in *pass 5*.)

6.8.2 The *pass 5* internal *energy* price for each hour *h*, $IntEP^5_h$, shall apply to all injections and withdrawals scheduled to occur within Ontario, or at any bus in Ontario, in that hour. It shall be calculated as follows:

6.8.2.1 If $SLdViol^5_h = SGenViol^5_h = 0$, then supply and demand balance, and $IntEP^5_h$ shall be SPL^5_h.

6.8.2.2 If $SGenViol^5_h > 0$, then it was not possible to schedule enough load and exports to offset all must-run *generation facilities*, so $IntEP^5_h$ shall be set to $-MMCP$.

6.8.3 The calculation of the *pass 5 energy* price at each *intertie zone a* in each hour *h*, $ExtEP^5_{h,a}$ is similar to the calculation for *intertie zones* in previous passes, except that the terms pertaining to the impact of injections or withdrawals at external locations on transmission congestion and transmission losses occurring within Ontario are omitted, as the relevant constraints have not been included in the optimization. Therefore:

$$ExtEP^5_{h,a} = SPL^5_h - \sum_{z \in Z_{flow}} EnCoeff_{a,z} \cdot SPExtT^5_{z,h} + SPRUExtT^5_h - SPRDExtT^5_h$$

6.8.4 The calculation of *pass 5* internal *operating reserve* prices is similar to the calculation for *pass 3 operating reserve* prices. The difference results from the omission of regional *operating reserve* constraints in *pass 5*, thereby eliminating the need to consider the shadow prices of these constraints in *pass 5*. Therefore, the prices of synchronized *ten-minute operating reserve*, total *ten-minute operating reserve*, and total *thirty-minute operating reserve* shall respectively be calculated as follows:

$$Int10SP^5_{h,b} = SP10S^5_h + SP10R^5_h + SP30R^5_h;$$

$$Int10RP^5_{h,b} = SP10R^5_h + SP30R^5_h; \text{ and}$$

$$Int30RP^5_{h,b} = SP30R^5_h.$$

6.8.5 The calculation of *pass 5* prices for ten-minute and thirty-minute operating reserve at *intertie zones* mirrors the calculation of these prices in *pass 3*:

$$Ext10RP^5_{h,a} = SP10R^5_h + SP30R^5_h - \sum_{z \in Z_{sch}} 0.5(EnCoeff_{a,z} + 1)SPExtT^5_{z,h}, \text{, and}$$

$$Ext30RP^5_{h,a} = SP30R^5_h - \sum_{z \in Z_{sch}} 0.5(EnCoeff_{a,z} + 1)SPExtT^5_{z,h}.$$