Market Rule Amendment Proposal Form

Part 1 - Market Rule Information

Identification No.:	MR-00460-R00
Subject:	Market Renewal Program: The Real-Time Calculation Engine
Title:	Market Renewal Program: The Real-Time Calculation Engine
Nature of Proposal:	☐ Alteration ☒ Deletion ☒ Addition
Chapter:	7
Appendix:	Appendix 7.6 (New) Appendix 7.5 – Delete in its entirety
Sections:	
Sub-sections proposed for amending:	
Current Market Rules Baseline:	December 1, 2021

Part 2 - Proposal History

Version	Reason for Issuing	Version Date
1.0	Draft for Stakeholder Review	February 4, 2022
2.0	Draft for Stakeholder Review	July 8, 2022

Approved Amendment Publication Date:

Approved Amendment Effective Date:

Part 3 - Explanation for Proposed Amendment

Summary

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Background

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Discussion

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Part 4 - Proposed Amendment

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

1 Appendix 7.6A – The Real-Time Calculation Engine Process

1.1 Purpose

1.1.1 This appendix describes the process used by the *real-time calculation engine* to determine schedules and prices for the *real-time market* and real-time look-ahead period.

2 Real-Time Calculation Engine

2.1 Real-Time Look-Ahead Period

2.1.1 The real-time look-ahead period is the time horizon of the multi-interval optimization that includes the *dispatch interval* and the subsequent ten five-minute intervals.

2.2 Real-Time Calculation Engine Pass

2.2.1 The *real-time calculation engine* shall execute one pass, Pass 1, the Real-Time Scheduling and Pricing Pass in accordance with section 7, to produce *real-time schedules* and *locational marginal prices*.

3 Information Used by the Real-Time Calculation Engine

3.1.1 The *real-time calculation engine* shall use the information in section 3A.1 of Chapter 7.

4 Sets, Indices and Parameters Used by the Real-Time Calculation Engine

4.1 Fundamental Sets and Indices

4.1.1 A designates the set of all *intertie zones*;

4.1.2 B designates the set of buses identifying all *dispatchable* and non-*dispatchable resources* within Ontario;

4.1.3 $B^{DG} \subseteq B$ designates the set of buses identifying *dispatchable generation resources*;

4.1.4 $B^{DL} \subseteq B$ designates the set of buses identifying *dispatchable loads*;

4.1.5 $B^{HDR} \subseteq B$ designates the set of buses identifying *hourly demand response resources*;

4.1.6 $B^{HE} \subseteq B^{DG}$ designates the subset of buses identifying *dispatchable* hydroelectric *generation resources*;

4.1.7 $B^{NDG} \subseteq B$ designates the set of buses identifying *non-dispatchable generation resources*;

4.1.8 $B^{NoBid} \subseteq B$ designates the set of buses identifying *dispatchable loads* with no *bid* for *energy*;

4.1.9 $B^{NoOffer} \subseteq B$ designates the set of buses identifying *generation resources* with no *offer* for *energy*;

4.1.10 $B^{NO10DF} \subseteq B^{PSU}$ designates the subset of buses identifying *pseudo-units* that cannot provide *ten-minute operating reserve* from the duct firing region;

4.1.11 $B^{NQS} \subseteq B^{DG}$ designates the subset of buses identifying *dispatchable non-quick start resources*;

4.1.12 $B^{PSU} \subseteq B^{NQS}$ designates the subset of buses identifying *pseudo-units*;

4.1.13 $B_r^{REG} \subseteq B$ designates the set of internal buses in *operating reserve* region $r \in ORREG$;

4.1.14 $B_p^{ST} \subseteq B^{PSU}$ designates the subset of buses identifying *pseudo-units* with a share of steam turbine $p \in PST$;

4.1.15 $B^{VG} \subseteq B^{DG}$ designates the subset of buses identifying *dispatchable variable generation resources*;

4.1.16 C designates the set of contingencies that shall be considered in the *security* assessment function;

4.1.17 D designates the set of buses outside Ontario, corresponding to imports and exports at *intertie zones*;

4.1.18 $D_r^{REG} \subseteq D$ designates the set of *intertie zone* buses identifying *boundary entity resources* in *operating reserve* region $r \in ORREG$;

4.1.19 $D_a \subseteq D$ designates the set of all buses identifying *boundary entity resources* in *intertie zone* $a \in A$;

4.1.20 $DI \subseteq D$ designates the subset of *intertie zone* buses identifying *boundary entity resources* that correspond to import *offers*;

4.1.21 $DI_a \subseteq D_a$ designates the subset of *intertie zone* buses identifying *boundary entity resources* that correspond to import *offers* in *intertie zone* $a \in A$;

4.1.22 $DX \subseteq D$ designates the subset of *intertie zone* buses identifying *boundary entity resources* that correspond to export *bids*;

4.1.23 $DX_a \subseteq D_a$ designates the subset of *intertie zone* buses identifying *boundary entity resources* that correspond to export *bids* in *intertie zone* $a \in A$;

4.1.24 F designates the set of *facilities* and groups of *facilities* for which transmission constraints may be identified;

4.1.25 $F_i \subseteq F$ designates the set of *facilities* whose pre-contingency limit was violated in interval *i* as determined by a preceding *security* assessment function iteration;

4.1.26 $F_{i,c} \subseteq F$ designates the set of *facilities* whose post-contingency limit for contingency *c* is violated in interval *i* as determined by a preceding *security* assessment function iteration;

4.1.27 $I = \{1,..,n_I\}$ designates the set of all intervals, where n_I designates the number of five-minute intervals considered within the real-time look-ahead period;

4.1.28 $J_{i,b}^{E}$ designates the set of *bid* laminations for *energy* at $b \in B^{DL}$ for interval $i \in I$;

4.1.29 $J_{i,b}^{10S}$ designates the set of *offer* laminations for synchronized *ten-minute operating reserve* at bus $b \in B^{DL}$ for interval $i \in I$;

4.1.30 $J_{i,b}^{10N}$ designates the set of *offer* laminations for non-synchronized *ten-minute operating reserve* at bus $b \in B^{DL}$ for interval $i \in I$;

4.1.31 $J_{i,b}^{30R}$ designates the set of *offer* laminations for *thirty-minute operating reserve* at bus $b \in B^{DL}$ for interval $i \in I$;

4.1.32 $K_{i,b}^{DF} \subseteq K_{i,b}^{E}$ designates the set of *offer* laminations for *energy* corresponding to the duct firing region of a *pseudo-unit* at bus $b \in B^{PSU}$ in interval $i \in I$;

4.1.33 $K_{i,b}^{DR} \subseteq K_{i,b}^{E}$ designates the set of *offer* laminations for *energy* corresponding to the *dispatchable* region of a *pseudo-unit* at bus $b \in B^{PSU}$ in interval $i \in I$;

4.1.34 $K_{i,b}^{E}$ designates the set of *offer* laminations for *energy* at $b \in B^{NDG} \cup B^{DG}$ for interval $i \in I$;

4.1.35 $K_{i,b}^{MLP} \subseteq K_{i,b}^{E}$ designates the set of *offer* laminations for *energy* corresponding to the *minimum loading point* region of a *pseudo-unit* at bus $b \in B^{PSU}$ in interval $i \in I$;

4.1.36 $K_{i,b}^{10S}$ designates the set of *offer* laminations for synchronized *ten-minute operating reserve* at bus $b \in B^{DG}$ for interval $i \in I$;

4.1.37 $K_{i,b}^{10N}$ designates the set of *offer* laminations for non-synchronized *ten-minute operating reserve* at bus $b \in B^{DG}$ for interval $i \in I$;

4.1.38 $K_{i,b}^{30R}$ designates the set of *offer* laminations for *thirty-minute operating reserve* at bus $b \in B^{DG}$ for interval $i \in I$;

4.1.39 L designates the set of buses where the *locational marginal prices* represent prices for *delivery points* associated with non-*dispatchable* and *dispatchable generation resources*, *dispatchable loads*, *hourly demand response resources*, *price responsive loads* and *non-dispatchable loads;*

4.1.40 $L_m^{VIRT} \subseteq L$ designates the buses contributing to the *virtual zonal price* for *virtual transaction zone* $m \in M$;

4.1.41 $L_y^{NDL} \subseteq L$ designates the buses contributing to the zonal price for *non-dispatchable load* zone $y \in Y$;

4.1.42 M designates the set of *virtual transaction zones*;

4.1.43 PST designates the set of steam turbines *offered* as part of a *pseudo-unit*;

4.1.44 Y designates the *non-dispatchable load* zones in Ontario.

4.2 Market Participant Data Parameters

4.2.1 With respect to a *non-dispatchable generation resource* identified by bus $b \in B^{NDG}$:

4.2.1.1 $FNDG_{i,b}$ designates the fixed quantity of *energy* scheduled for interval $i \in I$;

4.2.1.2 $PNDG_{i,b,k}$ designates the price for the maximum incremental quantity of *energy* in interval $i \in I$ in association with *offer* lamination $k \in K^{E}_{i,b}$; and

4.2.1.3 $QNDG_{i,b,k}$ designates the maximum incremental quantity of *energy* that may be scheduled in interval $i \in I$ in association with *offer* lamination $k \in K^{E}_{i,b}$.

4.2.2 With respect to a *dispatchable generation resource* identified by bus $b \in B^{DG}$:

4.2.2.1 $DRRDG_{i,b,w}$ for $w \in \{1,..,NumRRDG_{i,b}\}$ designates the ramp rate in MW per minute at which the *resource* can decrease the amount of *energy* it supplies in interval $i \in I$ while operating in the range between $RmpRngMaxDG_{i,b,w-1}$ and $RmpRngMaxDG_{i,b,w}$;

4.2.2.2 $NumRRDG_{i,b}$ designates the number of ramp rates provided for interval $i \in I$;

4.2.2.3 $ORRDG_{b}$ designates the maximum *operating reserve* ramp rate in MW per minute;

4.2.2.4 $PDG_{i,b,k}$ designates the price for the maximum incremental quantity of *energy* in interval $i \in I$ in association with *offer* lamination $k \in K^{E}_{i,b}$;

4.2.2.5 $P10SDG_{i,b,k}$ designates the price for the maximum incremental quantity of synchronized *ten-minute operating reserve* in interval $i \in I$ in association with *offer* lamination $k \in K^{10S}_{i,b}$;

4.2.2.6 $P10NDG_{i,b,k}$ designates the price for the maximum incremental quantity of non-synchronized *ten-minute operating reserve* in interval $i \in I$ in association with *offer* lamination $k \in K^{10N}_{i,b}$;

4.2.2.7 $P30RDG_{i,b,k}$ designates the price for the maximum incremental quantity of *thirty-minute operating reserve* in interval $i \in I$ in association with *offer* lamination $k \in K^{30R}_{i,b}$;

4.2.2.8 $QDG_{i,b,k}$ designates the maximum incremental quantity of *energy* above the *minimum loading point* that may be scheduled in interval $i \in I$ in association with *offer* lamination $k \in K^{E}_{i,b}$;

4.2.2.9 $Q10SDG_{i,b,k}$ designates the maximum incremental quantity of synchronized *ten-minute operating reserve* in interval $i \in I$ in association with *offer* lamination $k \in K_{i,b}^{10S}$;

4.2.2.10 $Q10NDG_{i,b,k}$ designates the maximum incremental quantity of non-synchronized *ten-minute operating reserve* in interval $i \in I$ in association with *offer* lamination $k \in K_{i,b}^{10N}$;

4.2.2.11 $Q30RDG_{i,b,k}$ designates the maximum incremental quantity of *thirty-minute operating reserve* in interval $i \in I$ in association with *offer* lamination $k \in K_{i,b}^{30R}$;

4.2.2.12 $RLP30R_{i,b}$ designates the *reserve loading point* for *thirty-minute operating reserve* in interval $i \in I$;

4.2.2.13 $RLP10S_{i,b}$ designates the *reserve loading point* for synchronized *ten-minute operating reserve* in interval $i \in I$;

4.2.2.14 $RmpRngMaxDG_{i,b,w}$ for $w \in \{1,..,NumRRDG_{i,b}\}$ designates the wth ramp rate break point for interval $i \in I$;

4.2.2.15 $URRDG_{i,b,w}$ for $w \in \{1,..,NumRRDG_{i,b}\}$ designates the ramp rate in MW per minute at which the *resource* can increase the amount of *energy* it supplies in interval $i \in I$ while operating in the range between $RmpRngMaxDG_{i,b,w\text{-}1}$ and $RmpRngMaxDG_{i,b,w}$, where $RmpRngMaxDG_{i,b,0}$ shall be equal to zero.

4.2.3 With respect to a *dispatchable non-quick start resource* identified by bus $b \in B^{NQS}$:

4.2.3.1 $MinQDG_b$ designates the *minimum loading point* indicating the minimum output at which the *resource* must be scheduled except for times when the *resource* is starting up or shutting down.

4.2.4 With respect to a *dispatchable* hydroelectric *generation resource* identified by bus $b \in B^{HE}$:

4.2.4.1 $(ForL_{i,b,w}, ForU_{i,b,w})$ for $w \in \{1,..,NFor_{i,b}\}$ designate the lower and upper limits of the *forbidden regions* in interval $i \in I$ and indicate that the *resource* cannot be scheduled between $ForL_{i,b,w}$ and $ForU_{i,b,w}$ for all $w \in \{1,..,NFor_{i,b}\}$.

4.2.5 With respect to a *pseudo-unit* identified by bus $b \in B^{PSU}$:

4.2.5.1 $STShareMLP_b$ designates the steam turbine share of the *minimum loading point* region; and

4.2.5.2 $STShareDR_b$ designates the steam turbine share of the *dispatchable* region.

4.2.6 With respect to a *generation resource* with no *offer* for *energy* identified by bus $b \in B^{NoOffer}$:

4.2.6.1 $FNOG_{i,b}$ designates the fixed quantity of *energy* scheduled for injection for interval $i \in I$ determined by the *IESO*'s *energy* management system.

4.2.7 With respect to a *dispatchable load* identified by bus $b \in B^{DL}$:

4.2.7.1 $DRRDL_{i,b,w}$ for $w \in \{1,..,NumRRDL_{i,b}\}$ designates the ramp rate in MW per minute at which the *dispatchable load* can decrease its amount of *energy* consumption in interval $i \in I$ while operating in the range between $RmpRngMaxDL_{i,b,w-1}$ and $RmpRngMaxDL_{i,b,w}$;

4.2.7.2 $NumRRDL_{i,b}$ designates the number of ramp rates provided for interval $i \in I$;

4.2.7.3 $ORRDL_b$ designates the *operating reserve* ramp rate in MW per minute for reductions in load consumption;

4.2.7.4 $PDL_{i,b,j}$ designates the price for the maximum incremental quantity of *energy* in interval $i \in I$ in association with *bid* lamination $j \in J^E_{i,b}$;

4.2.7.5 $P10NDL_{i,b,j}$ designates the price for the maximum incremental quantity of non-synchronized *ten-minute operating reserve* in interval $i \in I$ in association with *offer* lamination $j \in J^{10N}_{i,b}$;

4.2.7.6 $P10SDL_{i,b,j}$ designates the price for the maximum incremental quantity of synchronized *ten-minute operating reserve* in interval $i \in I$ in association with *offer* lamination $j \in J^{10S}_{i,b}$;

4.2.7.7 $P30RDL_{i,b,j}$ designates the price for the maximum incremental quantity of *thirty-minute operating reserve* in interval $i \in I$ in association with *offer* lamination $j \in J^{30R}_{i,b}$;

4.2.7.8 $QDL_{i,b,j}$ designates the maximum incremental quantity of *energy* that may be scheduled in interval $i \in I$ in association with *bid* lamination $j \in J^E_{i,b}$;

4.2.7.9 $QDLFIRM_{i,b}$ designates the quantity of *energy* that is *bid* at the *maximum market clearing price* in interval $i \in I$;

4.2.7.10 $Q10NDL_{i,b,j}$ designates the maximum incremental quanity of non-synchronized *ten-minute operating reserve* that may be scheduled in interval $i \in I$ in association with *offer* lamination $j \in J^{10N}_{i,b}$;

4.2.7.11 $Q10SDL_{i,b,j}$ designates the maximum incremental quantity of synchronized *ten-minute operating reserve* that may be scheduled in interval $i \in I$ in association with *offer* lamination $j \in J_{i,b}^{10S}$;

4.2.7.12 $Q30RDL_{i,b,j}$ designates the maximum incremental quantity of *thirty-minute operating reserve* that may be scheduled in interval $i \in I$ in association with *offer* lamination $j \in J_{i,b}^{30R}$;

4.2.7.13 $RmpRngMaxDL_{i,b,w}$ for $w \in \{1,..,NumRRDL_{i,b}\}$ designates the w[th] ramp rate break point for interval $i \in I$;

4.2.7.14 $URRDL_{i,b,w}$ for $w \in \{1,..,NumRRDL_{i,b}\}$ designates the ramp rate in MW per minute at which the *dispatchable load* can increase its amount of *energy* consumption in interval $i \in I$ while operating in the range between $RmpRngMaxDL_{i,b,w-1}$ and $RmpRngMaxDL_{i,b,w}$, where $RmpRngMaxDL_{i,b,0}$ shall be equal to zero.

4.2.8 With respect to an *hourly demand response resource* identified by bus $b \in B^{HDR}$:

4.2.8.1 $FHDR_{i,b}$ designates the fixed schedule of *energy* consumption for interval $i \in I$ determined by the activation of the *hourly demand response resource*.

4.2.9 With respect to a *dispatchable load* with no *bid* for *energy* at bus $b \in B^{NoBid}$:

4.2.9.1 $FNBL_{i,b}$ designates the fixed quantity of *energy* scheduled for consumption for interval $i \in I$ determined by the *IESO*'s *energy* management system.

4.2.10 With respect to a *boundary entity resource* import at *intertie zone* bus $d \in DI$, where the *locational marginal price* represents the price for the *intertie metering point* and its fixed schedules are the most recent *interchange schedules*:

4.2.10.1 $FIGPrc_{i,d}$ designates the fixed quantity of *energy* scheduled to import for interval $i \in I$ and used for calculating *locational marginal prices*;

4.2.10.2 $FIGSch_{i,d}$ designates the fixed quantity of *energy* scheduled to import for interval $i \in I$ and used for determining schedules;

4.2.10.3 $F10NIGPrc_{i,d}$ designates the fixed quantity of non-synchronized *ten-minute operating reserve* scheduled for interval $i \in I$ and used for calculating *locational market prices*;

4.2.10.4 $F10NIGSch_{i,d}$ designates the fixed quantity of non-synchronized *ten-minute operating reserve* scheduled for in interval $i \in I$ and used for determining schedules;

4.2.10.5 $F30RIGPrc_{i,d}$ designates the fixed quantity of *thirty-minute operating reserve* scheduled for interval $i \in I$ and used for calculating *locational marginal prices*; and

4.2.10.6 $F30RIGSch_{i,d}$ designates the fixed quantity of *thirty-minute operating reserve* scheduled for interval $i \in I$ and used for determining schedules.

4.2.11 With respect to a *boundary entity resource* export at *intertie zone* bus $d \in DX$, where the *locational marginal price* represents the price for the *intertie metering point* and its fixed schedules are the most recent *interchange schedules*:

4.2.11.1 $FXLPrc_{i,d}$ designates the fixed quantity of *energy* scheduled to export for interval $i \in I$ and used for calculating *locational marginal prices*;

4.2.11.2 $FXLSch_{i,d}$ designates the fixed quantity of *energy* scheduled to export for interval $i \in I$ and used for determining schedules;

4.2.11.3 $F10NXLPrc_{i,d}$ designates the fixed quantity of non-synchronized *ten-minute operating reserve* scheduled for interval $i \in I$ and used for calculating *locational marginal prices*;

4.2.11.4 $F10NXLSch_{i,d}$ designates the fixed quantity of non-synchronized *ten-minute operating reserve* scheduled for interval $i \in I$ and used for determining schedules;

4.2.11.5 $F30RXLPrc_{i,d}$ designates the fixed quantity of *thirty-minute operating reserve* scheduled for interval $i \in I$ and used for calculating *locational marginal prices*; and

4.2.11.6 $F30RXLSch_{i,d}$ designates the fixed quantity of *thirty-minute operating reserve* scheduled for interval $i \in I$ and used for determining schedules.

4.3 IESO Data Parameters

4.3.1 Variable Generation Forecast

4.3.1.1 $FG_{i,b}$ designates the *IESO's* centralized *variable generation* forecast for a *variable generation resource* identified by bus $b \in B^{VG}$ for interval $i \in I$.

4.3.2 Variable Generation Tie-Breaking

4.3.2.1 $NumVG_i$ designates the number of *variable generation resources* in the daily *dispatch* order for interval $i \in I$; and

4.3.2.2 $TBM_{i,b} \in \{1,..,NumVG_i\}$ designates the tie-breaking modifier for the *variable generation resource* at bus $b \in B^{VG}$ for interval $i \in I$.

4.3.3 Operating Reserve Requirements

4.3.3.1 $ORREG$ designates the set of regions for which regional *operating reserve* limits have been defined;

4.3.3.2 $REGMin10R_{i,r}$ designates the minimum requirement for total *ten-minute operating reserve* in region $r \in ORREG$ in interval $i \in I$;

4.3.3.3 $REGMin30R_{i,r}$ designates the minimum requirement for *thirty-minute operating reserve* in region $r \in ORREG$ in interval $i \in I$;

4.3.3.4 $REGMax10R_{i,r}$ designates the maximum amount of total *ten-minute operating reserve* that may be scheduled in region $r \in ORREG$ in interval $i \in I$;

4.3.3.5 $REGMax30R_{i,r}$ designates the maximum amount of *thirty-minute operating reserve* that may be scheduled in region $r \in ORREG$ in interval $i \in I$;

4.3.3.6 $TOT10S_i$ designates the synchronized *ten-minute operating reserve* requirement;

4.3.3.7 $TOT10R_i$ designates the total *ten-minute operating reserve* requirement; and

4.3.3.8 $TOT30R_i$ designates the *thirty-minute operating reserve* requirement.

4.3.4 Resource Minimums and Maximums

4.3.4.1 Where applicable the minimum or maximum output of a *dispatchable generation resource* and minimum or maximum consumption of a *dispatchable load* may be limited due to *reliability* constraints, applicable *contracted ancillary services*, day-ahead operational commitments, pre-dispatch operational commitments, *outages,* derates, *operating reserve* activation, and other constraints, such that:

4.3.4.1.1 $MaxDF_{i,b}$ designates the maximum output limit in interval i for the duct firing region of a *pseudo-unit* at bus $b \in B^{PSU}$;

4.3.4.1.2 $MaxDG_{i,b}$ designates the most restrictive maximum output limit for the *dispatchable generation resource* in interval i at bus $b \in B^{DG}$;

4.3.4.1.3 $MaxDL_{i,b}$ designates the most restrictive maximum consumption limit for the *dispatchable load* in interval i at bus $b \in B^{DL}$;

4.3.4.1.4 $MaxDR_{i,b}$ designates the maximum output limit in interval i for the *dispatchable* region of a *pseudo-unit* at bus $b \in B^{PSU}$;

4.3.4.1.5 $MinDG_{i,b}$ designates the most restrictive minimum output limit for the *dispatchable generation resource* in interval *i* at bus $b \in B^{DG}$; and

4.3.4.1.6 $MinDL_{i,b}$ designates the most restrictive minimum consumption limit for the *dispatchable load* in interval *i* at bus $b \in B^{DL}$.

4.3.5 Control Action Adjustments for Pricing

4.3.5.1 $CAAdj_i$ designates the *demand* adjustment required to calculate *locational marginal prices* appropriately when voltage reduction or load shedding has been implemented.

4.3.6 Constraint Violation Penalties for interval $i \in I$:

4.3.6.1 $(PLdViolSch_{i,w}, QLdViolSch_{i,w})$ for $w \in \{1,..,N_{LdViol_i}\}$ designate the price-quantity segments of the penalty curve for under *generation* used by the Real-Time Scheduling algorithm in section 8;

4.3.6.2 $(PLdViolPrc_{i,w}, QLdViolPrc_{i,w})$ for $w \in \{1,..,N_{LdViol_i}\}$ designate the price-quantity segments of the penalty curve for under *generation* used by the Real-Time Pricing algorithm in section 9;

4.3.6.3 $(PGenViolSch_{i,w}, QGenViolSch_{i,w})$ for $w \in \{1,..,N_{GenViol_i}\}$ designate the price-quantity segments of the penalty curve for over *generation* used by the Real-Time Scheduling algorithm in section 8;

4.3.6.4 $(PGenViolPrc_{i,w}, QGenViolPrc_{i,w})$ for $w \in \{1,..,N_{GenViol_i}\}$ designate the price-quantity segments of the penalty curve for over *generation* used by the Real-Time Pricing algorithm in section 9;

4.3.6.5 $(P10SViolSch_{i,w}, Q10SViolSch_{i,w})$ for $w \in \{1,..,N_{10SViol_i}\}$ designate the price-quantity segments of the penalty curve for the synchronized *ten-minute operating reserve* requirement used by the Real-Time Scheduling algorithm in section 8;

4.3.6.6 $(P10SViolPrc_{i,w}, Q10SViolPrc_{i,w})$ for $w \in \{1,..,N_{10SViol_i}\}$ designate the price-quantity segments of the penalty curve for the synchronized *ten-minute operating reserve* requirement used by the Real-Time Pricing algorithm in section 9;

4.3.6.7 $(P10RViolSch_{i,w}, Q10RViolSch_{i,w})$ for $w \in \{1,..,N_{10RViol_i}\}$ designate the price-quantity segments of the penalty curve for the total *ten-minute operating reserve* requirement used by the Real-Time Scheduling algorithm in section 8;

4.3.6.8 $(P10RViolPrc_{i,w}, Q10RViolPrc_{i,w})$ for $w \in \{1,..,N_{10RViol_i}\}$ designate the price-quantity segments of the penalty curve for the total *ten-minute operating reserve* requirement used by the Real-Time Pricing algorithm in section 9;

4.3.6.9 $(P30RViolSch_{i,w}, Q30RViolSch_{i,w})$ for $w \in \{1,..,N_{30RViol_i}\}$ designate the price-quantity segments of the penalty curve for the total *thirty-minute operating reserve* requirement and, when applicable, the flexibility *operating reserve* requirement used by the Real-Time Scheduling algorithm in section 8;

4.3.6.10 $(P30RViolPrc_{i,w}, Q30RViolPrc_{i,w})$ for $w \in \{1,..,N_{30RViol_i}\}$ designate the price-quantity segments of the penalty curve for the total *thirty-minute operating reserve* requirement and, when applicable, the flexibility *operating reserve* requirement used by the Real-Time Pricing algorithm in section 9;

4.3.6.11 $(PREG10RViolSch_{i,w}, QREG10RViolSch_{i,w})$ for $w \in \{1,..,N_{REG10RViol_i}\}$ designate the price-quantity segments of the penalty curve for area total *ten-minute operating reserve* minimum requirements used by the Real-Time Scheduling algorithm in section 8;

4.3.6.12 $(PREG10RViolPrc_{i,w}, QREG10RViolPrc_{i,w})$ for $w \in \{1,..,N_{REG10RViol_i}\}$ designate the price-quantity segments of the penalty curve for area total *ten-minute operating reserve* minimum requirements used by the Real-Time Pricing algorithm in section 9;

4.3.6.13 $(PREG30RViolSch_{i,w}, QREG30RViolSch_{i,w})$ for $w \in \{1,..,N_{REG30RViol_i}\}$ designate the price-quantity segments of the penalty curve for area *thirty-minute operating reserve* minimum requirements used by the Real-Time Scheduling algorithm in section 8;

4.3.6.14 $(PREG30RViolPrc_{i,w}, QREG30RViolPrc_{i,w})$ for $w \in \{1,..,N_{REG30RViol_i}\}$ designate the price-quantity segments of the penalty curve for area *thirty-minute operating reserve* minimum requirements used by the Real-Time Pricing algorithm in section 9;

4.3.6.15 $(PXREG10RViolSch_{i,w}, QXREG10RViolSch_{i,w})$ for $w \in \{1,..,N_{XREG10RViol_i}\}$ designate the price-quantity segments of the penalty curve for area total *ten-minute operating reserve* maximum restrictions used by the Real-Time Scheduling algorithm in section 8;

4.3.6.16 $(PXREG10RViolPrc_{i,w}, QXREG10RViolPrc_{i,w})$ for $w \in \{1,..,N_{XREG10RViol_i}\}$ designate the price-quantity segments of the penalty curve for area total *ten-minute operating reserve* maximum restrictions used by the Real-Time Pricing algorithm in section 9;

4.3.6.17 $(PXREG30RViolSch_{i,w}, QXREG30RViolSch_{i,w})$ for $w \in \{1,..,N_{XREG30RViol_i}\}$ designate the price-quantity segments of the penalty curve for area total *thirty-minute operating reserve* maximum restrictions used by the Real-Time Scheduling algorithm in section 8;

4.3.6.18 $(PXREG30RViolPrc_{i,w}, QXREG30RViolPrc_{i,w})$ for $w \in \{1,..,N_{XREG30RViol_i}\}$ designate the price-quantity segments of the penalty curve for area total *thirty-minute operating reserve* maximum restrictions used by the Real-Time Pricing algorithm in section 9;

4.3.6.19 $(PPreITLViolSch_{f,i,w}, QPreITLViolSch_{f,i,w})$ for $w \in \{1,..,N_{PreITLViol_{f,i}}\}$ designate the price-quantity segments of the penalty curve for exceeding the pre-contingency limit of the transmission constraint for *facility* $f \in F$ used by the Real-Time Scheduling algorithm in section 8;

4.3.6.20 $(PPreITLViolPrc_{f,i,w}, QPreITLViolPrc_{f,i,w})$ for $w \in \{1,..,N_{PreITLViol_{f,i}}\}$ designate the price-quantity segments of the penalty curve for exceeding the pre-contingency limit of the transmission constraint for *facility* $f \in F$ used by the Real-Time Pricing algorithm in section 9;

4.3.6.21 $(PITLViolSch_{c,f,i,w}, QITLViolSch_{c,f,i,w})$ for $w \in \{1,..,N_{ITLViol_{c,f,i}}\}$ designate the price-quantity segments of the penalty curve for exceeding the contingency $c \in C$ post-contingency limit of the transmission constraint for *facility* $f \in F$ used by the Real-Time Scheduling algorithm in section 8;

4.3.6.22 $(PITLViolPrc_{c,f,i,w}, QITLViolPrc_{c,f,i,w})$ for $w \in \{1,..,N_{ITLViol_{c,f,i}}\}$ designate the price-quantity segments of the penalty curve for exceeding the contingency $c \in C$ post-contingency limit of the transmission constraint for *facility* $f \in F$ used by the Real-Time Pricing algorithm in section 9; and

4.3.6.23 $NISLPen$ designates the net interchange scheduling limit constraint violation penalty price for *locational marginal pricing*.

4.3.7 Price Bounds

4.3.7.1 $EngyPrcCeil$ designates and is equal to the *maximum market clearing price* for *energy*;

4.3.7.2 $EngyPrcFlr$ designates and is equal to the *settlement floor price* for *energy*;

4.3.7.3 $ORPrcCeil$ designates and is equal to the *maximum operating reserve price* for all classes of *operating reserve*; and

4.3.7.4 $ORPrcFlr$ designates the minimum price for all classes of *operating reserve* and is equal to $0/MW.

4.3.8 Weighting Factors for Zonal Prices

4.3.8.1 $WF_{i,m,b}^{VIRT}$ designates the weighting factor for bus $b \in L_m^{VIRT}$ used to calculate the price for *virtual transaction zone* $m \in M$ for interval $i \in I$ and shall be equal to the weighting factor used in the *day-ahead market* for the applicable hour;

4.3.8.2 $WF_{i,y,b}^{NDL}$ designates the weighting factor for bus $b \in L_y^{NDL}$ used to calculate the price for *non-dispatchable load* zone $y \in Y$ for interval $i \in I$ and shall be obtained by renormalizing the load distribution factors so that the sum of weighting factors for a *non-dispatchable load* zone and for a given interval is one.

4.4 Other Data Parameters

4.4.1 Non-Dispatchable Demand Forecast

4.4.1.1 FL_i designates the five-minute province-wide non-*dispatchable demand* forecast for interval $i \in I$ calculated by the *security* assessment function.

4.4.2 Internal Transmission Constraints

4.4.2.1 $PreConSF_{i,f,b}$ designates the pre-contingency sensitivity factor for bus $b \in B \cup D$ indicating the fraction of *energy* injected at bus b which flows on *facility* f during interval i under pre-contingency conditions;

4.4.2.2 $AdjNormMaxFlow_{i,f}$ designates the limit corresponding to the maximum flow allowed on *facility* f in interval i under pre-contingency conditions;

4.4.2.3 $SF_{i,c,f,b}$ designates the post-contingency sensitivity factor for bus $b \in B \cup D$ indicating the fraction of *energy* injected at bus b which flows on *facility* f during interval i under post-contingency conditions for contingency c; and

4.4.2.4 $AdjEmMaxFlow_{i,c,f}$ designates the limit corresponding to the maximum flow allowed on *facility* f in interval i under post-contingency conditions for contingency c.

4.4.3 Transmission Losses

4.4.3.1 $LossAdj_i$ designates any adjustment needed for interval $i \in I$ to correct for any discrepancy between Ontario total system losses calculated using a base case power flow from the *security* assessment function and linearized losses that would be calculated using the marginal loss factors; and

4.4.3.2 $MglLoss_{i,b}$ designates the marginal loss factor and represents the marginal impact on transmission losses resulting from transmitting *energy* from the *reference bus* to serve an increment of additional load at *resource* bus $b \in B \cup D$ in interval $i \in I$.

5 Initialization

5.1 Purpose

5.1.1 The initialization processes set out in this section shall occur prior to the execution of the *real-time calculation engine* described in section 2.2.1 above.

5.2 Reference Bus

5.2.1 The *IESO* shall use Richview Transformer Station as the *real-time calculation engine's* default *reference bus* for the calculation of *locational marginal prices*.

5.2.2 If the default *reference bus* is out of service, another in-service bus shall be selected.

5.3 Islanding Conditions

5.3.1 In the event of a network split, the *real-time calculation engine* shall:

5.3.1.1 only evaluate *resources* that are within the *main island*;

5.3.1.2 use only forecasts of *demand* forecast areas in the *main island*; and

5.3.1.3 use a bus within the *main island* in place of the *reference bus* if the *reference bus* does not fall within the *main island*.

5.4 Variable Generation Tie-Breaking

5.4.1 For each interval $i \in I$, each *variable generation resource* bus $b \in B^{VG}$ and each *offer* lamination $k \in K^E_{i,b}$, the *offer* price $PDG_{i,b,k}$ shall be updated to $PDG_{i,b,k}$- $\left(\frac{TBM_{i,b}}{NumVG_i}\right)\rho$, where ρ is a small nominal value of order 10^{-4}.

5.5 Pseudo-Unit Constraints

5.5.1 Constraints for *pseudo-units* corresponding to the minimum and maximum constraints on physical *resources* shall be determined in accordance with section 10.

5.6 Initial Scheduling Assumptions

5.6.1 Initial Schedules

5.6.1.1 Initial *energy* schedules shall be based on the values deteremined by the *IESO's energy* management system and the schedules from the previous *real-time calculation engine* run, where:

5.6.1.1.1 $RTDLTel_{-1,b}$ designates the *energy* management system MW value for the *dispatchable load* at bus $b \in B^{DL}$;

5.6.1.1.2 $SDLSch_{0,b}^{Prev}$ designates the schedule determined for the *dispatchable load* at bus $b \in B^{DL}$ by the Real-Time Scheduling algorithm in section 8, of the previous *real-time calculation engine* run;

5.6.1.1.3 $RTDGTel_{-1,b}$ designates the *energy* management system MW value for the *dispatchable generation resource* at bus $b \in B^{DG}$;

5.6.1.1.4 $SDGSch_{0,b}^{Prev}$ designates the schedule determined for the *dispatchable generation resource* at bus $b \in B^{DG}$ by the Real-Time Scheduling algorithm in section 8, of the previous *real-time calculation engine* run;

5.6.1.1.5 $SDLPrc_{0,b}^{Prev}$ designates the schedule determined for the *dispatchable load* at bus $b \in B^{DL}$ by the Real-Time Pricing algorithm in section 9, of the previous *real-time calculation engine* run; and

5.6.1.1.6 $SDGPrc_{0,b}^{Prev}$ designates the schedule determined for the *dispatchable generation resource* at bus $b \in B^{DG}$ by the Real-Time Pricing algorithm in section 9, of the previous *real-time calculation engine* run.

5.6.1.2 For the *dispatchable load* at bus b, the intitial schedule, $SDLInitSch_{0,b}$, for the Real-Time Scheduling algorithm in section 8, shall be determined as follows:

5.6.1.2.1 Step 1: Calculate $TelUp_{0,b}$ using the submitted up ramp rates and break points to determine the maximum consumption level the *dispatchable load* can achieve in five minutes from $RTDLTel_{-1,b}$;

5.6.1.2.2 Step 2: Calculate $TelDown_{0,b}$ using the submitted down ramp rates and break points to determine the minimum consumption level the *dispatchable load* can achieve in five minutes from $RTDLTel_{-1,b}$; and

5.6.1.2.3 Step 3: If the schedule from the previous *real-time calculation engine* run is achievable by ramping from the $RTDLTel_{-1,b}$, then set the initial schedule to the schedule from the previous *real-time calculation engine* run. Otherwise, set the initial schedule to the nearest boundary:

If $TelDown_{0,b} \leq SDLSch_{0,b}^{Prev} \leq TelUp_{0,b}$, then set $SDLInitSch_{0,b} = SDLSch_{0,b}^{Prev}$

If $SDLSch_{0,b}^{Prev} < TelDown_{0,b}$, then set $SDLInitSch_{0,b} = TelDown_{0,b}$

Otherwise, set $SDLInitSch_{0,b} = TelUp_{0,b}$.

5.6.1.3 For the *dispatchable generation resource* at bus b, the intitial schedule, $SDGInitSch_{0,b}$, for the Real-Time Scheduling algorithm in section 8, shall be determined as follows:

5.6.1.3.1 Step 1: Calculate $TelUp_{0,b}$ using the submitted up ramp rates and break points to determine the maximum production level the *resource* can achieve in five minutes from $RTDGTel_{-1,b}$;

5.6.1.3.2 Step 2: Calculate $TelDown_{0,b}$ using the submitted down ramp rates and break points to determine the minimum production level the *resource* can achieve in five minutes from $RTDGTel_{-1,b}$; and

5.6.1.3.3 Step 3: If the schedule from the previous *real-time calculation engine* run is achievable by ramping from the $RTDGTel_{-1,b}$, then set the initial schedule to the schedule from the previous *real-time calculation engine* run. Otherwise, set the initial schedule to the nearest boundary:

If $TelDown_{0,b} \leq SDGSch_{0,b}^{Prev} \leq TelUp_{0,b}$ then set $SDGInitSch_{0,b} = SDGSch_{0,b}^{Prev}$

If $SDGSch_{0,b}^{Prev} < TelDown_{0,b}$ then set $SDGInitSch_{0,b} = TelDown_{0,b}$

Otherwise, set $SDGInitSch_{0,b} = TelUp_{0,b}$.

5.6.1.4 For the *dispatchable load* at bus b, the intitial schedule, $SDLInitPrc_{0,b}$, for the Real-Time Pricing algorithm in section 9, shall be determined as follows:

If $SDLSch_{0,b}^{Prev} \leq SDLPrc_{0,b}^{Prev} \leq SDLInitSch_{0,b}$ or $SDLInitSch_{0,b} \leq SDLPrc_{0,b}^{Prev} \leq SDLSch_{0,b}^{Prev}$, then set $SDLInitPrc_{0,b} = SDLInitSch_{0,b}$;

Otherwise set $SDLInitPrc_{0,b} = SDLPrc_{0,b}^{Prev}$.

5.6.1.5 For the *dispatchable generation* at bus *b*, the intitial schedule $SDGInitPrc_{0,b}$, for the Real-Time Pricing algorithm in section 9, designates the initial schedule for the *dispatchable generation resource* at bus *b* and is determined as follows:

If $SDGSch_{0,b}^{Prev} \leq SDGPrc_{0,b}^{Prev} \leq SDGInitSch_{0,b}$ or $SDGInitSch_{0,b} \leq SDGPrc_{0,b}^{Prev} \leq SDGSch_{0,b}^{Prev}$ then set $SDGInitPrc_{0,b} = SDGInitSch_{0,b}$;

Otherwise set $SDGInitPrc_{0,b} = SDGPrc_{0,b}^{Prev}$.

5.6.2 Start-up and Shutdown for Non-Quick Start Resources

5.6.2.1 The start-up and shutdown for *non-quick start resources* at bus $b \in B^{NQS}$ and interval $i \in I$ shall be based on the following parameters that are determined based on observed *resource* operation as well as confirmed start-up and shutdown times:

5.6.2.1.1 $AtZero_{i,b} \in \{0,1\}$, which designates that the *resource* is scheduled to be offline;

5.6.2.1.2 $SU_{i,b} \in \{0,1\}$, which designates that the *resource* must be scheduled on its start-up trajectory. This input may indicate an upcoming confirmed start-up or that the *resource* has started ramping up already;

5.6.2.1.3 $AtMLP_{i,b} \in \{0,1\}$, which designates that the *resource* is scheduled to operate at or above its *minimum loading point* due to a minimum generation constraint or the *resource* shutdown has yet to be confirmed by the *IESO*;

5.6.2.1.4 $EvalSD_{i,b} \in \{0,1\}$, which designates that the *resource* has been de-committed by the *pre-dispatch calculation engine*, such de-commitment has been confirmed by the *IESO,* and the *resource* can be evaluated for *energy* schedules below its *minimum loading point* but can still be scheduled at or above its *minimum loading point*; and

5.6.2.1.5 $SD_{i,b} \in \{0,1\}$, which designates that the *resource* must be scheduled on its shutdown trajectory. This input may indicate an upcoming mandatory shutdown or that the *resource* has already started ramping down.

5.6.2.2 For all parameters in section 5.6.2.1:

$$AtZero_{i,b} + SU_{i,b} + AtMLP_{i,b} + EvalSD_{i,b} + SD_{i,b} = 1.$$

6 Security Assessment Function in the Real-Time Calculation Engine

6.1 Interaction between the Security Assessment Function and Optimization Functions

6.1.1 The scheduling and pricing algorithms of the *real-time calculation engine* pass shall perform multiple iterations of the optimization functions and the *security* assessment function to check for violations of monitored thermal limits and operating *security limits* using the schedules produced by the optimization functions.

6.1.2 As multiple iterations are performed, the transmission constraints produced by the *security* assessment function shall be used by the optimization functions.

6.1.3 The *security* assessment function shall use the physical *resource* representation of combined cycle *facilities* that are registered as *pseudo-units*.

6.2 Inputs into the Security Assessment Function

6.2.1 The *security* assessment function shall use the following inputs:

6.2.1.1 the *IESO demand* forecasts; and

6.2.1.2 applicable *IESO-controlled grid* information pursuant to section 3A.1 of Chapter 7.

6.2.2 The *security* assessment function shall also use the following outputs of the optimization functions:

6.2.2.1 the schedules for *dispatchable loads* and *hourly demand response resources*;

6.2.2.2 the schedules for *non-dispatchable generation resources* and *dispatchable generation resources*; and

6.2.2.3 the schedules for *boundary entity resources* at each *intertie* zone.

6.3 Security Assessment Function Processing

6.3.1 The *security* assessment function shall determine the province-wide non-*dispatchable demand* forecast quantity, FL_i, using *demand* forecasts for *demand* forecast areas, the *IESO's energy* management system MW quantities and the scheduled quantities from the previous *real-time calculation engine* run as follows:

6.3.1.1 sum the *IESO* five-minute *demand* forecasts for *demand* forecast areas;

6.3.1.2 subtract the expected consumption of all physical *hourly demand response resources*;

6.3.1.3 subtract the expected consumption of all virtual *hourly demand response resources*; and

6.3.1.4 subtract the expected consumption of all *dispatchable loads*.

6.3.2 The *security* assessment function shall perform the following calculations and analyses:

6.3.2.1 A base case solution function shall prepare a power flow solution for each interval in the real-time look-ahead period. The base case solution function shall select the power system model state applicable to the forecast of conditions for the interval and input schedules.

6.3.2.2 The base case solution function shall use an AC power flow analysis. If the AC power flow analysis fails to converge, the base case solution function shall use a non-linear DC power flow analysis. If the non-linear DC power flow analysis fails to converge, the base case solution function shall use a linear DC power flow analysis.

6.3.2.3 If the AC or non-linear DC power flow analysis converges, continuous thermal limits for all monitored equipment and operating *security limits* shall be monitored to check for pre-contingency limit violations.

6.3.2.4 Violated pre-contingency limits shall be linearized using pre-contingency sensitivity factors and incorporated as constraints for use by the optimization functions.

6.3.2.5 If the linear DC power flow analysis is used, the pre-contingency *security* assessment may develop linear constraints to facilitate the convergence of the AC or non-linear DC power flow analysis in the subsequent iterations.

6.3.2.6 A linear power flow analysis shall be used to simulate contingencies, calculate post-contingency flows and check all monitored equipment for limited-time thermal limit violations.

6.3.2.7 Violated post-contingency limits shall be linearized using post-contingency sensitivity factors and incorporated as constraints for use by the optimization functions.

6.3.2.8 The base case solution shall be used to calculate Ontario *transmission system* losses, marginal loss factors and loss adjustment for each interval. The impact of losses on branches between the *resource* bus and the *resource connection point* to the *IESO-controlled grid* and losses on branches outside Ontario shall be excluded when determining marginal loss factors.

6.3.2.9 The *real-time calculation engine* shall use a set of fixed marginal loss factors for each *dispatch hour*. The same set of fixed marginal loss factors shall apply to all five-minute intervals that fall in the *dispatch hour*. The set of fixed marginal loss factors for each *dispatch hour* shall be determined based on the marginal loss factors calculated in the previous hour by the Real-Time Scheduling algorithm in section 8 of the *real-time calculation engine*.

6.3.2.10 The marginal loss factors for the advisory intervals that fall in the hour following the *dispatch hour* shall be determined based on the fixed marginal loss factors for the *dispatch hour* described in section 6.3.2.9 and the marginal loss factors calculated by the Real-Time Scheduling algorithm in section 8 of the previous *real-time calculation engine* run.

6.3.2.11 The Real-Time Scheduling and Real-Time Pricing algorithms in sections 8 and 9, respectively, shall use the same set of marginal loss factors.

6.4 Outputs from the Security Assessment Function

6.4.1 The outputs of the *security* assessment function used in the optimization functions include the following:

6.4.1.1 a set of linearized constraints for all violated pre-contingency and post-contingency limits for each interval. The sensitivities and limits associated with the constraints shall be those provided by the most recent *security* assessment function iteration;

6.4.1.2 pre-contingency and post-contingency sensitivity factors for each interval;

6.4.1.3 the marginal loss factors as described in sections 6.3.2.8 – 6.3.2.11; and

6.4.1.4 loss adjustment quantity for each interval.

7 Pass 1: Real-Time Scheduling and Pricing

7.1.1 Pass 1 shall use *market participant* and *IESO* inputs and *resource* and system constraints to determine a set of *resource* schedules and *locational marginal prices*. Pass 1 shall consist of the following algorithms:

- the Real-Time Scheduling algorithm described in section 8;
- the Real-Time Pricing algorithm described in section 9;

8 Real-Time Scheduling

8.1 Purpose

8.1.1 The Real-Time Scheduling algorithm shall perform a *security*-constrained economic *dispatch* to maximize gains from trade using *dispatch data* submitted by *registered market participants* or where applicable, the *reference level values* for *financial dispatch data parameters* mitigated in previous *pre-dispatch calculation engine* runs in accordance with Appendix 7.2A, section 14.7, to meet the *IESO's* province-wide non-*dispatchable demand* forecast and *IESO*-specified *operating reserve* requirements for each interval of the real-time look-ahead period.

8.2 Information, Sets, Indices and Parameters

8.2.1 Information, sets, indices and parameters used by Real-Time Scheduling algorithm are described in sections 3 and 4.

8.3 Variables and Objective Function

8.3.1 The Real-Time Scheduling algorithm shall solve for the following variables:

8.3.1.1 $SDL_{i,b,j}$, which designates the amount of *energy* that a *dispatchable load* scheduled at bus $b \in B^{DL}$ in interval $i \in I$ in association with lamination $j \in J^{E}_{i,b}$;

8.3.1.2 $S10SDL_{i,b,j}$, which designates the amount of synchronized *ten-minute operating reserve* that a *dispatchable load* is scheduled to provide at bus $b \in B^{DL}$ in interval $i \in I$ in association with lamination $j \in J^{10S}_{i,b}$;

8.3.1.3 $S10NDL_{i,b,j}$, which designates the amount of non-synchronized *ten-minute operating reserve* that a *dispatchable load* is scheduled to provide at bus $b \in B^{DL}$ in interval $i \in I$ in association with lamination $j \in J_{i,b}^{10N}$;

8.3.1.4 $S30RDL_{i,b,j}$, which designates the amount of *thirty-minute operating reserve* that a *dispatchable load* is scheduled to provide at bus $b \in B^{DL}$ in interval $i \in I$ in association with lamination $j \in J_{i,b}^{30R}$;

8.3.1.5 $SNDG_{i,b,k}$, which designates the amount of *energy* that a *non-dispatchable generation resource* scheduled at bus $b \in B^{NDG}$ in interval $i \in I$ in association with lamination $k \in K_{i,b}^{E}$;

8.3.1.6 $SDG_{i,b,k}$, which designates the amount of *energy* that a *dispatchable generation resource* is scheduled at bus $b \in B^{DG}$ in interval $i \in I$ in association with lamination $k \in K_{i,b}^{E}$;

8.3.1.7 $S10SDG_{i,b,k}$, which designates the amount of synchronized *ten-minute operating reserve* that a *dispatchable generation resource* is scheduled to provide at bus $b \in B^{DG}$ in interval $i \in I$ in association with lamination $k \in K_{i,b}^{10S}$;

8.3.1.8 $S10NDG_{i,b,k}$, which designates the amount of non-synchronized *ten-minute operating reserve* that a *dispatchable generation resource* is scheduled to provide at bus $b \in B^{DG}$ in interval $i \in I$ in association with lamination $k \in K_{i,b}^{10N}$;

8.3.1.9 $S30RDG_{i,b,k}$, which designates the amount of *thirty-minute operating reserve* that a *dispatchable generation resource* is scheduled to provide at bus $b \in B^{DG}$ in interval $i \in I$ in association with lamination $k \in K_{i,b}^{30R}$;

8.3.1.10 $SCT_{i,b}$, which designates the schedule of the combustion turbine associated with the *pseudo-unit* at bus $b \in B^{PSU}$ in interval $i \in I$;

8.3.1.11 $SST_{i,p}$, which designates the schedule of steam turbine $p \in PST$ in interval $i \in I$;

8.3.1.12 TB_i, which designates any adjustment to the objective function to facilitate pro-rata tie-breaking in interval $i \in I$, as described in section 8.3.2.1; and

8.3.1.13 $ViolCost_i$, which designates the cost incurred in order to avoid having the schedules violate constraints for interval $i \in I$, as described in section 8.3.2.3.

8.3.2 The objective function for the Real-Time Scheduling algorithm shall maximize gains from trade by maximizing the following expression:

$$\sum_{i=1..n_I} (ObjDL_i - ObjNDG_i - ObjDG_i - TB_i - ViolCost_i)$$

where:

$$ObjDL_i = \sum_{b \in B^{DL}} \left(\begin{array}{c} \sum_{j \in J_{i,b}^{E}} SDL_{i,b,j} \cdot PDL_{i,b,j} - \sum_{j \in J_{i,b}^{10S}} S10SDL_{i,b,j} \cdot P10SDL_{i,b,j} - \\ \sum_{j \in J_{i,b}^{10N}} S10NDL_{i,b,j} \cdot P10NDL_{i,b,j} - \sum_{j \in J_{i,b}^{30R}} S30RDL_{i,b,j} \cdot P30RDL_{i,b,j} \end{array} \right);$$

$$ObjNDG_i = \sum_{b \in B^{NDG}} \left(\sum_{k \in K_{i,b}^{E}} SNDG_{i,b,k} \cdot PNDG_{i,b,k} \right);$$

and

$$ObjDG_i = \sum_{b \in B^{DG}} \left(\begin{array}{c} \sum_{k \in K_{i,b}^{E}} SDG_{i,b,k} \cdot PDG_{i,b,k} + \sum_{k \in K_{i,b}^{10S}} S10SDG_{i,b,k} \cdot P10SDG_{i,b,k} + \\ \sum_{k \in K_{i,b}^{10N}} S10NDG_{i,b,k} \cdot P10NDG_{i,b,k} + \sum_{k \in K_{i,b}^{30R}} S30RDG_{i,b,k} \cdot P30RDG_{i,b,k} \end{array} \right).$$

8.3.2.1 The tie-breaking term (TB_i) shall sum a term for each *bid* or *offer* lamination. For each lamination, this term shall be the product of a small penalty cost and the quantity of the lamination scheduled. The penalty cost shall be calculated by multiplying a base penalty cost of *TBPen* by the amount of the lamination scheduled and then dividing by the maximum amount that could have been scheduled. That is:

$$TB_i = TBDL_i + TBNDG_i + TBDG_i$$

where:

$$TBDL_i = \sum_{b \in B^{DL}} \left(\begin{array}{c} \sum_{j \in J_{i,b}^{E}} \left(\frac{(SDL_{i,b,j})^2 \cdot TBPen}{QDL_{i,b,j}} \right) + \sum_{j \in J_{i,b}^{10S}} \left(\frac{(S10SDL_{i,b,j})^2 \cdot TBPen}{Q10SDL_{i,b,j}} \right) + \\ \sum_{j \in J_{i,b}^{10N}} \left(\frac{(S10NDL_{i,b,j})^2 \cdot TBPen}{Q10NDL_{i,b,j}} \right) + \sum_{j \in J_{i,b}^{30R}} \left(\frac{(S30RDL_{i,b,j})^2 \cdot TBPen}{Q30RDL_{i,b,j}} \right) \end{array} \right);$$

$$TBNDG_i = \sum_{b \in B^{NDG}} \left(\sum_{k \in K_{i,b}^{E}} \left(\frac{\left(SNDG_{i,b,k}\right)^2 \cdot TBPen}{QNDG_{i,b,k}} \right) \right);$$

and

$$TBDG_i = \sum_{b \in B^{DG}} \left(\begin{array}{c} \sum_{k \in K_{i,b}^{E}} \left(\frac{\left(SDG_{i,b,k}\right)^2 \cdot TBPen}{QDG_{i,b,k}} \right) + \sum_{k \in K_{i,b}^{10S}} \left(\frac{\left(S10SDG_{i,b,k}\right)^2 \cdot TBPen}{Q10SDG_{i,b,k}} \right) + \\ \sum_{k \in K_{i,b}^{10N}} \left(\frac{\left(S10NDG_{i,b,k}\right)^2 \cdot TBPen}{Q10NDG_{i,b,k}} \right) + \sum_{k \in K_{i,b}^{30R}} \left(\frac{\left(S30RDG_{i,b,k}\right)^2 \cdot TBPen}{Q30RDG_{i,b,k}} \right) \end{array} \right).$$

8.3.2.2 $ViolCost_i$ shall be calculated for interval $i \in I$ using the following variables:

8.3.2.2.1 $SLdViol_{i,w}$, which designates the violation variable affiliated with segment $w \in \{1,..,N_{LdViol_i}\}$ of the penalty curve for the *energy* balance constraint allowing under-generation;

8.3.2.2.2 $SGenViol_{i,w}$, which designates the violation variable affiliated with segment $w \in \{1,..,N_{GenViol_i}\}$ of the penalty curve for the *energy* balance constraint allowing over-generation;

8.3.2.2.3 $S10SViol_{i,w}$, which designates the violation variable affiliated with segment $w \in \{1,..,N_{10SViol_i}\}$ of the penalty curve for the synchronized *ten-minute operating reserve* requirement;

8.3.2.2.4 $S10RViol_{i,w}$, which designates the violation variable affiliated with segment $w \in \{1,..,N_{10RViol_i}\}$ of the penalty curve for the total *ten-minute operating reserve* requirement;

8.3.2.2.5 $S30RViol_{i,w}$, which designates the violation variable affiliated with segment $w \in \{1,..,N_{30RViol_i}\}$ of the penalty curve for the *thirty-minute operating reserve* requirement and, when applicable, the flexibility *operating reserve* requirement;

8.3.2.2.6 $SREG10RViol_{r,i,w}$, which designates the violation variable affiliated with segment $w \in \{1,..,N_{REG10RViol_i}\}$ of the penalty curve for violating the area total *ten-minute operating reserve* minimum requirement in region $r \in ORREG$;

8.3.2.2.7 $SREG30RViol_{r,i,w}$, which designates the violation variable affiliated with segment $w \in \{1,..,N_{REG30RViol_i}\}$ of the penalty curve for violating the area *thirty-minute operating reserve* minimum requirement in region $r \in ORREG$;

8.3.2.2.8 $SXREG10RViol_{r,i,w}$, which designates the violation variable affiliated with segment $w \in \{1,..,N_{XREG10RViol_i}\}$ of the penalty curve for violating the area total *ten-minute operating reserve* maximum restriction in region $r \in ORREG$;

8.3.2.2.9 $SXREG30RViol_{r,i,w}$, which designates the violation variable affiliated with segment $w \in \{1,..,N_{XREG30RViol_i}\}$ of the penalty curve for violating the area *thirty-minute operating reserve* maximum restriction in region $r \in ORREG$;

8.3.2.2.10 $SPreITLViol_{f,i,w}$, which designates the violation variable affiliated with segment $w \in \{1,..,N_{PreITLViol_{f,i}}\}$ of the penalty curve for violating the pre-contingency transmission limit for *facility* $f \in F$; and

8.3.2.2.11 $SITLViol_{c,f,i,w}$, which designates the violation variable affiliated with segment $w \in \{1,..,N_{ITLViol_{c,f,i}}\}$ of the penalty curve for violating the post-contingency transmission limit for *facility* $f \in F$ and contingency $c \in C$.

8.3.2.3 $ViolCost_i$ shall be calculated as follows:

$$
\begin{aligned}
ViolCost_i = & \sum_{w=1..N_{LdViol_i}} SLdViol_{i,w} \cdot PLdViolSch_{i,w} \\
& - \sum_{w=1..N_{GenViol_i}} SGenViol_{i,w} \cdot PGenViolSch_{i,w} \\
& + \sum_{w=1..N_{10SViol_i}} S10SViol_{i,w} \cdot P10SViolSch_{i,w} \\
& + \sum_{w=1..N_{10RViol_i}} S10RViol_{i,w} \cdot P10RViolSch_{i,w} \\
& + \sum_{w=1..N_{30RViol_i}} S30RViol_{i,w} \cdot P30RViolSch_{i,w} \\
& + \sum_{r \in ORREG} \left(\sum_{w=1..N_{REG10RViol_i}} SREG10RViol_{r,i,w} \cdot PREG10RViolSch_{i,w} \right) \\
& + \sum_{r \in ORREG} \left(\sum_{w=1..N_{REG30RViol_i}} SREG30RViol_{r,i,w} \cdot PREG30RViolSch_{i,w} \right) \\
& + \sum_{r \in ORREG} \left(\sum_{w=1..N_{XREG10RViol_i}} SXREG10RViol_{r,i,w} \cdot PXREG10RViolSch_{i,w} \right) \\
& + \sum_{r \in ORREG} \left(\sum_{w=1..N_{XREG30RViol_i}} SXREG30RViol_{r,i,w} \cdot PXREG30RViolSch_{i,w} \right) \\
& + \sum_{f \in F_i} \left(\sum_{w=1..N_{PreITLViol_{f,i}}} SPreITLViol_{f,i,w} \cdot PPreITLViolSch_{f,i,w} \right) \\
& + \sum_{c \in C} \sum_{f \in F_{i,c}} \left(\sum_{w=1..N_{ITLViol_{c,f,i}}} SITLViol_{c,f,i,w} \cdot PITLViolSch_{c,f,i,w} \right).
\end{aligned}
$$

8.4 Constraints

8.4.1 The Real-Time Scheduling algorithm optimization function shall apply the constraints described in sections 8.5 – 8.7.

8.5 Dispatch Data Constraints Applying to Individual Intervals

8.5.1 Scheduling Variable Bounds

8.5.1.1 No schedule shall be negative, nor shall any schedule exceed the quantity *offered* for *energy* and *operating reserve* respectively. Therefore:

$0 \leq SDL_{i,b,j} \leq QDL_{i,b,j}$ for all $b \in B^{DL}$, $j \in J^{E}_{i,b}$;

$0 \leq S10SDL_{i,b,j} \leq Q10SDL_{i,b,j}$ for all $b \in B^{DL}$, $j \in J^{10S}_{i,b}$;

$0 \leq S10NDL_{i,b,j} \leq Q10NDL_{i,b,j}$ for all $b \in B^{DL}$, $j \in J^{10N}_{i,b}$;

$0 \leq S30RDL_{i,b,j} \leq Q30RDL_{i,b,j}$ for all $b \in B^{DL}$, $j \in J^{30R}_{i,b}$;

$0 \leq SNDG_{i,b,k} \leq QNDG_{i,b,k}$ for all $b \in B^{NDG}$, $k \in K^{E}_{i,b}$;

$0 \leq SDG_{i,b,k} \leq QDG_{i,b,k}$ for all $b \in B^{DG}$, $k \in K^{E}_{i,b}$;

$0 \leq S10SDG_{i,b,k} \leq Q10SDG_{i,b,k}$ for all $b \in B^{DG}$, $k \in K^{10S}_{i,b}$;

$0 \leq S10NDG_{i,b,k} \leq Q10NDG_{i,b,k}$ for all $b \in B^{DG}$, $k \in K^{10N}_{i,b}$; and

$0 \leq S30RDG_{i,b,k} \leq Q30RDG_{i,b,k}$ for all $b \in B^{DG}$, $k \in K^{30R}_{I,b}$

for all intervals $i \in I$.

8.5.1.2 A *non-quick start resource* cannot provide *energy* when it is scheduled to be offline. Therefore, for all intervals $i \in I$, *non-quick start resource* buses $b \in B^{NQS}$, and *offer* laminations $k \in K^{E}_{i,b}$:

$$0 \leq SDG_{i,b,k} \leq \left(1 - AtZero_{i,b}\right) \cdot QDG_{i,b,k}.$$

8.5.1.3 A *non-quick start resource* cannot provide *operating reserve* unless it is scheduled at or above its *minimum loading point*. Therefore, for all intervals $i \in I$ and *non-quick start resource* buses $b \in B^{NQS}$:

$0 \leq S10SDG_{i,b,k} \leq (AtMLP_{i,b} + EvalSD_{i,b}) \cdot Q10SDG_{i,b,k}$ for all $k \in K^{10S}_{i,b}$;

$0 \leq S10NDG_{i,b,k} \leq (AtMLP_{i,b} + EvalSD_{i,b}) \cdot Q10NDG_{i,b,k}$ for all $k \in K^{10N}_{i,b}$; and

$0 \leq S30RDG_{i,b,k} \leq (AtMLP_{i,b} + EvalSD_{i,b}) \cdot Q30RDG_{i,b,k}$ for all $k \in K^{30R}_{i,b}$.

8.5.2 Resource Initial Conditions

8.5.2.1 The initial schedule for a *dispatchable load* at bus $b \in B^{DL}$ shall be fixed to the *resource* initial schedules. For all *dispatchable load* buses $b \in B^{DL}$:

$$\sum_{j \in J^{E}_{0,b}} SDL_{0,b,j} = SDLInitSch_{0,b}$$

8.5.2.2 The initial schedule for a *dispatchable generation resource* at bus $b \in B^{DG}$ shall be fixed to the *resource* initial schedules. For all *dispatchable generation resource* buses $b \in B^{DG}$:

$$\sum_{k\in K^E_{0,b}} SDG_{0,b,k} = SDGInitSch_{0,b}$$

8.5.3 Resource Minimums and Maximums for Energy

8.5.3.1 A constraint shall limit schedules for *dispatchable loads* within their minimum and maximum consumption for an interval. For all intervals $i \in I$ and all buses $b \in B^{DL}$:

$$MinDL_{i,b} \leq \sum_{j\in J^E_{i,b}} SDL_{i,b,j} \leq MaxDL_{i,b}.$$

8.5.3.2 The non-*dispatchable* portion of a *dispatchable load* shall always be scheduled. For all intervals $i \in I$ and all buses $b \in B^{DL}$:

$$\sum_{j\in J^E_{i,b}} SDL_{i,b,j} \geq QDLFIRM_{i,b}.$$

8.5.3.3 The *non-dispatchable generation resources* shall be scheduled to the fixed quantity determined by their observed output. For all intervals $i \in I$ and all buses $b \in B^{NDG}$:

$$\sum_{k\in K^E_{i,b}} SNDG_{i,b,k} = FNDG_{i,b}.$$

8.5.3.4 A constraint shall limit schedules for *dispatchable generation resources* within their minimum and maximum output for an interval. For a *dispatchable variable generation resource*, the maximum schedule shall be limited by its forecast. That is:

8.5.3.4.1 For all intervals $i \in I$ and all buses $b \in B^{DG}$,

$$AdjMaxDG_{i,b} = \begin{cases} min(MaxDG_{i,b}, FG_{i,b}) & if\ b \in B^{VG} \\ MaxDG_{i,b} & otherwise \end{cases}$$

and

$$AdjMinDG_{i,b} = min\left(MinDG_{i,b}, AdjMaxDG_{i,b}\right).$$

8.5.3.4.2 For all intervals $i \in I$ and all buses $b \in B^{DG}$:

$$AdjMinDG_{i,b} \leq \sum_{k\in K^E_{i,b}} SDG_{i,b,k} \leq AdjMaxDG_{i,b}.$$

8.5.3.5 A constraint shall limit the schedule for a *non-quick start resource* at or above its *minimum loading point* when such *resource* is committed or when the *resource* shutdown is yet to be confirmed by the *IESO*. For all *non-quick start resource* buses $b \in B^{NQS}$ and intervals $i \in I$:

$$\sum_{k \in K^{E}_{i,b}} SDG_{i,b,k} \geq AtMLP_{i,b} \cdot MinQDG_{b}.$$

8.5.4 Operating Reserve Requirements

8.5.4.1 The total synchronized *ten-minute operating reserve*, non-synchronized *ten-minute operating reserve* and *thirty-minute operating reserve* scheduled from a *dispatchable load* shall not exceed:

8.5.4.1.1 the *dispatchable load's* ramp capability over 30 minutes;

8.5.4.1.2 the total scheduled consumption less the non-*dispatchable* portion; and

8.5.4.1.3 the remaining portion of its capacity that is *dispatchable* after considering minimum load consumption constraints.

8.5.4.2 These restrictions shall be enforced by the following constraints for all intervals $i \in I$ and all buses $b \in B^{DL}$:

$$\sum_{j \in J^{10S}_{i,b}} S10SDL_{i,b,j} + \sum_{j \in J^{10N}_{i,b}} S10NDL_{i,b,j} + \sum_{j \in J^{30R}_{i,b}} S30RDL_{i,b,j} \leq 30 \cdot ORRDL_{b};$$

$$\sum_{j \in J^{10S}_{i,b}} S10SDL_{i,b,j} + \sum_{j \in J^{10N}_{i,b}} S10NDL_{i,b,j} + \sum_{j \in J^{30R}_{i,b}} S30RDL_{i,b,j} \leq \sum_{j \in J^{E}_{i,b}} SDL_{i,b,j} - QDLFIRM_{i,b};$$

and

$$\sum_{j \in J^{10S}_{i,b}} S10SDL_{i,b,j} + \sum_{j \in J^{10N}_{i,b}} S10NDL_{i,b,j} + \sum_{j \in J^{30R}_{i,b}} S30RDL_{i,b,j} \leq \sum_{j \in J^{E}_{i,b}} SDL_{i,b,j} - MinDL_{i,b}.$$

8.5.4.3 The amount of both synchronized and non-synchronized *ten-minute operating reserve* that a *dispatchable load* is scheduled to provide shall not exceed the amount by which the *dispatchable load* can decrease its consumption over 10 minutes, as limited by its *operating reserve* ramp rate. This restriction shall be enforced by the following constraint for all intervals $i \in I$ and all buses $b \in B^{DL}$:

$$\sum_{j \in J^{10S}_{i,b}} S10SDL_{i,b,j} + \sum_{j \in J^{10N}_{i,b}} S10NDL_{i,b,j} \leq 10 \cdot ORRDL_{b}.$$

8.5.4.4 The total *operating reserve* scheduled from a *dispatchable generation resource* shall not exceed the *resource*'s ramp capability over 30 minutes, its remaining capacity, and its unscheduled capacity. These restrictions shall be enforced by the following constraints for all intervals $i \in I$ and all buses $b \in B^{DG}$:

$$\sum_{k \in K_{i,b}^{10S}} S10SDG_{i,b,k} + \sum_{k \in K_{i,b}^{10N}} S10NDG_{i,b,k} + \sum_{k \in K_{i,b}^{30R}} S30RDG_{i,b,k} \leq 30 \cdot ORRDG_b;$$

$$\sum_{k \in K_{i,b}^{10S}} S10SDG_{i,b,k} + \sum_{k \in K_{i,b}^{10N}} S10NDG_{i,b,k} + \sum_{k \in K_{i,b}^{30R}} S30RDG_{i,b,k} \leq \sum_{k \in K_{i,b}^{E}} (QDG_{i,b,k} - SDG_{i,b,k});$$

and

$$\sum_{k \in K_{i,b}^{10S}} S10SDG_{i,b,k} + \sum_{k \in K_{i,b}^{10N}} S10NDG_{i,b,k} + \sum_{k \in K_{i,b}^{30R}} S30RDG_{i,b,k} \leq AdjMaxDG_{i,b} - \sum_{k \in K_{i,b}^{E}} SDG_{i,b,k}.$$

8.5.4.5 The amount of both synchronized and non-synchronized *ten-minute operating reserve* that a *dispatchable generation resource* is scheduled to provide shall not exceed the amount by which the *resource* can increase its output over 10 minutes, as limited by its *operating reserve* ramp rate. This restriction shall be enforced by the following constraint for all intervals $i \in I$ and all buses $b \in B^{DG}$:

$$\sum_{k \in K_{i,b}^{10S}} S10SDG_{i,b,k} + \sum_{k \in K_{i,b}^{10N}} S10NDG_{i,b,k} \leq 10 \cdot ORRDG_b.$$

8.5.4.6 The amount of synchronized *ten-minute operating reserve* that a *dispatchable generation resource* is scheduled to provide shall be limited by its *reserve loading point* for synchronized *ten-minute operating reserve*. This restriction shall be enforced by the following constraint for all intervals $i \in I$ and all buses $b \in B^{DG}$ with $RLP10S_{i,b} > 0$:

$$\sum_{k \in K_{i,b}^{10S}} S10SDG_{i,b,k} \le \left(\sum_{k \in K_{i,b}^{E}} SDG_{i,b,k} \right) \cdot \left(\frac{1}{RLP10S_{i,b}} \right) \cdot \left(min \left\{ 10 \cdot ORRDG_b, \sum_{k \in K_{i,b}^{10S}} Q10SDG_{i,b,k} \right\} \right).$$

8.5.4.7 The amount of *thirty-minute operating reserve* that a *dispatchable generation resource* is scheduled to provide shall be limited by its *reserve loading point* for *thirty-minute operating reserve*. This restriction shall be enforced by the following constraint for all intervals $i \in I$ and all buses $b \in B^{DG}$ with $RLP30R_{i,b} > 0$:

$$\sum_{k \in K_{i,b}^{30R}} S30RDG_{i,b,k} \le \left(\sum_{k \in K_{i,b}^{E}} SDG_{i,b,k} \right) \cdot \left(\frac{1}{RLP30R_{i,b}} \right) \cdot \left(min \left\{ 30 \cdot ORRDG_b, \sum_{k \in K_{i,b}^{30R}} Q30RDG_{i,b,k} \right\} \right).$$

8.5.5 Pseudo-Units

8.5.5.1 A constraint shall be required to calculate physical *generation resource* schedules from *pseudo-unit* schedules using the steam turbine shares in the operating regions of the *pseudo-unit* determined in section 10. For all intervals $i \in I$ and *pseudo-unit* buses $b \in B^{PSU}$:

$$SSTMod_{i,p} = \sum_{b \in B_p^{ST}} \left(\begin{array}{c} STShareMLP_b \cdot \left(\sum_{k \in K_{i,b}^{MLP}} SDG_{i,b,k} \right) + \\ STShareDR_b \cdot \left(\sum_{k \in K_{i,b}^{DR}} SDG_{i,b,k} \right) + \sum_{k \in K_{i,b}^{DF}} SDG_{i,b,k} \end{array} \right).$$

$$SCTMod_{i,b} = (1 - STShareMLP_b) \cdot \left(\sum_{k \in K_{i,b}^{MLP}} SDG_{i,b,k} \right) + (1 - STShareDR_b) \cdot \left(\sum_{k \in K_{i,b}^{DR}} SDG_{i,b,k} \right),$$

8.5.5.1.1 and for all intervals $i \in I$ and steam turbines $p \in PST$:

8.5.5.2 Maximum constraints shall be enforced on the operating region to which they apply for both *energy* and *operating reserve* schedules. For all intervals $i \in I$ and *pseudo-unit* buses $b \in B^{PSU}$:

$$\sum_{k \in K_{i,b}^{DR}} SDG_{i,b,k} \leq MaxDR_{i,b},$$

$$\sum_{k \in K_{i,b}^{DF}} SDG_{i,b,k} \leq MaxDF_{i,b},$$

and

$$\sum_{k \in K_{i,b}^{DR}} SDG_{i,b,k} + \sum_{k \in K_{i,b}^{DF}} SDG_{i,b,k} + \sum_{k \in K_{i,b}^{10S}} S10SDG_{i,b,k} + \sum_{k \in K_{i,b}^{10N}} S10NDG_{i,b,k} + \sum_{k \in K_{i,b}^{30R}} S30RDG_{i,b,k} \leq MaxDR_{i,b} + MaxDF_{i,b}.$$

8.5.5.3 For a *pseudo-unit* that cannot provide *ten-minute operating reserve* from its duct firing region, constraints shall limit the *pseudo-unit* from being scheduled to provide *ten-minute operating reserve* whenever the *pseudo-unit* is scheduled for *energy* in its duct firing region.

8.5.5.4 For the purposes of the *energy* balance constraint in section 8.7.1 and the transmission constraints in section 8.7.3, the combustion turbine schedule for the *pseudo-unit* at bus $b \in B^{PSU}$ in interval $i \in I$, $SCT_{i,b}$ shall be equal to:

8.5.5.4.1 $SCTMod_{i,b}$ if the *pseudo-unit* is scheduled at or above *minimum loading point*;

8.5.5.4.2 the portion of $UpTraj_{i,b}$ or $DnTraj_{i,b}$ defined in the section 8.6.2 that was allocated to the combustion turbine in accordance with section 10.6 if the *resource* is ramping to or ramping from its *minimum loading point*; or

8.5.5.4.3 0 otherwise.

8.5.5.5 For the purposes of the *energy* balance constraint in section 8.7.1 and the transmission constraints in section 8.7.3, the steam turbine schedule for $p \in PST$, $SST_{i,p}$ shall be equal to $SSTMod_{i,p}$ where $SST_{i,p}$ will be corrected to account for the contribution from *pseudo-units* $b \in B_p^{ST}$ ramping to or ramping from *minimum loading point* as determined by the allocation of $UpTraj_{i,b}$ or $DnTraj_{i,b}$ in accordance with section 10.6.

8.5.6 Dispatchable Hydroelectric Generation Resources

8.5.6.1 A *dispatchable* hydroelectric *generation resource* shall be scheduled within its *forbidden region* if the *resource* is being ramped through the *forbidden region* at its maximum *offered* ramp capability.

8.6 Dispatch Data Inter-Interval/Multi-Interval Constraints

8.6.1 Energy Ramping

8.6.1.1 For *disptachable loads*, the ramping constraint in section 8.6.1.4 uses $URRDL_b$ to represent a ramp up rate selected from $URRDL_{i,b,w}$ and uses $DRRDL_b$ to represent a ramp down rate selected from $DRRDL_{i,b,w}$.

8.6.1.2 For *disptachable generation resources*, the ramping constraint in section 8.6.1.5 uses $URRDG_b$ to represent a ramp up rate selected from $URRDG_{i,b,w}$ and uses $DRRDG_b$ to represent a ramp down rate selected from $DRRDG_{i,b,w}$.

8.6.1.3 The *real-time calculation engine* shall respect the ramping restrictions determined by the up to five *offered* MW quantity, ramp up rate and ramp down rate value sets.

8.6.1.4 In the case of *dispatchable loads*, *energy* schedules cannot vary by more than an interval's ramping capability for that *resource*. This constraint shall be enforced by the following for all intervals $i \in I$ and buses $b \in B^{DL}$:

$$\sum_{j \in J_{i-1,b}^E} SDL_{i-1,b,j} - 5 \cdot DRRDL_b \leq \sum_{j \in J_{i,b}^E} SDL_{i,b,j} \leq \sum_{j \in J_{i-1,b}^E} SDL_{i-1,b,j} + 5 \cdot URRDL_b.$$

8.6.1.5 *Energy* schedules for a *dispatchable generation resource* cannot vary by more than an interval's ramping capability for that *resource*. This constraint shall be enforced by the following for all intervals $i \in I$ and buses $b \in B^{DG}$:

$$\sum_{k\in K^E_{i-1,b}} SDG_{i-1,b,k} - 5\cdot DRRDG_b \le \sum_{k\in K^E_{i,b}} SDG_{i,b,k} \le \sum_{k\in K^E_{i-1,b}} SDG_{i-1,b,k} + 5\cdot URRDG_b.$$

8.6.2 Non-Quick Start Resource Start-up and Shutdown

8.6.2.1 For all intervals in the real-time look-ahead period in which a *non-quick start resource* is scheduled to start-up, such *resource* shall be scheduled on a fixed ramp-up trajectory as determined by its *offered* ramp rates. The ramp-up trajectory ($UpTraj_{i,b}$) for interval $i \in I$ such that $SU_{i,b}=1$ is determined as follows:

8.6.2.1.1 If $i = 1$, then $UpTraj_{i,b}$ shall be determined from the *resource* initial schedule and the *offered* ramp up capability;

8.6.2.1.2 If $i > 1$ and $SU_{i\text{-}1,b} = 0$, then $UpTraj_{i,b}$ shall be determined from the *offered* ramp up capability from 0; and

8.6.2.1.3 For all intervals $i \in I$ such that $SU_{i,b}=1$:

$$\sum_{k\in K^E_{i,b}} SDG_{i,b,k} = UpTraj_{i,b}.$$

8.6.2.2 For all intervals in the real-time look-ahead period in which a *non-quick start resource* is scheduled to shutdown, such *resource* shall be scheduled on a fixed ramp-down trajectory as determined by its *offered* ramp rates. The ramp-down trajectory ($DnTraj_{i,b}$) for interval $i \in I$ such that $SD_{i,b} = 1$ is determined as follows:

8.6.2.2.1 If $i = 1$, then $DnTraj_{i,b}$ shall be determined from the *resource* initial schedule and the *offered* ramp down capability;

8.6.2.2.2 If $i > 1$ and $SD_{i\text{-}1,b} = 0$, then $DnTraj_{i,b}$ shall be $MinQDG_b$; and

8.6.2.2.3 If $i > 1$ and $SD_{i\text{-}1,b} = 1$, then $DnTraj_{i,b}$ shall be determined from the *offered* ramp down capability from $DnTraj_{i\text{-}1,b}$.

8.6.2.2.4 For all intervals $i \in I$ such that $SD_{i,b} = 1$:

$$\sum_{k\in K^E_{i,b}} SDG_{i,b,k} = DnTraj_{i,b}.$$

8.6.3 Operating Reserve Ramping

8.6.3.1 Constraints shall be applied to recognize that interval to interval changes to a *dispatchable load*'s schedule for *energy* may modify the amount of *operating reserve* that the *resource* can provide. For all intervals $i \in I$ and all buses $b \in B^{DL}$:

$$\sum_{j \in J_{i,b}^{10S}} S10SDL_{i,b,j} + \sum_{j \in J_{i,b}^{10N}} S10NDL_{i,b,j} + \sum_{j \in J_{i,b}^{30R}} S30RDL_{i,b,j} \leq - \sum_{j \in J_{i-1,b}^{E}} SDL_{i-1,b,j} + \sum_{j \in J_{i,b}^{E}} SDL_{i,b,j} + 30 \cdot ORRDL_b$$

and

$$\sum_{j \in J_{i,b}^{10S}} S10SDL_{i,b,j} + \sum_{j \in J_{i,b}^{10N}} S10NDL_{i,b,j} \leq - \sum_{j \in J_{i-1,b}^{E}} SDL_{i-1,b,j} + \sum_{j \in J_{i,b}^{E}} SDL_{i,b,j} + 10 \cdot ORRDL_b.$$

8.6.3.2 Constraints shall be applied to recognize that interval to interval changes in a *dispatchable generation resource's* schedule for *energy* may modify the amount of *operating reserve* that the *resource* can provide. For all intervals $i \in I$ and all buses $b \in B^{DG}$:

$$\sum_{k \in K_{i,b}^{10S}} S10SDG_{i,b,k} + \sum_{k \in K_{i,b}^{10N}} S10NDG_{i,b,k} + \sum_{k \in K_{i,b}^{30R}} S30RDG_{i,b,k} \leq \sum_{k \in K_{i-1,b}^{E}} SDG_{i-1,b,k} - \sum_{k \in K_{i,b}^{E}} SDG_{i,b,k} + 30 \cdot ORRDG_b$$

and

$$\sum_{k \in K_{i,b}^{10S}} S10SDG_{i,b,k} + \sum_{k \in K_{i,b}^{10N}} S10NDG_{i,b,k} \leq \sum_{k \in K_{i-1,b}^{E}} SDG_{i-1,b,k} - \sum_{k \in K_{i,b}^{E}} SDG_{i,b,k} + 10 \cdot ORRDG_b.$$

8.7 Constraints for Reliability Requirements

8.7.1 Energy Balance

8.7.1.1 The total amount of *energy* withdrawals scheduled at load bus $b \in B$ in interval $i \in I$, $With_{i,b}$ shall be:

$$With_{i,b} = \begin{cases} \sum_{j \in J_{i,b}^{E}} SDL_{i,b,j} & if\ b \in B^{DL} \\ FHDR_{i,b} & if\ b \in B^{HDR} \\ FNBL_{i,b} & if\ b \in B^{NoBid} \end{cases}$$

8.7.1.2 The total amount of export *energy* scheduled at *intertie zone* bus $d \in DX$ in interval $i \in I$, $With_{i,d}$, as the fixed exports from Ontario to the *intertie zone* export bus shall be:

$$With_{i,d} = FXLSch_{i,d}.$$

8.7.1.3 The total amount of injections scheduled at internal bus $b \in B$, in interval $i \in I$, $Inj_{i,b}$ shall be:

$$Inj_{i,b} = \begin{cases} \sum_{k \in K_{i,b}^{E}} SNDG_{i,b,k} & if\ b \in B^{NDG} \\ \sum_{k \in K_{i,b}^{E}} SDG_{i,b,k} & if\ b \in B^{DG} \\ FNOG_{i,b} & if\ b \in B^{NoOffer} \end{cases}$$

8.7.1.4 The total amount of import *energy* scheduled at *intertie zone* bus $d \in DI$ in interval $i \in I$, $Inj_{i,d}$, as the imports into Ontario from that *intertie zone* bus shall be:

$$Inj_{i,d} = FIGSch_{i,d}.$$

8.7.1.5 Injections and withdrawals at each bus shall be multiplied by one plus the marginal loss factor to reflect the losses or reduction in losses that result when injections or withdrawals occur at locations other than the *reference bus*. These loss-adjusted injections and withdrawals must then be equal to each other after taking into account the adjustment for any discrepancy between total and marginal losses. Load or generation reduction associated with the demand constraint violation shall be subtracted from the total load or generation for the *real-time calculation engine* to produce a solution.

For interval $i \in I$, the *energy* balance shall be:

$$FL_i + \sum_{b \in B^{DL} \cup B^{HDR} \cup B^{NoBid}} (1 + MglLoss_{i,b}) \cdot With_{i,b} + \sum_{d \in DX} (1 + MglLoss_{i,d}) \cdot With_{i,d} - \sum_{w=1..N_{LdViol_i}} SLdViol_{i,w} = \sum_{b \in B^{NDG} \cup B^{DG} \cup B^{NoOffer}} \left(1 + MglLoss_{i,b}\right) \cdot Inj_{i,b} + \sum_{d \in DI} \left(1 + MglLoss_{i,d}\right) \cdot Inj_{i,d} - \sum_{w=1..N_{GenViol_i}} SGenViol_{i,w} + LossAdj_i.$$

8.7.2 Operating Reserve Requirements

8.7.2.1 *Operating reserve* shall be scheduled to meet system-wide requirements for synchronized *ten-minute operating reserve*, total *ten-minute operating reserve*, and *thirty-minute operating reserve* while respecting all applicable regional minimum requirements and regional maximum restrictions for *operating reserve*.

8.7.2.2 Constraint violation penalty curves shall be used to impose a penalty cost for not meeting the *IESO's* system-wide *operating reserve* requirements, not meeting a regional minimum requirement, or not adhering to a regional maximum restriction. Full *operating reserve* requirements shall be scheduled unless the cost of doing so would be higher than the applicable penalty cost. For each interval $i \in I$:

$$\sum_{b \in B^{DL}} \left(\sum_{j \in J_{i,b}^{10S}} S10SDL_{i,b,j} \right) + \sum_{b \in B^{DG}} \left(\sum_{k \in K_{i,b}^{10S}} S10SDG_{i,b,k} \right) + \sum_{w=1..N_{10SViol_i}} S10SViol_{i,w} \geq TOT10S_i;$$

$$\sum_{b\in B^{DL}}\left(\sum_{j\in J_{i,b}^{10S}} S10SDL_{i,b,j}\right)+\sum_{b\in B^{DG}}\left(\sum_{k\in K_{i,b}^{10S}} S10SDG_{i,b,k}\right)$$
$$+\sum_{b\in B^{DL}}\left(\sum_{j\in J_{i,b}^{10N}} S10NDL_{i,b,j}\right)$$
$$+\sum_{b\in B^{DG}}\left(\sum_{k\in K_{i,b}^{10N}} S10NDG_{i,b,k}\right)+\sum_{d\in DX} F10NXLSch_{i,d}$$
$$+\sum_{d\in DI} F10NIGSch_{i,d}+\sum_{w=1..N_{10RViol_i}} S10RViol_{i,w}$$
$$\geq TOT10R_i;$$

and

$$\sum_{b\in B^{DL}}\left(\sum_{j\in J_{i,b}^{10S}} S10SDL_{i,b,j}\right)+\sum_{b\in B^{DG}}\left(\sum_{k\in K_{i,b}^{10S}} S10SDG_{i,b,k}\right)$$
$$+\sum_{b\in B^{DL}}\left(\sum_{j\in J_{i,b}^{10N}} S10NDL_{i,b,j}\right)$$
$$+\sum_{b\in B^{DG}}\left(\sum_{k\in K_{i,b}^{10N}} S10NDG_{i,b,k}\right)+\sum_{d\in DX} F10NXLSch_{i,d}$$
$$+\sum_{d\in DI} F10NIGSch_{i,d}+\sum_{b\in B^{DL}}\left(\sum_{j\in J_{i,b}^{30R}} S30RDL_{i,b,j}\right)$$
$$+\sum_{b\in B^{DG}}\left(\sum_{k\in K_{i,b}^{30R}} S30RDG_{i,b,k}\right)+\sum_{d\in DX} F30RXLSch_{i,d}$$
$$+\sum_{d\in DI} F30RIGSch_{i,d}+\sum_{w=1..N_{30RViol_i}} S30RViol_{i,w}$$
$$\geq TOT30R_i.$$

8.7.2.3 The following constraints shall be applied for each interval $i \in I$ and each region $r \in ORREG$:

$$\sum_{b \in B_r^{REG} \cap B^{DL}} \left(\sum_{j \in J_{i,b}^{10S}} S10SDL_{i,b,j} \right) + \sum_{b \in B_r^{REG} \cap B^{DG}} \left(\sum_{k \in K_{i,b}^{10S}} S10SDG_{i,b,k} \right) + \sum_{b \in B_r^{REG} \cap B^{DL}} \left(\sum_{j \in J_{i,b}^{10N}} S10NDL_{i,b,j} \right) + \sum_{b \in B_r^{REG} \cap B^{DG}} \left(\sum_{k \in K_{i,b}^{10N}} S10NDG_{i,b,k} \right) + \sum_{d \in D_r^{REG} \cap DX} F10NXLSch_{i,d} + \sum_{d \in D_r^{REG} \cap DI} F10NIGSch_{i,d} + \sum_{w=1..N_{REG10RViol_i}} SREG10RViol_{r,i,w} \geq REGMin10R_{i,r};$$

$$\sum_{b \in B_r^{REG} \cap B^{DL}} \left(\sum_{j \in J_{i,b}^{10S}} S10SDL_{i,b,j} \right) + \sum_{b \in B_r^{REG} \cap B^{DG}} \left(\sum_{k \in K_{i,b}^{10S}} S10SDG_{i,b,k} \right) + \sum_{b \in B_r^{REG} \cap B^{DL}} \left(\sum_{j \in J_{i,b}^{10N}} S10NDL_{i,b,j} \right) + \sum_{b \in B_r^{REG} \cap B^{DG}} \left(\sum_{k \in K_{i,b}^{10N}} S10NDG_{i,b,k} \right) + \sum_{d \in D_r^{REG} \cap DX} F10NXLSch_{i,d} + \sum_{d \in D_r^{REG} \cap DI} F10NIGSch_{i,d} - \sum_{w=1..N_{XREG10RViol_i}} SXREG10RViol_{r,i,w} \leq REGMax10R_{i,r};$$

$$\sum_{b \in B_r^{REG} \cap B^{DL}} \left(\sum_{j \in J_{i,b}^{10S}} S10SDL_{i,b,j} \right) + \sum_{b \in B_r^{REG} \cap B^{DG}} \left(\sum_{k \in K_{i,b}^{10S}} S10SDG_{i,b,k} \right) + \sum_{b \in B_r^{REG} \cap B^{DL}} \left(\sum_{j \in J_{i,b}^{10N}} S10NDL_{i,b,j} \right) + \sum_{b \in B_r^{REG} \cap B^{DG}} \left(\sum_{k \in K_{i,b}^{10N}} S10NDG_{i,b,k} \right) + \sum_{d \in D_r^{REG} \cap DX} F10NXLSch_{i,d} + \sum_{d \in D_r^{REG} \cap DI} F10NIGSch_{i,d} + \sum_{b \in B_r^{REG} \cap B^{DL}} \left(\sum_{j \in J_{i,b}^{30R}} S30RDL_{i,b,j} \right) + \sum_{b \in B_r^{REG} \cap B^{DG}} \left(\sum_{k \in K_{i,b}^{30R}} S30RDG_{i,b,k} \right) + \sum_{d \in D_r^{REG} \cap DX} F30RXLSch_{i,d} + \sum_{d \in D_r^{REG} \cap DI} F30RIGSch_{i,d} + \sum_{w=1..N_{REG30RViol_i}} SREG30RViol_{r,i,w} \geq REGMin30R_{i,r};$$

and

$$\sum_{b \in B_r^{REG} \cap B^{DL}} \left(\sum_{j \in J_{i,b}^{10S}} S10SDL_{i,b,j} \right) + \sum_{b \in B_r^{REG} \cap B^{DG}} \left(\sum_{k \in K_{i,b}^{10S}} S10SDG_{i,b,k} \right)$$
$$+ \sum_{b \in B_r^{REG} \cap B^{DL}} \left(\sum_{j \in J_{i,b}^{10N}} S10NDL_{i,b,j} \right) + \sum_{b \in B_r^{REG} \cap B^{DG}} \left(\sum_{k \in K_{i,b}^{10N}} S10NDG_{i,b,k} \right)$$
$$+ \sum_{d \in D_r^{REG} \cap DX} F10NXLSch_{i,d} + \sum_{d \in D_r^{REG} \cap DI} F10NIGSch_{i,d}$$
$$+ \sum_{b \in B_r^{REG} \cap B^{DL}} \left(\sum_{j \in J_{i,b}^{30R}} S30RDL_{i,b,j} \right)$$
$$+ \sum_{b \in B_r^{REG} \cap B^{DG}} \left(\sum_{k \in K_{i,b}^{30R}} S30RDG_{i,b,k} \right) + \sum_{d \in D_r^{REG} \cap DX} F30RXLSch_{i,d}$$
$$+ \sum_{d \in D_r^{REG} \cap DI} F30RIGSch_{i,d}$$
$$- \sum_{w=1..N_{XREG30RViol_i}} SXREG30RViol_{r,i,w}$$
$$\leq REGMax30R_{i,r}.$$

8.7.3 IESO Internal Transmission Limits

8.7.3.1 A set of *energy* schedules shall be produced that do not violate any *security* limits in the pre-contingency state and the post-contingency state subject to the remainder of this section 8.7.3. The total amount of *energy* scheduled to be injected and withdrawn at each bus used by the *energy* balance constraint in section 8.7.1.5, shall be used to produce these schedules.

8.7.3.2 Pre-contigency, $SPreITLViol_{f,i,w}$, and post-contingency, $SITLViol_{c,f,i,w}$, transmission limit violation variables shall allow the *real-time calculation engine* to find a solution.

8.7.3.3 For all intervals $i \in I$ and *facilities* $f \in F_i$, the linearized constraints for violated pre-contingency limits obtained from the *security* assesment function shall take the form:

$$\sum_{b \in B^{NDG} \cup B^{DG} \cup B^{NoOffer}} PreConSF_{i,f,b} \cdot Inj_{i,b} - \sum_{b \in B^{DL} \cup B^{HDR} \cup B^{NoBid}} PreConSF_{i,f,b} \cdot With_{i,b} + \sum_{d \in DI} PreConSF_{i,f,d} \cdot Inj_{i,d} - \sum_{d \in DX} PreConSF_{i,f,d} \cdot With_{i,d} - \sum_{w=1..N_{PreITLViol_{f,i}}} SPreITLViol_{f,i,w} \leq AdjNormMaxFlow_{i,f}.$$

8.7.3.4 For all intervals $i \in I$, contingencies $c \in C$, and *facilities* $f \in F_{i,c}$, the linearized constraints for violated post-contingency limits obtained from the *security* assesment function shall take the form:

$$\sum_{b \in B^{NDG} \cup B^{DG} \cup B^{NoOffer}} SF_{i,c,f,b} \cdot Inj_{i,b} - \sum_{b \in B^{DL} \cup B^{HDR} \cup B^{NoBid}} SF_{i,c,f,b} \cdot With_{i,b} + \sum_{d \in DI} SF_{i,c,f,d} \cdot Inj_{i,d} - \sum_{d \in DX} SF_{i,c,f,d} \cdot With_{i,d} - \sum_{w=1..N_{ITLViol_{c,f,i}}} SITLViol_{c,f,i,w} \leq AdjEmMaxFlow_{i,c,f}.$$

8.7.4 Penalty Price Variable Bounds

8.7.4.1 Penalty price variables shall be restricted to the ranges determined by the constraint violation penalty curves for the Real-Time Scheduling algorithm and for all intervals $i \in I$:

$0 \leq SLdViol_{i,w} \leq QLdViolSch_{i,w}$ for all $w \in \{1,..,N_{LdViol_i}\}$;

$0 \leq SGenViol_{i,w} \leq QGenViolSch_{i,w}$ for all $w \in \{1,..,N_{GenViol_i}\}$;

$0 \leq S10SViol_{i,w} \leq Q10SViolSch_{i,w}$ for all $w \in \{1,..,N_{10SViol_i}\}$;

$0 \leq S10RViol_{i,w} \leq Q10RViolSch_{i,w}$ for all $w \in \{1,..,N_{10RViol_i}\}$;

$0 \leq S30RViol_{i,w} \leq Q30RViolSch_{i,w}$ for all $w \in \{1,..,N_{30RViol_i}\}$;

$0 \leq SREG10RViol_{r,i,w} \leq QREG10RViolSch_{i,w}$ for all $r \in ORREG$, $w \in \{1,..,N_{REG10RViol_i}\}$;

$0 \leq SREG30RViol_{r,i,w} \leq QREG30RViolSch_{i,w}$ for all $r \in ORREG$, $w \in \{1,..,N_{REG30RViol_i}\}$;

$0 \leq SXREG10RViol_{r,i,w} \leq QXREG10RViolSch_{i,w}$ for all $r \in ORREG$, $w \in \{1,..,N_{XREG10RViol_i}\}$;

$0 \leq SXREG30RViol_{r,i,w} \leq QXREG30RViolSch_{i,w}$ for all $r \in ORREG$, $w \in \{1,..,N_{XREG30RViol_i}\}$;

$0 \leq SPreITLViol_{f,i,w} \leq QPreITLViolSch_{f,i,w}$ for all $f \in F_i$, $w \in \{1,..,N_{PreITLViol_{f,i}}\}$;

and

$0 \leq SITLViol_{c,f,i,w} \leq QITLViolSch_{c,f,i,w}$ for all $c \in C, f \in F_{i,c}$, $w \in \{1,..,N_{ITLViol_{c,f,i}}\}$.

8.8 Outputs

8.8.1 Outputs for the Real-Time Scheduling algorithm includes *resource* schedules.

9 Real-Time Pricing

9.1 Purpose

9.1.1 The Real-Time Pricing algorithm shall perform a *security*-constrained economic *dispatch* to maximize gains from trade to meet the *IESO's* province-wide non-*dispatchable demand* forecast and the *IESO*-specified *operating reserve* requirements for each interval of the real-time look-ahead period.

9.2 Information, Sets, Indices and Parameters

9.2.1 Information, sets, indices and parameters used by the Real-Time Pricing algorithm are described in sections 3 and 4. In addition, the following *resource* schedules from the Real-Time Scheduling algorithm in section 8 shall be used in the Real-Time Pricing algorithm:

9.2.1.1 $SD_{i,b}^{RTS} \in \{0,1\}$, which designates whether the *dispatchable generation resource* at bus $b \in B^{NQS}$ was scheduled on a shutdown trajectory in interval $i \in I$ such that $EvalSD_{i,b} = 1$;

9.2.1.2 $SDLInitSch_{0,b}$, which designates the initial schedule for the *dispatchable load* at bus $b \in B^{DL}$ used in the Real-Time Scheduling algorithm in section 8; and

9.2.1.3 $SDGInitSch_{0,b}$, which designates the initial schedule for the *dispatchable generation resource* at bus $b \in B^{DG}$ used in the Real-Time Scheduling algorithm in section 8.

9.3 Variables and Objective Function

9.3.1 The Real-Time Pricing algorithm shall solve for the same variables as the Real-Time Scheduling algorithm in section 8.3.1.

9.3.2 The objective function for the Real-Time Pricing algorithm shall maximize gains from trade by maximizing the expression in section 8.3.2 for the Real-Time Scheduling algorithm.

9.3.3 $ViolCost_i$ shall be calculated as follows:

$$
\begin{aligned}
ViolCost_i = & \sum_{w=1..N_{LdViol_i}} SLdViol_{i,w} \cdot PLdViolPrc_{i,w} \\
& - \sum_{w=1..N_{GenViol_i}} SGenViol_{i,w} \cdot PGenViolPrc_{i,w} \\
& + \sum_{w=1..N_{10SViol_i}} S10SViol_{i,w} \cdot P10SViolPrc_{i,w} \\
& + \sum_{w=1..N_{10RViol_i}} S10RViol_{i,w} \cdot P10RViolPrc_{i,w} \\
& + \sum_{w=1..N_{30RViol_i}} S30RViol_{i,w} \cdot P30RViolPrc_{i,w} \\
& + \sum_{r \in ORREG} \left(\sum_{w=1..N_{REG10RViol_i}} SREG10RViol_{r,i,w} \cdot PREG10RViolPrc_{i,w} \right) \\
& + \sum_{r \in ORREG} \left(\sum_{w=1..N_{REG30RViol_i}} SREG30RViol_{r,i,w} \cdot PREG30RViolPrc_{i,w} \right) \\
& + \sum_{r \in ORREG} \left(\sum_{w=1..N_{XREG10RViol_i}} SXREG10RViol_{r,i,w} \cdot PXREG10RViolPrc_{i,w} \right) \\
& + \sum_{r \in ORREG} \left(\sum_{w=1..N_{XREG30RViol_i}} SXREG30RViol_{r,i,w} \cdot PXREG30RViolPrc_{i,w} \right) \\
& + \sum_{f \in F_i} \left(\sum_{w=1..N_{PreITLViol_{f,i}}} SPreITLViol_{f,i,w} \cdot PPreITLViolPrc_{f,i,w} \right) \\
& + \sum_{c \in C} \sum_{f \in F_{i,c}} \left(\sum_{w=1..N_{ITLViol_{c,f,i}}} SITLViol_{c,f,i,w} \cdot PITLViolPrc_{c,f,i,w} \right).
\end{aligned}
$$

9.3.3.1 The constraints in section 9.4 shall apply to the Real-Time Pricing algorithm.

9.4 Constraints

9.4.1 The Real-Time Pricing algorithm optimization function shall apply the constraints described in sections 9.5 – 9.8.

9.5 Dispatch Data Constraints Applying to Individual Intervals

9.5.1 Scheduling Variable Bounds

9.5.1.1 The constraints in section 8.5.1 shall apply in the Real-Time Pricing algorithm, with the following exceptions for a *non-quick start resource* bus $b \in B^{NQS}$ and interval $i \in I$, where:

9.5.1.1.1 $AtZero_{i,b}$ shall be replaced by $AtZero_{i,b}^{RTP}$;

9.5.1.1.2 $AtMLP_{i,b}$ shall be replaced by $AtMLP_{i,b}^{RTP}$; and

9.5.1.1.3 $EvalSD_{i,b}$ shall be replaced by $EvalSD_{i,b}^{RTP}$.

9.5.2 Resource Initial Conditions

9.5.2.1 The initial schedule for a *dispatchable load* at bus $b \in B^{DL}$ shall be fixed to the *resource* initial schedules. For all *dispatchable load* buses $b \in B^{DL}$:

$$\sum_{j \in J_{0,b}^{E}} SDL_{0,b,j} = SDLInitPrc_{0,b}$$

9.5.2.2 The initial schedule for a *dispatchable generation resource* at bus $b \in B^{DG}$ shall be fixed to the *resource* initial schedules. For all *dispatchable generation resource* buses $b \in B^{DG}$:

$$\sum_{k \in K_{0,b}^{E}} SDG_{0,b,k} = SDGInitPrc_{0,b}$$

9.5.3 Resource Minimums and Maximums

9.5.3.1 The constraints in section 8.5.3 shall apply in the Real-Time Pricing algorithm, with the following exception:

9.5.3.1.1 $AtMLP_{i,b}$ shall be replaced by $AtMLP_{i,b}^{RTP}$

where $AtMLP_{i,b}^{RTP}$ is determined in accordance with section 9.8.1.

9.5.4 Operating Reserve Requirements

9.5.4.1 The constraints in section 8.5.4 shall apply in the Real-Time Pricing algorithm.

9.5.5 Pseudo-Units

9.5.5.1 The constraints in section 8.5.5 shall apply in the Real-Time Pricing algorithm.

9.5.6 Dispatchable Hydroelectric Generation Resources

9.5.6.1 The constraints in section 8.5.6 shall apply in the Real-Time Pricing algorithm.

9.6 Dispatch Data Inter-Interval/Multi-Interval Constraints

9.6.1 Energy Ramping

9.6.1.1 The constraints in section 8.6.1 shall apply in the Real-Time Pricing algorithm.

9.6.2 Non-Quick Start Resource Start-up and Shutdown

9.6.2.1 The constraints in section 8.6.2 shall apply in the Real-Time Pricing algorithm, with the exception of the *non-quick start resource* start-up and shutdown statuses, which are determined in accordance with section 9.8.1.

9.6.3 Operating Reserve Ramping

9.6.3.1 The constraints in section 8.6.3 shall apply in the Real-Time Pricing algorithm.

9.7 Constraints for Reliability Requirements

9.7.1 Energy Balance

9.7.1.1 The constraint in section 8.7.1 shall apply in the Real-Time Pricing algorithm, with the following exceptions:

9.7.1.1.1 $FXLSch_{i,d}$ shall be replaced by $FXLPrc_{i,d}$ in section 8.7.1.2;

9.7.1.1.2 $FIGSch_{i,d}$ shall be replaced by $FIGPrc_{i,d}$ in section 8.7.1.4; and

9.7.1.1.3 The *energy* balance constraint in section 8.7.1.5 shall be modified to account for the *demand* adjustment required to calculate *locational marginal prices* when a voltage reduction or load shedding has been implemented, as follows:

$$FL_i + CAAdj_i + \sum_{b \in B^{DL} \cup B^{HDR} \cup B^{NoBid}} (1 + MglLoss_{i,b}) \cdot With_{i,b} + \sum_{d \in DX} (1 + MglLoss_{i,d}) \cdot With_{i,d} - \sum_{w=1..N_{LdViol_i}} SLdViol_{i,w} = \sum_{b \in B^{NDG} \cup B^{DG} \cup B^{NoOffer}} (1 + MglLoss_{i,b}) \cdot Inj_{i,b} + \sum_{d \in DI} (1 + MglLoss_{i,d}) \cdot Inj_{i,d} - \sum_{w=1..N_{GenViol_i}} SGenViol_{i,w} + LossAdj_i.$$

9.7.2 Operating Reserve Requirements

9.7.2.1 The constraint in section 8.7.2 shall apply in the Real-Time Pricing algorithm, with the following exceptions:

9.7.2.1.1 $F10NXLSch_{i,d}$ shall be replaced by $F10NXLPrc_{i,d}$ for all $d \in DX$;

9.7.2.1.2 $F10NIGSch_{i,d}$ shall be replaced by $F10NIGPrc_{i,d}$ for all $d \in DI$;

9.7.2.1.3 $F30RXLSch_{i,d}$ shall be replaced by $F30RXLPrc_{i,d}$ for all $d \in DX$; and

9.7.2.1.4 $F30RIGSch_{i,d}$ shall be replaced by $F30RIGPrc_{i,d}$ for all $d \in DI$.

9.7.3 IESO Internal Transmission Limits

9.7.3.1 The constraints in section 8.7.3 shall apply in the Real-Time Pricing algorithm except the sensitivities and limits considered shall be those provided by the most recent *security* assessment function iteration of the Real-Time Pricing algorithm.

9.7.4 Penalty Price Variable Bounds

9.7.4.1 The following constraints shall restrict the penalty price variables to the ranges determined by the constraint violation penalty curves. For all intervals $i \in I$:

$0 \leq SLdViol_{i,w} \leq QLdViolPrc_{i,w}$	for all $w \in \{1,..,N_{LdViol_i}\}$;
$0 \leq SGenViol_{i,w} \leq QGenViolPrc_{i,w}$	for all $w \in \{1,..,N_{GenViol_i}\}$;
$0 \leq S10SViol_{i,w} \leq Q10SViolPrc_{i,w}$	for all $w \in \{1,..,N_{10SViol_i}\}$;
$0 \leq S10RViol_{i,w} \leq Q10RViolPrc_{i,w}$	for all $w \in \{1,..,N_{10RViol_i}\}$;
$0 \leq S30RViol_{i,w} \leq Q30RViolPrc_{i,w}$	for all $w \in \{1,..,N_{30RViol_i}\}$;
$0 \leq SREG10RViol_{r,i,w} \leq QREG10RViolPrc_{i,w}$	for all $r \in ORREG$, $w \in \{1,..,N_{REG10RViol_i}\}$;
$0 \leq SREG30RViol_{r,i,w} \leq QREG30RViolPrc_{i,w}$	for all $r \in ORREG$, $w \in \{1,..,N_{REG30RViol_i}\}$;
$0 \leq SXREG10RViol_{r,i,w} \leq QXREG10RViolPrc_{i,w}$	for all $r \in ORREG$, $w \in \{1,..,N_{XREG10RViol_i}\}$;
$0 \leq SXREG30RViol_{r,i,w} \leq QXREG30RViolPrc_{i,w}$	for all $r \in ORREG$, $w \in \{1,..,N_{XREG30RViol_i}\}$;
$0 \leq SPreITLViol_{f,i,w} \leq QPreITLViolPrc_{f,i,w}$	for all $f \in F_i$, $w \in \{1,..,N_{PreITLViol_{f,i}}\}$; and
$0 \leq SITLViol_{c,f,i,w} \leq QITLViolPrc_{c,f,i,w}$	for all $c \in C$, $f \in F_{i,c}$, $w \in \{1,..,N_{ITLViol_{c,f,i}}\}$.

9.8 Constraints to Ensure the Price Setting Eligibility of Offer/Bid Laminations

9.8.1 Non-Quick Start Resources

9.8.1.1 The Real-Time Pricing algorithm shall modify the following start-up and shutdown statuses for a *non-quick start resource* at bus $b \in B^{NQS}$ and interval $i \in I$:

9.8.1.1.1 $AtZero_{i,b}^{RTP} \in \{0,1\}$, which designates that the *resource* is not scheduled and is calculated as follows:

$$AtZero_{i,b}^{RTP} = AtZero_{i,b}.$$

9.8.1.1.2 $SU_{i,b}^{RTP} \in \{0,1\}$, which designates that the *resource* must be scheduled for *energy* on its start-up trajectory and is calculated as follows:

$$SU_{i,b}^{RTP} = SU_{i,b}.$$

9.8.1.1.3 $AtMLP_{i,b}^{RTP} \in \{0,1\}$, which designates that the *resource* is scheduled for *energy* at or above the *minimum loading point* and is calculated as follows:

$$AtMLP_{i,b}^{RTP} = \begin{cases} AtMLP_{i,b} & if\ EvalSD_{i,b} = 0 \\ 1 - SD_{i,b}^{RTS} & if\ EvalSD_{i,b} = 1 \end{cases}$$

9.8.1.1.4 $EvalSD_{i,b}^{RTP} \in \{0,1\}$, which designates that the *resource* can be scheduled for *energy* below the *minimum loading point* and is calculated as follows:

$$EvalSD_{i,b}^{RTP} = 0.$$

9.8.1.1.5 $SD_{i,b}^{RTP} \in \{0,1\}$, which designates that the *resource* must be scheduled for *energy* on its shutdown trajectory and is calculated as follows:

$$SD_{i,b}^{RTP} = \begin{cases} SD_{i,b} & if\ EvalSD_{i,b} = 0 \\ SD_{i,b}^{RTS} & if\ EvalSD_{i,b} = 1 \end{cases}$$

9.9 Outputs

9.9.1 Outputs for the Real-Time Pricing algorithm include:

9.9.1.1 shadow prices;

9.9.1.2 *locational marginal prices* and their components; and

9.9.1.3 sensitivity factors.

10 Pseudo-Unit Modelling

10.1 Pseudo-Unit Model Parameters

10.1.1 The *real-time calculation engine* shall use the following registration and *dispatch data* to determine the underlying relationship between a *pseudo-unit* and the associated physical *resources* for a combined cycle *facility* with K combustion turbines and one steam turbine:

10.1.1.1 $CMCR_k$, which designates the registered *maximum continuous rating* of combustion turbine $k \in \{1,..,K\}$ in MW;

10.1.1.2 $CMLP_k$, which designates the *minimum loading point* of combustion turbine $k \in \{1,..,K\}$ in MW;

10.1.1.3 $SMCR$, which designates the registered *maximum continuous rating* of the steam turbine in MW;

10.1.1.4 $SMLP$, which designates the *minimum loading point* of the steam turbine in MW for a 1x1 configuration;

10.1.1.5 SDF, which designates the amount of duct firing capacity available on the steam turbine in MW;

10.1.1.6 $STPortion_k$, which designates the percentage of the steam turbine capacity attributed to *pseudo-unit* $k \in \{1,..,K\}$; and

10.1.1.7 $CSCM_k \in \{0,1\}$, which designates whether *pseudo-unit* $k \in \{1,..,K\}$ is flagged to operate in *single cycle mode*.

10.1.2 The *real-time calculation engine* shall calculate the following model parameters for each *pseudo-unit* $k \in \{1,..K\}$:

10.1.2.1 $MMCR_k$, which designates the *maximum continuous rating* of *pseudo-unit* k and is calculated as follows:

$$CMCR_k + SMCR \cdot STPortion_k \cdot (1 - CSCM_k)$$

10.1.2.2 $MMLP_k$, which designates the *minimum loading point* of *pseudo-unit* k and is calculated as follows:

$$CMLP_k + SMLP \cdot (1 - CSCM_k)$$

10.1.2.3 MDF_k, which designates the duct firing capacity of *pseudo-unit* k and is calculated as follows:

$$SDF \cdot STPortion_k \cdot (1 - CSCM_k)$$

10.1.2.4 MDR_k, which designates the *dispatchable* capacity of *pseudo-unit* k and is calculated as follows:

$$MMCR_k - MMLP_k - MDF_k$$

10.1.3 The *real-time calculation engine* shall define three operating regions of *pseudo-unit* $k \in \{1,..K\}$, as follows:

10.1.3.1 The *minimum loading point* region shall be the capacity between 0 and $MMLP_k$;

10.1.3.2 The *dispatchable* region shall be the capacity between $MMLP_k$ and $MMLP_k + MDR_k$;

10.1.3.3 The duct firing region shall be the capacity between $MMLP_k + MDR_k$ and $MMCR_k$.

10.1.4 The *real-time calculation engine* shall calculate the associated combustion turbine and steam turbine shares for the three operating regions of *pseudo-unit* $k \in \{1,..K\}$, as follows:

10.1.4.1 For the minimum loading point region:

10.1.4.1.1 Steam turbine share: $STShareMLP_k = \frac{SMLP \cdot (1 - CSCM_k)}{MMLP_k}$;

10.1.4.1.2 Combustion turbine share: $CTShareMLP_k = \frac{CMLP_k}{MMLP_k}$; and

10.1.4.2 For the *dispatchable* region:

10.1.4.2.1 Steam turbine share:

$$STShareDR_k = \frac{(1-CSCM_k)(SMCR \cdot STPortion_k - SMLP\text{-}SDF \cdot STPortion_k)}{MDR_k}; \text{ and}$$

10.1.4.2.2 Combustion turbine share:

$$CTShareDR_k = \frac{CMCR_k - CMLP_k}{MDR_k}; \text{ and}$$

10.1.4.3 For the duct firing region:

10.1.4.3.1 Steam turbine share shall be equal to 1; and

10.1.4.3.2 Combustion turbine share shall be equal to 0.

10.2 Application of Physical Resource Deratings to the Pseudo-Unit Model

10.2.1 The *real-time calculation engine* shall apply deratings submitted by *market participants* to the applicable *dispatchable* capacity and duct firing capacity parameters for a *pseudo-unit*, where:

10.2.1.1 $CTCap_{i,k}$ designates the capacity of combustion turbine $k \in \{1,..,K\}$ in interval i as determined by submitted deratings;

10.2.1.2 $STCap_i$ designates the capacity of the steam turbine in interval i as determined by submitted deratings; and

10.2.1.3 $TotalQ_{i,k}$ designates the total *offered* quantity of *energy* for *pseudo-unit* $k \in \{1,..,K\}$ in interval i.

10.2.2 The *real-time calculation engine* shall solve for the following operating region parameters for each *pseudo-unit* $k \in \{1,..,K\}$:

10.2.2.1 $MLP_{i,k}$ designates the *minimum loading point* of *pseudo-unit* k in interval i;

10.2.2.2 $DR_{i,k}$ designates the *dispatchable* capacity region of *pseudo-unit* k in interval i; and

10.2.2.3 $DF_{i,k}$ designates the duct firing capacity region of *pseudo-unit* k in interval i.

10.2.3 Pre-Processing of De-rates

10.2.3.1 The *real-time calculation engine* shall perform the following pre-processing steps to determine the available operating regions for a *pseudo-unit* based on the combustion turbine and steam turbine share and the application of the *pseudo-unit* deratings. For *pseudo-unit* $k \in \{1,..,K\}$ for interval $i \in I$:

10.2.3.1.1 Step 1: Calculate the amount of the *offer* for *energy* that is attributed to each combustion turbine ($CTAmt_{i,k}$) and steam turbine portion ($STAmt_{i,k}$):

If $TotalQ_{i,k} < MMLP_k$, then:

Calculate $CTAmt_{i,k} = 0$; and

Calculate $STAmt_{i,k} = 0$.

Otherwise:

$CTAmtMLP = MMLP_k \cdot CTShareMLP_k$; and

$STAmtMLP = MMLP_k \cdot STShareMLP_k$.

If $TotalQ_{i,k} > MMLP_k + MDR_k$, then:

$CTAmtDR = MDR_k \cdot CTShareDR_k$;

$STAmtDR = MDR_k \cdot STShareDR_k$; and

$STAmtDF = (1 - CSCM_k) \cdot (TotalQ_{i,k} - MMLP_k - MDR_k)$.

Otherwise:

$CTAmtDR = (TotalQ_{i,k} - MMLP_k) \cdot CTShareDR_k$;

$STAmtDR = (TotalQ_{i,k} - MMLP_k) \cdot STShareDR_k$;

$STAmtDF = 0$;

$CTAmt_{i,k} = CTAmtMLP + CTAmtDR$; and

$STAmt_{i,k} = STAmtMLP + STAmtDR + STAmtDF$.

10.2.3.1.2 Step 2: Allocate the steam turbine capacity to each *pseudo-unit*:

$$PRSTCap_{i,k} = \left(\frac{STAmt_{i,k}}{\sum_{w \in \{1,..,K\}} STAmt_{i,w}} \right) \cdot STCap_i$$

10.2.3.1.3 Step 3: Determine if the *pseudo-unit* is available:

If $CTAmt_{i,k} < CMLP_k$, then the *pseudo-unit* is unavailable.

If $STAmt_{i,k} < SMLP \cdot (1 - CSCM_k)$, then the *pseudo-unit* is unavailable.

If $CTCap_{i,k} < CMLP_k$, then the *pseudo-unit* is unavailable.

If $PRSTCap_{i,k} < SMLP \cdot (1 - CSCM_k)$, then the *pseudo-unit* is unavailable.

10.2.3.1.4 Step 4: Initialize the operating region parameters for interval $i \in I$ to the model parameter values:

Set $MLP_{i,k} = MMLP_k$.

Set $DR_{i,k} = MDR_k$.

Set $DF_{i,k} = MDF_k$.

10.2.3.1.5 Step 5: Apply the derating for the combustion turbine to the *dispatchable* region:

Calculate P so that $CMLP_k + P \cdot CTShareDR_k \cdot MDR_k = CTCap_{i,k}$; and

Set $DR_{i,k} = min(DR_{i,k}, P \cdot MDR_k)$.

10.2.3.1.6 Step 6: Apply the derating for the steam turbine to the duct firing and *dispatchable* regions for *pseudo-units* not operating in *single cycle mode*:

Calculate R so that $SMLP + R \cdot STShareDR_k \cdot MDR_k = PRSTCap_{i,k}$.

If $R \leq 1$, update $DF_{i,k} = 0$, and $DR_{i,k} = min(DR_{i,k}, R \cdot MDR_k)$.

If $R > 1$, update $DF_{i,k} = min(DF_{i,k}, PRSTCap_{i,k} - SMLP - STShareDR_k \cdot MDR_k)$.

10.2.4 Available Energy Laminations

10.2.4.1 The *real-time calculation engine* shall determine the *offer* quantity laminations that may be scheduled for *energy* and *operating reserve* in each operating region for interval $i \in I$ for each *pseudo-unit* $k \in \{1,..,K\}$, subject to section 10.2.4.2, where:

10.2.4.1.1 $QMLP_{i,k}$ designates the total quantity that may be scheduled in the *minimum loading point* region;

10.2.4.1.2 $QDR_{i,k}$ designates the total quantity that may be scheduled in the *dispatchable* region; and

10.2.4.1.3 $QDF_{i,k}$ designates the total quantity that may be scheduled in the duct firing region.

10.2.4.2 The available *offered* quantity laminations shall be subject to the following conditions:

$0 \leq QMLP_{i,k} \leq MLP_{i,k}$;

$0 \leq QDR_{i,k} \leq DR_{i,k}$;

$0 \leq QDF_{i,k} \leq DF_{i,k}$;

if $QMLP_{i,k} < MLP_{i,k}$, then the *pseudo-unit* is unavailable and $QDR_{i,k} = QDF_{i,k} = 0$; and

if $QDR_{i,k} < DR_{i,k}$, then $QDF_{i,k} = 0$.

10.3 Convert Physical Resource Constraints to Pseudo-Unit Constraints

10.3.1 The *real-time calculation engine* shall convert physical *resource* constraints to *pseudo-unit* constraints, where:

10.3.1.1 $PSUMin^{q}_{i,k}$ designates the minimum limitation on *pseudo-unit* k determined by translating constraint q. When constraint q does not provide a minimum limitation on *pseudo-unit* k, then $PSUMin^{q}_{i,k}$ shall be set equal to 0;

10.3.1.2 $PSUMax^{q}_{i,k}$ designates the maximum limitation on *pseudo-unit* k determined by translating constraint q. When constraint q does not provide a maximum limitation on *pseudo-unit* k, then $PSUMax^{q}_{i,k}$ shall be set equal to $MLP_{i,k}+DR_{i,k}+DF_{i,k}$; and

10.3.1.3 $CTCmtd_{i,k} \in \{0,1\}$ designates whether combustion turbine $k \in \{1,..K\}$ is considered committed in interval $i \in I$.

10.3.2 The *real-time calculation engine* shall calculate the minimum and maximum limitations, subject to section 10.3.3.1, as follows:

10.3.2.1 Minimum limitation: $MinDG_{i,k} = max_{q \in \{1,..Q\}} PSUMin^{q}_{i,k}$

10.3.2.2 Maximum limitation: $MaxDG_{i,k} = min_{q \in \{1,..Q\}} PSUMax^{q}_{i,k}$

where Q designates the number of constraints impacting a combined cycle *facility* that have been provided to the *real-time calculation engine*.

10.3.3 Pseudo-Unit Minimum and Maximum Constraints

10.3.3.1 *Pseudo-unit* minimum and maximum constraints shall be calculated as follows:

10.3.3.1.1 $PSUMin_{i,k} = PMin$ where $PMin$ shall be a minimum constraint provided on *pseudo-unit* $k \in \{1,..,K\}$ for interval $i \in I$; and

10.3.3.1.2 $PSUMax_{i,k} = PMax$ where $PMax$ shall be a maximum constraint provided on *pseudo-unit* $k \in \{1,..,K\}$ for interval $i \in I$.

10.3.4 Combustion Turbine Minimum and Maximum Constraints

10.3.4.1 If the *pseudo-unit* is not flagged to operate in *single cycle mode*, then the combustion turbine minimum constraint shall be converted to a *pseudo-unit* constraint as follows:

If $CTMin < MLP_{i,k} \cdot CTShareMLP_k$, then set

$STMinMLP = CTMin \cdot \left(\frac{STShareMLP_k}{CTShareMLP_k}\right)$,

$STMinDR = 0$.

Otherwise, if $CTMin \geq MLP_{i,k} \cdot CTShareMLP_k$, then set

$STMinMLP = MLP_{i,k} \cdot STShareMLP_k$,

$STMinDR = \left(CTMin\text{-}MLP_{i,k} \cdot CTShareMLP_k\right) \cdot \left(\frac{STShareDR_k}{CTShareDR_k}\right)$.

Therefore:

$PSUMin_{i,k} = CTMin + STMinMLP + STMinDR$.

10.3.4.2 If a *pseudo-unit* is flagged to operate in *single cycle mode*, then the combustion turbine minimum constraint shall be converted to a *pseudo-unit* constraint as follows:

$$PSUMin_{i,k} = CTMin.$$

10.3.4.3 If the *pseudo-unit* is not flagged to operate in *single cycle mode*, then the combustion turbine maximum constraint shall be converted to a *pseudo-unit* constraint as follows:

If $CTMax < MLP_{i,k} \cdot CTShareMLP_k$, then $PSUMax_{i,k} = 0$ and the *pseudo-unit* is unavailable.

Otherwise, calculate the value of the constraint on the steam turbine within the *minimum loading point* and *dispatchable* regions:

$$STMaxMLP = MLP_{i,k} \cdot STShareMLP_k$$

$$STMaxDR = \left(CTMax\text{-}MLP_{i,k} \cdot CTShareMLP_k\right) \cdot \left(\frac{STShareDR_k}{CTShareDR_k}\right)$$

$$PSUMax_{i,k} = CTMax + STMaxMLP + STMaxDR$$

10.3.4.4 If a *pseudo-unit* is flagged to operate in *single cycle mode*, then the combustion turbine maximum constraint shall be converted to a *pseudo-unit* constraint as follows:

$$PSUMax_{i,k} = CTMax.$$

10.3.5 Steam Turbine Minimum and Maximum Constraints

10.3.5.1 The *real-time calculation engine* shall convert a stream turbine minimum constraint to a *pseudo-unit* constraints as follows:

10.3.5.1.1 Step 1: Identify $A \subseteq \{1,..,K\}$, which designates the set of *pseudo-units* to which the constraint may be allocated where *pseudo-unit* $k \in \{1,..,K\}$ is placed in set A if and only if $CSCM_k = 0$ and $CTCmtd_{i,k} = 1$. If the set A is empty, then no further steps are required, otherwise proceed to Step 2.

10.3.5.1.2 Step 2: Determine the steam turbine portion of the capacity for *pseudo-unit* $k \in A$:

$$STCap_k = QMLP_{i,k} \cdot STShareMLP_k + QDR_{i,k} \cdot STShareDR_k + QDF_{i,k}.$$

10.3.5.1.3 Step 3: Allocate the $STMin$ constraint to each *pseudo-unit* $k \in A$, where $STMin$ constraint shall be allocated equally to each *pseudo-unit* $k \in A$, where $STPMin_k$ is limited by $STCap_k$.

10.3.5.1.4 Step 4: The steam turbine portion minimum constraint shall be converted to a *pseudo-unit* constraint ,where for each *pseudo-unit* $k \in A$:

If $STPMin_k < MLP_{i,k} \cdot STShareMLP_k$, then set

$CTMinMLP_k = STPMin_k \cdot \left(\frac{CTShareMLP_k}{STShareMLP_k}\right)$; and

$CTMinDR_k = 0$.

Otherwise, if $STPMin_k \geq MLP_{i,k} \cdot STShareMLP_k$, then set

$CTMinMLP_k = MLP_{i,k} \cdot CTShareMLP_k$; and

$CTMinDR_k = \left(STPMin_k - MLP_{i,k} \cdot STShareMLP_k\right) \cdot \left(\frac{CTShareDR_k}{STShareDR_k}\right)$.

Therefore:

$$PSUMin_{i,k} = STPMin_k + CTMinMLP_k + CTMinDR_k.$$

10.3.5.1.4 If *pseudo-units* with sufficient steam turbine capacity are not commited, then the *real-time calculation engine* shall not convert the entire quantity of the steam turbine minimum constraint to *pseudo-unit* constraints.

10.3.5.2 The steam turbine maximum constraint shall be converted to a *pseudo-unit* constraint as follows:

$$PRSTMax_{i,k} = \left(\frac{STAmt_{i,k}}{\sum_{w\in\{1,..,K\}} STAmt_{i,w}}\right) \cdot STMax.$$

If the converted steam turbine maximum constraint limits the steam turbine portion to below its *minimum loading point*, then

$$PSUMax_{i,k} = 0.$$

Otherwise, calculate R so that $SMLP + R \cdot STShareDR_k \cdot MDR_k = PRSTMax_{i,k}$

If $R \leq 1$, set $PSUMax_{i,k} = MLP_{i,k} + min(DR_{i,k}, R \cdot MDR_k)$.

If $R > 1$, set $PSUMax_{i,k} = MLP_{i,k} + DR_{i,k} + PRSTMax_{i,k} - SMLP - STShareDR_k \cdot MDR_k$.

10.3.5.3 If the steam turbine minimum and maximum constraints are equal but do not convert to equal *pseudo-unit* minimum and maximum constraints, then the steam turbine minimum constraint conversion in section 10.3.5.1 shall be used to determine equal *pseudo-unit* minimum and maximum constraints.

10.4 Steam Turbine Forced Outages

10.4.1 If the steam turbine experiences a *forced outage*, the *real-time calculation engine* shall evaluate the corresponding *pseudo-units* as being *offered* in *single cycle mode*.

10.5 Determination of Energy Management System MW Values for Pseudo-Units

10.5.1 The *real-time calculation engine* shall determine the effective *energy* management system MW value for each *pseudo-unit* from the *IESO's energy* management system MW values for the corresponding physical *resources*, where:

10.5.1.1 $CTTel_k$ designates the *energy* management system MW value for combustion turbine $k \in \{1,..,K\}$;

10.5.1.2 $STTel$ designates the *energy* management system MW value for the steam turbine;

10.5.1.3 $PSUTel_k$ designates the effective *energy* management system MW value for *pseudo-unit* $k \in \{1,..,K\}$;

10.5.1.4 $TMLP_k$ designates the effective *minimim loading point* operating range for the time at which *energy* management system MW value was determined;

10.5.1.5 TDR_k designates the effective *dispatchable* region operating range for the time at which *energy* management system MW value was determined; and

10.5.1.6 TDF_k, designates the effective duct firing region operating range for the time at which *energy* management system MW value was determined.

10.5.2 The *real-time calculation engine* shall determine the effective *energy* management system MW values for *pseudo-units* as follows:

10.5.2.1 Step 1: For all combustion turbines, assign the following *energy* management system MW values to the corresponding *pseudo-unit* $k \in \{1,..,K\}$:

10.5.2.1.1 $CTMLPTel_k$, which designates the MW value assigned to the combustion turbine's share of the *minimum loading point* region and is calculated as follows:

$$CTMLPTel_k = min\{CTTel_k, CTShareMLP_k \cdot TMLP_k\}.$$

10.5.2.1.2 $CTDRTel_k$, which designates the MW value assigned to the combustion turbine's share of the *dispatchable* region and is calculated as follows:

If $CTMLPTel_k < CTTel_k$, then set $CTDRTel_k = min\{(CTTel_k - CTMLPTel_k), CTShareDR_k \cdot TDR_k\}$

Otherwise, set $CTDRTel_k = 0$.

10.5.2.2 Step 2: Determine the maximum *energy* management system MW value for the steam turbine that may be assigned to the steam turbine's share of the *pseudo-unit's minimum loading point* and *dispatchable* regions based on the amount assigned to the combustion turbine's share of the *minimum loading point* and *dispatchable* regions. For *pseudo-unit* $k \in \{1,..,K\}$:

10.5.2.2.1 $STMLPMax_k$ designates the maximum MW value that may be assigned to the steam turbine's share of the *minimum loading point* region and is calculated as follows:

$$STMLPMax_k = CTMLPTel_k \cdot \left(\frac{STShareMLP_k}{CTShareMLP_k}\right).$$

10.5.2.2.2 $STDRMax_k$ designates the maximum MW value that may be assigned to the steam turbine's share of the *dispatchable* region and is calculated as follows:

$$STDRMax_k = CTDRTel_k \cdot \left(\frac{STShareDR_k}{CTShareDR_k}\right).$$

10.5.2.3 Step 3: Allocate the *energy* management system MW value for the steam turbine to the *minimum loading point* and *dispatchable* regions of the *pseudo-unit* in proportion to the maximum amount that may be allocated. For *pseudo-unit* $k \in \{1,..,K\}$:

10.5.2.3.1 $STMLPTel_k$ designates the MW value assigned to the steam turbine share of the *minimum loading point* region and is calculated as follows:

$$STMLPTel_k = min\left\{STMLPMax_k, \left(\frac{STMLPMax_k}{\sum_{w=1..K}(STMLPMax_w + STDRMax_w)}\right) \cdot STTel\right\}$$

10.5.2.3.2 $STDRTel_k$ designates the MW value assigned the steam turbine share of the *dispatchable* region and is calculated as follows

$$STDRTel_k = min\left\{STDRMax_k, \left(\frac{STDRMax_k}{\sum_{w=1..K}(STMLPMax_w + STDRMax_w)}\right) \cdot STTel\right\}$$

10.5.2.4 Step 4: Determine the remaining portion of the *energy* management system MW value for the steam turbine that is yet to be distributed ($STRemTel$) as follows:

$$STRemTel = STTel - \sum_{k=1..K}(STMLPTel_k + STDRTel_k)$$

10.5.2.5 Step 5: Determine the maximum *energy* management system MW value for the remaining steam turbine that may be assigned to the duct firing region for the *pseudo-unit* based on whether the *pseudo-unit* is fully loaded for its *minimum loading point* and *dispatchable* regions. For *pseudo-unit* $k \in \{1,..,K\}$:

10.5.2.5.1 $STDFMax_k$ designates the maximum MW value that may be assigned to the duct firing region and is calculated as follows:

If $(CTMLPTel_k + CTDRTel_k + STMLPTel_k + STDRTel_k) \geq TMLP_k + TDR_k$, then set $STDFMax_k = TDF_k$

Otherwise, set $STDFMax_k = 0$.

10.5.2.6 Step 6: Distribute the remaining portion of the *energy* management system MW value for the steam turbine to the duct firing regions of the *pseudo-unit* in proportion to the maximum amount that may be allocated. For *pseudo-unit* $k \in \{1,..,K\}$:

10.5.2.6.1 $STDFTel_k$ designates the MW value assigned to the duct firing region and is calculated as follows:

$$STDFTel_k = min\left\{STDFMax_k, \left(\frac{STDFMax_k}{\sum_{w=1..K} STDFMax_w}\right) \cdot STRemTel\right\}.$$

10.5.2.7 Step 7: Determine the effective real-time *energy* management system MW value for the *pseudo-unit* by summing the MW values assigned to operating regions of the *pseudo-unit*. For *pseudo-unit* $k \in \{1,..,K\}$:

$$PSUTel_k = CTMLPTel_k + CTDRTel_k + STMLPTel_k + STDRTel_k + STDFTel_k.$$

10.6 Conversion of Pseudo-Unit Schedules to Physical Resource Schedules

10.6.1 For a combined cycle *facility* with K combustion turbines and one steam turbine, the *real-time calculation engine* shall compute the following *energy* and *operating reserve* schedules for interval $i \in I$:

10.6.1.1 $CTE_{i,k}$ designates the *energy* schedule for combustion turbine $k \in \{1,..,K\}$;

10.6.1.2 $STPE_{i,k}$ designates the *energy* schedule for the steam turbine portion of *pseudo-unit* $k \in \{1,..,K\}$;

10.6.1.3 STE_i designates the *energy* schedule for the steam turbine;

10.6.1.4 $CT10S_{i,k}$ designates the synchronized *ten-minute operating reserve* schedule for combustion turbine $k \in \{1,..,K\}$;

10.6.1.5 $STP10S_{i,k}$ designates the synchronized *ten-minute operating reserve* schedule for the steam turbine portion of *pseudo-unit* $k \in \{1,..,K\}$;

10.6.1.6 $ST10S_i$ designates the synchronized *ten-minute operating reserve* schedule for the steam turbine;

10.6.1.7 $CT10N_{i,k}$ designates the non-synchronized *ten-minute operating reserve* schedule for combustion turbine $k \in \{1,..,K\}$;

10.6.1.8 $STP10N_{i,k}$ designates the non-synchronized *ten-minute operating reserve* schedule for the steam turbine portion of *pseudo-unit* $k \in \{1,..,K\}$;

10.6.1.9 $ST10N_i$ designates the non-synchronized *ten-minute operating reserve* schedule for the steam turbine;

10.6.1.10 $CT30R_{i,k}$ designates the *thirty-minute operating reserve* schedule for combustion turbine $k \in \{1,..,K\}$;

10.6.1.11 $STP30R_{i,k}$ designates the *thirty-minute operating reserve* schedule for the steam turbine portion of *pseudo-unit* $k \in \{1,..,K\}$; and

10.6.1.12 $ST30R_i$ designates the *thirty-minute operating reserve* schedule for the steam turbine.

10.6.2 The *real-time calculation engine* shall determine the following *energy* and *operating reserve* schedules for *pseudo-unit* $k \in \{1,..,K\}$ in interval $i \in I$:

10.6.2.1 $SE_{i,k}$ designates the total amount of *energy* scheduled and $SE_{i,k} = SEMLP_{i,k} + SEDR_{i,k} + SEDF_{i,k}$, where:

10.6.2.1.1 $SEMLP_{i,k}$ designates the portion of the schedule corresponding to the *minimum loading point* region, where $0 \leq SEMLP_{i,k} \leq QMLP_{i,k}$;

10.6.2.1.2 $SEDR_{i,k}$ designates the portion of the schedule corresponding to the *dispatchable* region, where $0 \leq SEDR_{i,k} \leq QDR_{i,k}$ and $SEDR_{i,k} > 0$ only if $SEMLP_{i,k} = QMLP_{i,k}$;

10.6.2.1.3 $SEDF_{i,k}$ designates the portion of the schedule corresponding to the duct firing region, where $0 \leq SEDF_{i,k} \leq QDF_{i,k}$ and $SEDF_{i,k} > 0$ only if $SEDR_{i,k} = QDR_{i,k}$;

10.6.2.2 $S10S_{i,k}$ designates the total amount of synchronized *ten-minute operating reserve* scheduled;

10.6.2.3 $S10N_{i,k}$ designates the total amount of non-synchronized *ten-minute operating reserve* scheduled. If the *pseudo-unit* cannot provide *operating reserve* from its duct firing region, then $0 \leq SE_{i,k} + S10S_{i,k} + S10N_{i,k} \leq QMLP_{i,k} + QDR_{i,k}$; and

10.6.2.4 $S30R_{i,k}$ designates the total amount of *thirty-minute operating reserve* scheduled, where $0 \leq SE_{i,k} + S10S_{i,k} + S10N_{i,k} + S30R_{i,k} \leq QMLP_{i,k} + QDR_{i,k} + QDF_{i,k}$.

10.6.3 The *real-time calculation engine* shall convert *pseudo-unit* schedules to physical *generation resource* schedules for *energy* and *operating reserve*, where:

10.6.3.1 $STOn \in \{0,1\}$ designates whether the steam turbine is currently online;

10.6.3.2 $CTE_{0,k}$ designates the initial *energy* schedule allocated to the combustion turbine $k \in \{1,..,K\}$; and

10.6.3.3 $STPE_{0,k}$ designates the initial *energy* schedule allocated to the steam turbine portion of *pseudo-unit* $k \in \{1,..,K\}$.

10.6.4 The *real-time calculation engine* shall convert *pseudo-unit* schedules to physical *resource* schedules for *energy* and *operating reserve*, as follows:

10.6.4.1 If $SE_{i,k} \geq MLP_{i,k}$, then:

$CTE_{i,k} = SEMLP_{i,k} \cdot CTShareMLP_k + SEDR_{i,k} \cdot CTShareDR_k$;

$STPE_{i,k} = SEMLP_{i,k} \cdot STShareMLP_k + SEDR_{i,k} \cdot STShareDR_k + SEDF_{i,k}$;

$RoomDR_{i,k} = QDR_{i,k} - SEDR_{i,k}$;

$10SDR_{i,k} = min(RoomDR_{i,k}, S10S_{i,k})$;

$10NDR_{i,k} = min(RoomDR_{i,k} - 10SDR_{i,k}, S10N_{i,k})$;

$30RDR_{i,k} = min(RoomDR_{i,k} - 10SDR_{i,k} - 10NDR_{i,k}, S30R_{i,k})$;

$CT10S_{i,k} = 10SDR_{i,k} \cdot CTShareDR_k$;

$STP10S_{i,k} = 10SDR_{i,k} \cdot STShareDR_k + (S10S_{i,k} - 10SDR_{i,k})$;

$CT10N_{i,k} = 10NDR_{i,k} \cdot CTShareDR_k$;

$STP10N_{i,k} = 10NDR_{i,k} \cdot STShareDR_k + (S10N_{i,k} - 10NDR_{i,k})$;

$CT30R_{i,k} = 30RDR_{i,k} \cdot CTShareDR_k$; and

$STP30R_{i,k} = 30RDR_{i,k} \cdot STShareDR_k + (S30R_{i,k} - 30RDR_{i,k})$.

10.6.4.2 If $SE_{i,k} < MLP_{i,k}$ and is on a ramp up trajectory, then the *energy* schedules for the combustion turbine and steam turbine are determined as follows:

10.6.4.3 If the steam turbine is not online, then the *pseudo-unit* schedule will be assigned to the combustion turbine as follows:

$CTE_{i,k} = SE_{i,k}$; and

$STPE_{i,k} = 0$.

10.6.4.4 If the steam turbine is online, the incremental *pseudo-unit* schedule will be assigned to the steam turbine until the assigned combustion turbine and steam turbine schedules adhere to the *pseudo-unit* model as follows:

If $\left(\frac{STPE_{i-1,k}}{STPE_{i-1,k}+CTE_{i-1,k}}\right) < STShareMLP_k$, then

$CTE_{i,k} = CTE_{i-1,k}$,

$STPE_{i,k} = SE_{i,k} - CTE_{i-1,k}$.

Otherwise:

$CTE_{i,k} = SE_{i,k} \cdot CTShareMLP_k$; and

$STPE_{i,k} = SE_{i,k} \cdot STShareMLP_k$.

10.6.4.5 If $SE_{i,k} < MLP_{i,k}$ and is on a ramp-down trajectory, then the *energy* schedules for the combustion turbine and steam turbine are determined as follows:

10.6.4.6 If the steam turbine is not online, then the *pseudo-unit* schedule will be assigned to the combustion turbine as follows:

$CTE_{i,k} = SE_{i,k}$; and

$STPE_{i,k} = 0$.

10.6.4.7 If the steam turbine is online, the *pseudo-unit* schedule will be assigned according to the *pseudo-unit* model as follows

$CTE_{i,k} = SE_{i,k} \cdot CTShareMLP_k$; and

$STPE_{i,k} = SE_{i,k} \cdot STShareMLP_k$.

10.6.4.8 If $SE_{i,k} < MLP_{i,k}$, then the *operating reserve* schedules for the combustion turbine and steam turbine are as follows:

$S10S_{i,k} = S10N_{i,k} = S30R_{i,k} = 0$;

$CT10S_{i,k} = 0$;

$STP10S_{i,k} = 0$;

$CT10N_{i,k} = 0$;

$STP10N_{i,k} = 0$;

$CT30R_{i,k} = 0$; and

$STP30R_{i,k} = 0$.

10.6.4.9 The steam turbines portion schedules from section 10.6.4.1 through 10.6.4.8 shall be summed to obtain the steam turbine schedule as follows:

$$STE_i = \sum_{k=1,\dots,K} STPE_{i,k} ;$$

$$ST10S_i = \sum_{k=1,\dots,K} STP10S_{i,k} ;$$

$$ST10N_i = \sum_{k=1,\dots,K} STP10N_{i,k} ;$$

and

$$ST30R_i = \sum_{k=1,\dots,K} STP30R_{i,k} ;$$

11 Pricing Formulas

11.1 Purpose

11.1.1 The *real-time calculation engine* shall calculate *locational marginal prices* using shadow prices, constraint sensitivities and marginal loss factors.

11.2 Sets, Indices and Parameters

11.2.1 The sets, indices and parameters used to calculate *locational marginal prices* are described in section 4. In addition, the following shadow prices from Pass 1 shall be used:

11.2.1.1 $SPEmT^1_{i,c,f}$ designates the Pass 1 shadow price for the post-contingency transmission constraint for *facility* $f \in F$ in contingency $c \in C$ in interval *i*;

11.2.1.2 SPL^1_i designates the Pass 1 shadow price for the *energy* balance constraint in interval *i*;

11.2.1.3 $SPNormT^1_{i,f}$ designates the Pass 1 shadow price for the pre-contingency transmission constraint for *facility* $f \in F$ in interval *i*;

11.2.1.4 $SP10S^1_i$ designates the Pass 1 shadow price for the total synchronized *ten-minute operating reserve* requirement constraint in interval *i*;

11.2.1.5 $SP10R^1_i$ designates the Pass 1 shadow price for the total *ten-minute operating reserve* requirement constraint in interval *i*;

11.2.1.6 $SP30R^1_i$ designates the Pass 1 shadow price for the total *thirty-minute operating reserve* requirement constraint in interval *i*;

11.2.1.7 $SPREGMin10R^1_{i,r}$ designates the Pass 1 shadow price for the minimum *ten-minute operating reserve* constraint for region $r \in ORREG$ in interval *i*;

11.2.1.8 $SPREGMin30R^1_{i,r}$ designates the Pass 1 shadow price for the minimum *thirty-minute operating reserve* constraint for region $r \in ORREG$ in interval *i*;

11.2.1.9 $SPREGMax10R^1_{i,r}$ designates the Pass 1 shadow price for the maximum *ten-minute operating reserve* constraint for region $r \in ORREG$ in interval *i*;

11.2.1.10 $SPREGMax30R^1_{i,r}$ designates the Pass 1 shadow price for the maximum *thirty-minute operating reserve* constraint for region $r \in ORREG$ in interval *i*.

11.3 Locational Marginal Prices for Energy

11.3.1 Energy Locational Marginal Prices for Delivery Points

11.3.1.1 The *real-time calculation engine* shall calculate a *locational marginal price* and components for *energy* for Pass 1 and each interval $i \in I$ for every bus $b \in L$ and:

11.3.1.1.1 $LMP^1_{i,b}$ designates the Pass 1 interval i *locational marginal price* for *energy*;

11.3.1.1.2 $PRef^1_i$ designates the Pass 1 interval i *locational marginal price* for *energy* at the *reference bus*;

11.3.1.1.3 $PLoss^1_{i,b}$ designates the Pass 1 interval i loss component; and

11.3.1.1.4 $PCong^1_{i,b}$ designates the Pass 1 interval i congestion component.

11.3.1.2 The *real-time calculation engine* shall calculate an initial *locational marginal price* for *energy*, a *locational marginal price* for *energy* at the *reference bus*, a loss component and a congestion component for Pass 1 at bus $b \in L$ in interval $i \in I$, as follows:

$$InitLMP^1_{i,b} = InitPRef^1_i + InitPLoss^1_{i,b} + InitPCong^1_{i,b}$$

where:

$$InitPRef^1_i = SPL^1_i;$$

$$InitPLoss^1_{i,b} = MglLoss_{i,b} \cdot SPL^1_i;$$

and

$$InitPCong^1_{i,b} = \sum_{f \in F_i} PreConSF_{i,f,b} \cdot SPNormT^1_{i,f} + \sum_{c \in C} \sum_{f \in F_{i,c}} SF_{i,c,f,b} \cdot SPEmT^1_{i,c,f}.$$

11.3.1.3 If the initial *locational marginal price* for *energy* at the *reference bus* ($InitPRef^1_i$) is not within the *settlement* bounds ($EngyPrcFlr, EngyPrcCeil$), then the *real-time calculation engine* shall modify the *locational marginal price* for *energy* at the *reference bus* as follows:

If $InitPRef^1_i > EngyPrcCeil$, set $PRef^1_i = EngyPrcCeil$

If $InitPRef^1_i < EngyPrcFlr$, set $PRef^1_i = EngyPrcFlr$

Otherwise, set $PRef_i^1 = InitPRef_i^1$

11.3.1.4 If the initial *locational marginal price* for *energy* ($InitLMP_{i,b}^1$) is not within the *settlement* bounds ($EngyPrcFlr, EngyPrcCeil$), then the *real-time calculation engine* shall modify the *locational marginal price* for *energy* as follows:

If $InitLMP_{i,b}^1 > EngyPrcCeil$, set $LMP_{i,b}^1 = EngyPrcCeil$.

If $InitLMP_{i,b}^1 < EngyPrcFlr$, set $LMP_{i,b}^1 = EngyPrcFlr$.

Otherwise, set $LMP_{i,b}^1 = InitLMP_{i,b}^1$

11.3.1.5 The *real-time calculation engine* shall modify the loss component as follows:

If $PRef_i^1 \neq InitPRef_i^1$, set $PLoss_{i,b}^1 = MglLoss_{i,b} \cdot PRef_i^1$

Otherwise, set $PLoss_{i,b}^1 = InitPLoss_{i,b}^1$

11.3.1.6 The *real-time calculation engine* shall modify the congestion component as follows:

If $LMP_{i,b}^1 - PRef_i^1 - PLoss_{i,b}^1$ and $InitPCong_{i,b}^1$ have the same mathematical sign, then set $PCong_{i,b}^1 = LMP_{i,b}^1 - PRef_i^1 - PLoss_{i,b}^1$

Otherwise, set $PCong_{i,b}^1 = 0$ and set $PLoss_{i,b}^1 = LMP_{i,b}^1 - PRef_i^1$

11.3.2 Energy Locational Marginal Prices for Intertie Metering Points

11.3.2.1 The *real-time calculation engine* shall calculate a *locational marginal price* and components for *energy* for Pass 1 and each interval $i \in I$ for *intertie zone* bus $d \in D$, where:

11.3.2.1.1 $ExtLMP_{i,d}^{PD}$ designates the *locational marginal price* for *energy* for the *dispatch hour* in which interval *i* falls as calculated by the *pre-dispatch calculation engine*;

11.3.2.1.2 $ICP_{i,d}^1$ designates the Pass 1 interval *i intertie congestion price*;

11.3.2.1.3 $ICP_{i,d}^{PD}$ designates the *intertie congestion price* for the *dispatch hour* in which interval *i* falls as calculated by the *pre-dispatch calculation engine*;

11.3.2.1.4 $IntLMP_{i,d}^1$ designates the Pass 1 interval *i intertie border price* for *energy*;

11.3.2.1.5 $ExtLMP_{i,d}^1$ designates the Pass 1 interval *i locational marginal price* for *energy*;

11.3.2.1.6 $PExtCong^{1}_{i,d}$ designates the Pass 1 interval i external congestion component for the *intertie congestion price*;

11.3.2.1.7 $PExtCong^{PD}_{i,d}$ designates the external congestion component for the *intertie congestion price* for the *dispatch hour* in which interval i falls as calculated by the *pre-dispatch calculation engine*;

11.3.2.1.8 $PIntCong^{1}_{i,d}$ designates the Pass 1 interval i internal congestion component for *energy*;

11.3.2.1.9 $PLoss^{1}_{i,d}$ designates the Pass 1 interval i loss component;

11.3.2.1.10 $PNISL^{1}_{i,d}$ designates the Pass 1 interval i net interchange scheduling limit congestion component for the *intertie congestion price*;

11.3.2.1.11 $PNISL^{PD}_{i,d}$ designates the net interchange scheduling limit congestion component for the *intertie congestion price* for the *dispatch hour* in which interval i falls as calculated by the *pre-dispatch calculation engine*; and

11.3.2.2 The *real-time calculation engine* shall calculate an *intertie border price* for *energy*, a *locational marginal price* for *energy* for the *reference bus*, a loss component and a congestion component for *energy* for Pass 1 at *intertie zone* bus $d \in D_a$ in *intertie zone* $a \in A$ in interval $i \in I$, subject to section 11.3.2.11, as follows:

$$InitIntLMP^{1}_{i,d} = InitPRef^{1}_{i} + InitPLoss^{1}_{i,d} + InitPIntCong^{1}_{i,d}$$

where

$InitPRef^{1}_{i} = SPL^{1}_{i}$;

$InitPLoss^{1}_{i,d} = MglLoss_{i,d} \cdot SPL^{1}_{i}$;

and

$$InitPIntCong^{1}_{i,d} = \sum_{f \in F_i} PreConSF_{i,f,d} \cdot SPNormT^{1}_{i,f} + \sum_{c \in C} \sum_{f \in F_{i,c}} SF_{i,c,f,d} \cdot SPEmT^{1}_{i,c,f}$$

11.3.2.3 If there is import congestion in pre-dispatch such that $ICP_{i,d}^{PD} < 0$, the *real-time calculation engine* shall calculate an initial *locational marginal price*, an *intertie congestion price*, and the net interchange scheduling limit congestion component for the *intertie congestion price* for *energy* for Pass 1 at *intertie zone* bus $d \in D$ in interval $i \in I$ as follows:

$$InitExtLMP_{i,d}^{1} = min\left(InitIntLMP_{i,d}^{1}, ExtLMP_{i,d}^{PD}\right);$$

$$InitICP_{i,d}^{1} = InitExtLMP_{i,d}^{1} - InitIntLMP_{i,d}^{1};$$

where:

If $InitExtLMP_{i,d}^{1} = InitIntLMP_{i,d}^{1}$, then $InitICP_{i,d}^{1} = 0$ and $InitPNISL_{i,d}^{1} = 0;$

and

If $InitExtLMP_{i,d}^{1} = ExtLMP_{i,d}^{PD}$, then $InitICP_{i,d}^{1}$ and $InitPNISL_{i,d}^{1}$ shall be prorated based on their pre-dispatch magnitudes so that their sum equals the effective real-time *intertie congestion price*.

11.3.2.4 If there is export congestion in pre-dispatch such that $ICP_{i,d}^{PD} > 0$, the *real-time calculation engine* shall calculate an initial *locational marginal price*, an *intertie congestion price*, and the net interchange scheduling limit congestion component for the *intertie congestion price* for *energy* for Pass 1 at *intertie zone* bus $d \in D$ in interval $i \in I$ as follows:

$$InitExtLMP_{i,d}^{1} = InitIntLMP_{i,d}^{1} + InitICP_{i,d}^{1}$$

where:

$$InitICP_{i,d}^{1} = InitPExtCong_{i,d}^{1} + InitPNISL_{i,d}^{1};$$

$$InitPExtCong_{i,d}^{1} = PExtCong_{i,d}^{PD};$$

and

$$InitPNISL_{i,d}^{1} = PNISL_{i,d}^{PD}.$$

11.3.2.5 If there is no *intertie* congestion in pre-dispatch such that $ICP_{i,d}^{PD} = 0$ or an *intertie zone* is out-of-service in real-time, then the *real-time calculation engine* shall calculate an initial *locational marginal price*, an *intertie congestion price*, and the net interchange scheduling limit congestion component for the *intertie congestion price* for *energy* for Pass 1 at *intertie zone* bus $d \in D$ in interval $i \in I$ as follows:

$$InitExtLMP_{i,d}^{1} = InitIntLMP_{i,d}^{1} + InitICP_{i,d}^{1}$$

where

$InitICP^{1}_{i,d} = InitPExtCong^{1}_{i,d} + InitPNISL^{1}_{i,d} = 0$

$InitPExtCong^{1}_{i,d} = PExtCong^{PD}_{i,d}$;

and

$InitPNISL^{1}_{i,d} = PNISL^{PD}_{i,d}$.

11.3.2.6 If the *intertie border price* for *energy* ($InitIntLMP^{1}_{i,d}$) is not within the *settlement* bounds ($EngyPrcFlr, EngyPrcCeil$), then the *real-time calculation engine* shall modify the *intertie border price* for *energy*, and its components, as follows:

11.3.2.6.1 The initial *locational marginal price* for the *reference bus* ($InitPRef^{1}_{i}$) shall be modified as per section 11.3.1.3;

11.3.2.6.2 The initial *intertie border price* ($InitIntLMP^{1}_{i,d}$) shall be modified as per section 11.3.1.4, where $InitLMP^{1}_{i,b} = InitIntLMP^{1}_{i,d}$;

11.3.2.6.3 The initial loss component ($InitPLoss^{1}_{i,d}$) shall be modified as per section 11.3.1.5; and

11.3.2.6.4 The initial internal congestion component ($InitPIntCong^{1}_{i,d}$) shall be modified as per section 11.3.1.6, where $InitPCong^{1}_{i,b} = InitPIntCong^{1}_{i,d}$.

11.3.2.7 If the initial *locational marginal price* for *energy* ($InitExtLMP^{1}_{i,d}$) is not within the *settlement* bounds ($EngyPrcFlr, EngyPrcCeil$), then the *real-time calculation engine* shall modify the *locational marginal price* for *energy*, as follows:

If $InitExtLMP^{1}_{i,d} > EngyPrcCeil$, set $ExtLMP^{1}_{i,d} = EngyPrcCeil$.

If $InitExtLMP^{1}_{i,d} < EngyPrcFlr$, set $ExtLMP^{1}_{i,d} = EngyPrcFlr$.

Otherwise, set $ExtLMP^{1}_{i,d} = InitExtLMP^{1}_{i,d}$.

11.3.2.8 If the modified *locational marginal price* for *energy* ($ExtLMP^{1}_{i,d}$) determined in section 11.3.2.7 is equal to the *intertie border price* for *energy* ($IntLMP^{1}_{i,d}$), then the *real-time calculation engine* shall modify the external congestion component for the *intertie congestion price* and net interchange scheduling limit congestion component for the *intertie congestion price*, as follows:

If $ExtLMP^{1}_{i,d} = IntLMP^{1}_{i,d}$, set $PExtCong^{1}_{i,d} = 0$ and $PNISL^{1}_{i,d} = 0$.

11.3.2.9 If the modified *locational marginal price* for *energy* ($ExtLMP^1_{i,d}$) determined in section 11.3.2.7 is not equal to the *intertie border price* for *energy* ($IntLMP^1_{i,d}$), then the *real-time calculation engine* shall modify the external congestion component for the *intertie congestion price* and net interchange scheduling limit congestion component for the *intertie congestion price*, as follows:

If $ExtLMP^1_{i,d} \neq IntLMP^1_{i,d}$, then set

$$PNISL^1_{i,d} = (ExtLMP^1_{i,d} - IntLMP^1_{i,d}) \cdot \left(\frac{InitPNISL^1_{i,d}}{InitPNISL^1_{i,d} + InitPExtCong^1_{i,d}}\right).$$

If $PNISL^1_{i,d} > NISLPen$, then set $PNISL^1_{i,d} = NISLPen$;

If $PNISL^1_{i,d} < (-1) \cdot NISLPen$, then set $PNISL^1_{i,d} = (-1) \cdot NISLPen$; and

Set $PExtCong^1_{i,d} = ExtLMP^1_{i,d} - IntLMP^1_{i,d} - PNISL^1_{i,d}$

11.3.2.10 The *real-time calculation engine* shall calculate the *intertie congestion price* as follows:

$$ICP^1_{i,d} = PExtCong^1_{i,d} + PNISL^1_{i,d}.$$

11.3.2.11 The *locational marginal price* for *energy* calculated by the *real-time calculation engine* shall be the same for all *boundary entity resource* buses at the same *intertie zone*. *Intertie* transactions associated with the same *boundary entity resource* bus, but specified as occurring at different *intertie zones*, subject to phase shifter operation, shall be modelled as flowing across independent paths. Pricing of these transactions shall utilize shadow prices associated with the internal transmission constraints, *intertie* limits and transmission losses applicable to the path associated to the relevant *intertie zone*.

11.3.3 Zonal Prices for Energy

11.3.3.1 The *real-time calculation engine* shall calculate the zonal price for *energy* and its components for Pass 1 and each interval $i \in I$, the *energy* price for *virtual transaction zone* $m \in M$, as follows:

$$VZonalP^1_{i,m} = PRef^1_i + VZonalPLoss^1_{i,m} + VZonalPCong^1_{i,m}$$

where:

$$VZonalPLoss^1_{i,m} = \sum_{b \in L^{VIRT}_m} WF^{VIRT}_{i,m,b} \cdot PLoss^1_{i,b}$$

and

$$VZonalPCong_{i,m}^{1} = \sum_{b \in L_m^{VIRT}} WF_{i,m,b}^{VIRT} \cdot PCong_{i,b}^{1}$$

11.3.3.2 The *real-time calculation engine* shall calculate the zonal price for *energy* and its components for Pass 1 and each interval $i \in I$ for *non-dispatchable load* zone $y \in Y$, as follows:

$$ZonalP_{i,y}^{1} = PRef_i^1 + ZonalPLoss_{i,y}^{1} + ZonalPCong_{i,y}^{1}$$

where:

$$ZonalPLoss_{i,y}^{1} = \sum_{b \in L_y^{NDL}} WF_{i,y,b}^{NDL} \cdot PLoss_{i,b}^{1}$$

and

$$ZonalPCong_{i,y}^{1} = \sum_{b \in L_y^{NDL}} WF_{i,y,b}^{NDL} \cdot PCong_{i,b}^{1}$$

11.3.3.3 The *Ontario zonal price* is calculated per section 11.3.3.2 where the *non-dispatchable load* zone is comprised of all *non-dispatchable loads* within Ontario.

11.3.4 Pseudo-Unit Pricing

11.3.4.1 The *real-time calculation engine* shall calculate a *locational marginal price* and components for *energy* for Pass 1 and each interval $i \in I$ for every *pseudo-unit* $k \in \{1,..,K\}$, where:

11.3.4.1.1 $CTMglLoss_{i,k}^{1}$ designates the marginal loss factor for the combustion turbine identified by *pseudo-unit* k for each interval i in Pass 1;

11.3.4.1.2 $STMglLoss_{i,k}^{p}$ designates the marginal loss factor for the steam turbine identified by *pseudo-unit* k for each interval i in Pass 1;

11.3.4.1.3 $CTPreConSF_{i,f,k}$ designates the pre-contingency sensitivity factor for the combustion turbine identified by *pseudo-unit* k on *facility* f during interval i under pre-contingency conditions;

11.3.4.1.4 $STPreConSF_{i,f,k}$ designates the pre-contingency sensitivity factor for the steam turbine identified by *pseudo-unit* k on *facility* f during interval i under pre-contingency conditions;

11.3.4.1.5 $CTSF_{i,c,f,k}$ designates the post-contingency sensitivity factor for the combustion turbine identified by *pseudo-unit* k on *facility* f during interval i under post-contigency conditions for contingency c; and

11.3.4.1.6 $STSF_{i,c,f,k}$ designates the post-contingency sensitivity factor for the steam turbine identified by *pseudo-unit* k on *facility* f during interval i under post-contingency conditions for contingency c.

11.3.4.2 The *real-time calculation engine* shall calculate an initial *locational marginal price* for *energy*, a *locational marginal price* for *energy* at the *reference bus*, a loss component and a congestion component for Pass 1 and each interval i for every *pseudo-unit* $k \in \{1,..,K\}$, as follows:

$$InitLMP_{i,k}^{1} = InitPRef_{i}^{1} + InitPLoss_{i,k}^{1} + InitPCong_{i,k}^{1}$$

where:

$$InitPRef_{i}^{1} = SPL_{i}^{1};$$

$$InitPLoss_{i,k}^{1} = MglLoss_{i,k}^{1} \cdot SPL_{i}^{1};$$

and

$$InitPCong_{i,k}^{1} = \sum_{f \in F_i} PreConSF_{i,f,k} \cdot SPNormT_{i,f}^{1} + \sum_{c \in C} \sum_{f \in F_{i,c}} SF_{i,c,f,k} \cdot SPEmT_{i,c,f}^{1}$$

11.3.4.3 If *pseudo-unit* $k \in \{1,..,K\}$ is scheduled within its *minimum loading point* range or not scheduled at all, its marginal loss and sensitivity factors shall be:

$$MglLoss_{i,k}^{1} = CTShareMLP_k \cdot CTMglLoss_{i,k}^{1} + STShareMLP_k \cdot STMglLoss_{i,k}^{1}$$

$$PreConSF_{i,f,k} = CTShareMLP_k \cdot CTPreConSF_{i,f,k} + STShareMLP_k \cdot STPreConSF_{i,f,k}$$

$$SF_{i,c,f,k} = CTShareMLP_k \cdot CTSF_{i,c,f,k} + STShareMLP_k \cdot STSF_{i,c,f,k}$$

11.3.4.4 If *pseudo-unit* $k \in \{1,..,K\}$ is scheduled within its *dispatchable* region, its marginal loss and sensitivity factors shall be:

$$MglLoss_{i,k}^{1} = CTShareDR_k \cdot CTMglLoss_{i,k}^{1} + STShareDR_k \cdot STMglLoss_{i,k}^{1}$$

$$PreConSF_{i,f,k} = CTShareDR_k \cdot CTPreConSF_{i,f,k} + STShareDR_k \cdot STPreConSF_{i,f,k}$$

$$SF_{i,c,f,k} = CTShareDR_k \cdot CTSF_{i,c,f,k} + STShareDR_k \cdot STSF_{i,c,f,k}$$

11.3.4.5 If *pseudo-unit* $k \in \{1,..,K\}$ is scheduled within its duct firing region, its marginal loss and sensitivity factors shall be:

$$MglLoss_{i,k}^{1} = STMglLoss_{i,k}^{1}$$

$$PreConSF_{i,f,k} = STPreConSF_{i,f,k}$$

$$SF_{i,c,f,k} = STSF_{i,c,f,k}$$

11.4 Locational Marginal Prices for Operating Reserve

11.4.1 Operating Reserve Locational Marginal Prices for Delivery Points

11.4.1.1 The *real-time calculation engine* shall calculate *locational marginal price*s and components for *operating reserve* for Pass 1 and each interval i for a *delivery point* associated with the *dispatchable generation resource* or *dispatchable load* bus $b \in B$, where:

11.4.1.1.1 $L30RP_{i,b}^{1}$ designates the Pass 1 interval i *locational marginal price* for *thirty-minute operating reserve*;

11.4.1.1.2 $P30RRef_{i}^{1}$ designates the Pass 1 interval i *locational marginal price* for *thirty-minute operating reserve* at the *reference bus*;

11.4.1.1.3 $P30RCong_{i,b}^{1}$ designates the Pass 1 interval i congestion component for *thirty-minute operating reserve*;

11.4.1.1.4 $L10NP_{i,b}^{1}$ designates the Pass 1 interval i *locational marginal price* for non-synchronized *ten-minute operating reserve*;

11.4.1.1.5 $P10NRef_{i}^{1}$ designates the Pass 1 interval i *locational marginal price* for non-synchronized *ten-minute operating reserve* at the *reference bus*;

11.4.1.1.6 $P10NCong_{i,b}^{1}$ designates the Pass 1 interval i congestion component for non-synchronized *ten-minute operating reserve*;

11.4.1.1.7 $L10SP_{i,b}^{1}$ designates the Pass 1 interval i *locational marginal price* for synchronized *ten-minute operating reserve*;

11.4.1.1.8 $P10SRef_{i}^{1}$ designates the Pass 1 interval i *locational marginal price* for synchronized *ten-minute operating reserve* at the *reference bus*;

11.4.1.1.9 $P10SCong^1_{i,b}$ designates the Pass 1 interval i congestion component for synchronized *ten-minute operating reserve*; and

11.4.1.1.10 $ORREG_b \subseteq ORREG$ as the subset of $ORREG$ consisting of regions that include bus b.

11.4.1.2 The *real-time calculation engine* shall calculate an initial *locational marginal price*, a *locational marginal price* at the *reference bus*, and congestion components for Pass 1 for a *delivery point* associated with the *dispatchable generation resource* or *dispatchable load* at bus $b \in B$ in interval $i \in I$ for each class of *operating reserve*, as follows:

$$InitL30RP^1_{i,b} = InitP30RRef^1_i + InitP30RCong^1_{i,b}$$

where:

$$InitP30RRef^1_i = SP30R^1_i$$

and

$$InitP30RCong^1_{i,b} = \sum_{r \in ORREG_b} SPREGMin30R^1_{i,r} - \sum_{r \in ORREG_b} SPREGMax30R^1_{i,r}$$

$$InitL10NP^1_{i,b} = InitP10NRef^1_i + InitP10NCong^1_{i,b}$$

where:

$$InitP10NRef^1_i = SP10R^1_i + SP30R^1_i$$

and

$$InitP10NCong^1_{i,b} = \sum_{r \in ORREG_b} \left(SPREGMin10R^1_{i,r} + SPREGMin30R^1_{i,r}\right) - \sum_{r \in ORREG_b} \left(SPREGMax10R^1_{i,r} + SPREGMax30R^1_{i,r}\right)$$

$$InitL10SP^1_{i,b} = InitP10SRef^1_i + InitP10SCong^1_{i,b}$$

where:

$$InitP10SRef^1_i = SP10S^1_i + SP10R^1_i + SP30R^1_i$$

and

$$InitP10SCong_{i,b}^{1} = \sum_{r \in ORREG_b} \left(SPREGMin10R_{i,r}^{1} + SPREGMin30R_{i,r}^{1}\right) - \sum_{r \in ORREG_b} \left(SPREGMax10R_{i,r}^{1} + SPREGMax30R_{i,r}^{1}\right)$$

11.4.1.3 If the initial *locational marginal price* at the *reference bus* ($InitP30RRef_i^1$, $InitP10NRef_i^1$ or $InitP10SRef_i^1$,) is not within the *settlement* bounds ($ORPrcFlr$, $ORPrcCeil$), then the *real-time calculation engine* shall modify the *locational marginal price* at the *reference bus* for each class of *operating reserve* as follows:

If $InitP30RRef_i^1 > ORPrcCeil$, set $P30RRef_i^1 = ORPrcCeil$;

If $InitP30RRef_i^1 < ORPrcFlr$, set $P30RRef_i^1 = ORPrcFlr$;

Otherwise, set $P30RRef_t^1 = InitP30RRef_i^1$.

If $InitP10NRef_i^1 > ORPrcCeil$, set $P10NRef_i^1 = ORPrcCeil$

If $InitP10NRef_i^1 < ORPrcFlr$, set $P10NRef_i^1 = ORPrcFlr$

Otherwise, set $P10NRef_i^1 = InitP10NRef_i^1$

If $InitP10SRef_i^1, ORPrcFlr > ORPrcCeil$, set $P10SRef_i^1 = ORPrcCeil$

If $InitP10SRef_i^1, ORPrcFlr < ORPrcFlr$, set $P10SRef_i^1 = ORPrcFlr$

Otherwise, set $P10SRef_i^1 = InitP10SRef_i^1$

11.4.1.4 If the initial *locational marginal price* ($InitL30RP_{i,b}^1$, $InitL10NP_{i,b}^1$, or $InitL10SP_{i,b}^1$) is not within the *settlement* bounds ($ORPrcFlr$, $ORPrcCeil$), then the *real-time calculation engine* shall modify the *locational marginal price* for each class of *operating reserve* as follows:

If $InitL30RP_{i,b}^1 > ORPrcCeil$, set $L30RP_{i,b}^1 = ORPrcCeil$;

If $InitL30RP_{i,b}^1 < ORPrcFlr$, set $L30RP_{i,b}^1 = ORPrcFlr$;

Otherwise, set $L30RP_{i,b}^1 = InitL30RP_{i,b}^1$.

If $InitL10NP_{i,b}^1 > ORPrcCeil$, set $L10NP_{i,b}^1 = ORPrcCeil$;

If $InitL10NP_{i,b}^1 < ORPrcFlr$, set $L10NP_{i,b}^1 = ORPrcFlr$;

Otherwise, set $L10NP_{i,b}^1 = InitL10NP_{i,b}^1$.

If $InitL10SP^{1}_{i,b} > ORPrcCeil$, set $L10SP^{1}_{i,b} = ORPrcCeil$;

If $InitL10SP^{1}_{i,b} < ORPrcFlr$, set $L10SP^{1}_{i,b} = ORPrcFlr$;

Otherwise, set $L10SP^{1}_{i,b} = InitL10SP^{1}_{i,b}$.

11.4.1.5 If the initial *locational marginal price* ($InitL30RP^{1}_{i,b}$, $InitL10NP^{1}_{i,b}$, or $InitL10SP^{1}_{i,b}$) is not within the *settlement* bounds ($ORPrcFlr$, $ORPrcCeil$), then the *real-time calculation engine* shall modify the congestion component for each class of *operating reserve* as follows:

Set $P30RCong^{1}_{i,b} = L30RP^{1}_{i,b} - P30RRef^{1}_{i}$;

Set $P10NCong^{1}_{i,b} = L10NP^{1}_{i,b} - P10NRef^{1}_{i}$; and

Set $P10SCong^{1}_{i,b} = L10SP^{1}_{i,b} - P10SRef^{1}_{i}$.

11.4.2 Operating Reserve Locational Marginal Prices for Intertie Metering Points

11.4.2.1 The *real-time calculation engine* shall calculate *locational marginal prices* and components for *operating reserve* for Pass 1 and each interval $i \in I$, for *intertie zone* bus $d \in D$, where:

11.4.2.1.1 $ExtL30RP^{1}_{i,d}$ designates the Pass 1 interval *i locational marginal price* for *thirty-minute operating reserve*;

11.4.2.1.2 $ExtL30RP^{PD}_{i,d}$ designates the *locational marginal price* for *thirty-minute operating reserve* for the *dispatch hour* in which interval *i* falls as calculated by the *pre-dispatch calculation engine*;

11.4.2.1.3 $P30RExtCong^{1}_{i,d}$ designates the Pass 1 interval *i intertie* congestion component for *thirty-minute operating reserve*;

11.4.2.1.4 $P30RExtCong^{PD}_{i,d}$ designates the *intertie* congestion component for *thirty-minute operating reserve* for the *dispatch hour* in which interval *i* falls as calculated by the *pre-dispatch calculation engine*;

11.4.2.1.5 $ExtL10NP^{1}_{i,d}$ designates the Pass 1 interval *i locational marginal price* for non-synchronized *ten-minute operating reserve*;

11.4.2.1.6 $ExtL10NP_{i,d}^{PD}$ designates the *locational marginal price* for non-synchronized *ten-minute operating reserve* for the *dispatch hour* in which interval i falls as calculated by the *pre-dispatch calculation engine*;

11.4.2.1.7 $P30RRef_i^1$ designates the Pass 1 interval i *locational marginal price* for *thirty-minute operating reserve* at the *reference bus*;

11.4.2.1.8 $P30RIntCong_{i,d}^1$ designates the Pass 1 interval i internal congestion component for *thirty-minute operating reserve*;

11.4.2.1.9 $P10NRef_i^1$ designates the Pass 1 interval i *locational marginal price* for non-synchronized *ten-minute operating reserve* at the *reference bus*;

11.4.2.1.10 $P10NIntCong_{i,d}^1$ designates the Pass 1 interval i internal congestion component for non-synchronized *ten-minute operating reserve*;

11.4.2.1.11 $P10NExtCong_{i,d}^1$ designates the Pass 1 interval i *intertie* congestion component for non-synchronized *ten-minute operating reserve*; and

11.4.2.1.12 $P10NExtCong_{i,d}^{PD}$ designates the *intertie* congestion component for non-synchronized *ten-minute operating reserve* for the *dispatch hour* in which interval i falls as calculated by the *pre-dispatch calculation engine*.

11.4.2.2 The *real-time calculation engine* shall calculate an initial *locational marginal price*, a *locational marginal price* at the *reference bus*, an internal congestion component and an *intertie* congestion component for Pass 1 at *intertie zone* bus $d \in D$ in interval $i \in I$, for each class of *operating reserve*, subject to section 11.4.2.8, as follows:

$$InitIntL30RP_{i,d}^1 = InitP30RRef_i^1 + InitP30RIntCong_{i,d}^1$$

where:

$$InitP30RRef_i^1 = SP30R_i^1$$

and

$$InitP30RIntCong_{i,d}^{1} = \sum_{r \in ORREG_d} SPREGMin30R_{i,r}^{1} - \sum_{r \in ORREG_d} SPREGMax30R_{i,r}^{1}$$

$$InitIntL10NP_{i,d}^{1} = InitP10NRef_i^{1} + InitP10NIntCong_{i,d}^{1}$$

where:

$$InitP10NRef_i^{1} = SP10R_i^{1} + SP30R_i^{1}$$

and

$$InitP10NIntCong_{i,d}^{1} = \sum_{r \in ORREG_d} \left(SPREGMin10R_{i,r}^{1} + SPREGMin30R_{i,r}^{1}\right) - \sum_{r \in ORREG_d} \left(SPREGMax10R_{i,r}^{1} + SPREGMax30R_{i,r}^{1}\right)$$

11.4.2.3 The *real-time calculation engine* shall calculate initial *locational marginal prices*, and its components for Pass 1 at *intertie zone* bus $d \in D$ in interval $i \in I$ for each class of *operating reserve* as follows:

11.4.2.3.1 If the *intertie* is import congested in pre-dispatch ($P30RExtCong_{i,d}^{PD} < 0$ or $P10NExtCong_{i,d}^{PD} < 0$), then the prices and components are determined in accordance with section 11.4.2.4;

11.4.2.3.2 If the *intertie* is not import congestion in pre-dispatch ($P30RExtCong_{i,d}^{PD} \geq 0$ or $P10NExtCong_{i,d}^{PD} \geq 0$) or if an *intertie zone* is out-of-service, then the prices and components are determined in accordance with section 11.4.2.5.

11.4.2.4 The *real-time calculation engine* shall calculate an initial *locational marginal price* and an external congestion component for the *intertie congestion price* for each class of *operating reserve* for Pass 1 at *intertie zone* bus $d \in D$ in interval $i \in I$ as follows:

$$InitExtL30RP_{i,d}^{1} = min(InitIntL30RP_{i,d}^{1}, ExtL30RP_{i,d}^{PD});$$

and

$$InitP30RExtCong_{i,d}^{1} = InitExtL30RP_{i,d}^{1} - InitIntL30RP_{i,d}^{1}.$$

$$InitExtL10NP_{i,d}^{1} = min(InitIntL10NP_{i,d}^{1}, ExtL10NP_{i,d}^{PD});$$

and

$$InitP10NExtCong_{i,d}^{1} = InitExtL10NP_{i,d}^{1} - InitIntL10NP_{i,d}^{1}.$$

11.4.2.5 The *real-time calculation engine* shall calculate an initial *locational marginal price* and an external congestion component for the *intertie congestion price* for each class of *operating reserve* for Pass 1 at *intertie zone* bus $d \in D$ in interval $i \in I$ as follows:

$$InitExtL30RP_{i,d}^{1} = InitIntL30RP_{i,d}^{1};$$

and

$$InitP30RExtCong_{i,d}^{1} = 0.$$

$$InitExtL10NP_{i,d}^{1} = InitIntL10NP_{i,d}^{1};$$

and

$$InitP10NExtCong_{i,d}^{1} = 0.$$

11.4.2.6 If the initial *locational marginal price* ($InitExtL30RP_{i,b}^{1}$) is not within the *settlement* bounds ($ORPrcFlr$, $ORPrcCeil$), then the *real-time calculation engine* shall modify the *locational marginal price*, the *locational marginal price* at the *reference bus*, and the congestion components for *thirty-minute operating reserve* as follows:

$$IntL30R = InitP30RRef_{i}^{1} + InitP30RIntCong_{i,d}^{1}$$

If $InitP30RRef_{i}^{1} > ORPrcCeil$, set $P30RRef_{i}^{1} = ORPrcCeil$;

If$InitP30RRef_{i}^{1} < ORPrcFlr$, set $P30RRef_{i}^{1} = ORPrcFlr$;

Otherwise, set $P30RRef_{i}^{1} = InitP30RRef_{i}^{1}$;

Set $P30RIntCong_{i,d}^{1} = ExtL30RP_{i,b}^{1} - P30RRef_{i}^{1}$;

If $InitExtL30RP_{i,b}^{1} > ORPrcCeil$, set $ExtL30RP_{i,b}^{1} = ORPrcCeil$;

If $InitExtL30RP_{i,b}^{1} < ORPrcFlr$, set $ExtL30RP_{i,b}^{1} = ORPrcFlr$;

Otherwise, $ExtL30RP_{i,b}^{1} = InitExtL30RP_{i,b}^{1}$; and

Set $P30RExtCong_{i,d}^{1} = ExtL30RP_{i,b}^{1} - P30RRef_{i}^{1} - P30RIntCong_{i,d}^{1}$

11.4.2.7 If the initial *locational marginal price* ($InitExtL10NP_{i,d}^{1}$) is not within the *settlement* bounds ($ORPrcFlr$, $ORPrcCeil$), then the *real-time calculation engine* shall modify the *locational marginal price*, the *locational marginal price* at the *reference bus*, and the congestion components for *ten-minute operating reserve* as follows:

$$IntL10N = InitP10NRef_{i}^{1} + InitP10NIntCong_{i,d}^{1}$$

If $InitP10NRef_{i}^{1} > ORPrcCeil$, set $P10NRef_{i}^{1} = ORPrcCeil$;

If $InitP10NRef_i^1 < ORPrcFlr$, set $P10NRef_i^1 = ORPrcFlr$;

Otherwise, $P10NRef_i^1 = InitP10NRef_i^1$; and

Set $P10NIntCong_{i,d}^1 = L10NP_{i,b}^1 - P10NRef_i^1$

If $InitExtL10NP_{i,b}^1 > ORPrcCeil$, set $ExtL10NP_{i,b}^1 = ORPrcCeil$;

If $InitExtL10NP_{i,b}^1 < ORPrcFlr$, set $ExtL10NP_{i,b}^1 = ORPrcFlr$;

Otherwise, $ExtL30RP_{i,b}^1 = InitExtL10NP_{i,b}^1$; and

Set $P10NExtCong_{i,d}^1 = ExtL10NP_{i,b}^1 - P10NRef_i^1 - P10NIntCong_{i,d}^1$

11.4.2.8 The *locational marginal price* calculated by the *real-time calculation engine* shall be the same for all *boundary entity resource* buses at the same *intertie zone*. Reserve imports associated with the same *boundary entity resource* bus, but specified as ocurring at a different *intertie zone*, subject to phase shifter operation, shall be modelled as flowing across independent paths. Pricing of these reserve imports shall utilize shadow prices associated with *intertie* limits and regional minimum and maximum *operating reserve* requirements applicable to the path associated to the relevant *intertie zone*.

11.5 Pricing for Islanded Nodes

11.5.1 For *non-quick start resources* that are not connected to the *main island*, the *real-time calculation engine* shall use the following reconnection logic where enabled by the *IESO* in the order set out below to calculate the *locational marginal prices* for *energy*:

11.5.1.1 Determine the connection paths over open switches that connect the *non-quick start resource* to the *main island*;

11.5.1.2 Determine the priority rating for each connection path identified based on a weighted sum of the base voltage over all open switches used by the reconnection path and the MW ratings of the newly connected branches; and

11.5.1.3 Select the reconnection path with the highest priority rating, breaking ties arbitrarily.

11.5.2 For all (i) *resources* other than those specified in section 11.5.1 not connected to the *main island*; (ii) *non-quick start resources* where a price was not able to be determined in accordance with section 11.5.1; the *real-time calculation engine* shall use the following logic in the order set out below to calculate *locational marginal prices* for *energy*, using a node-level and *facility*-level substitution list determined by the *IESO*:

11.5.2.1 Use the *locational marginal price* for *energy* at a node in the node-level substitution list where defined and enabled by the *IESO*, provided such node is connected to the *main island*;

11.5.2.2 If no such nodes are identified, use the average *locational marginal price* for *energy* of all nodes at the same voltage level within the same *facility* that are connected to the *main island*;

11.5.2.3 If no such nodes are identified, use the average *locational marginal price* for *energy* of all nodes within the same *facility* that are connected to the *main island*;

11.5.2.4 If no such nodes are identified, use the average *locational marginal price* for *energy* of all nodes from another *facility* that is connected to the *main island*, as determined by the *facility*-level substitution list where defined and enabled by the *IESO*; and

11.5.2.5 If a price is unable to be determined in accordance with sections 11.5.2.1 through 11.5.2.4, use the locational margi*nal price* for *energy* for the *reference bus*.