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Review of the Day-Ahead Dispatch Algorithm

Prepared for
Independent Electricity System Operator

June 2022

pwc

June 24, 2022

Steven Chopowick
Director, Risk, Performance, Resilience and Internal Audit
Independent Electricity System Operator
Station A, Box 4474
Toronto, Ontario
M5W 4E5

Dear Mr. Chopowick:

Subject: Independent Review of the Day-Ahead Calculation Engine used in the Ontario Electricity Market

The Independent Electricity System Operator ("IESO") oversees the safe, sustainable and reliable operation of Ontario's power system. This includes responsibility for managing Ontario's wholesale electricity market, through which the supply and demand for electricity are kept in balance and the Hourly Ontario Energy Price is set.

The Day-Ahead Calculation Engine (DACE) was implemented in October 2011.

In accordance with Market Rule 7.4.2.4, IESO commissions an independent review of the operation and application of the day-ahead dispatch algorithm at least once every two calendar years. PwC has been engaged by the IESO to perform the Review for 2022.

The objective of this review was to assess the compliance of the day-ahead dispatch algorithm with the following applicable Market Rules in accordance with the standards set out in CSAE 3530, Attestation Engagements to Report on Compliance of the Chartered Professional Accountants Canada Handbook:

- Chapter 7, Section 5.8 (The Day-Ahead Commitment Scheduling Process)
- Appendix 7.5A (The DACP Calculation Engine Process).

This report communicates the results of the review performed by PwC as of our test day, February 1, 2022.

Yours truly,

PricewaterhouseCoopers LLP

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1. Introduction

Background

The Independent Electricity System Operator (IESO) is responsible for operating Ontario's power system and electricity market to ensure an adequate, reliable and secure supply of energy for the province in the short- and long-term.

A key part of IESO's role is to administer the operation of the wholesale electricity market. This includes ensuring the dispatch of least cost generation and load facilities for energy and operating reserves and to maintain the power flows on transmission facilities within security and operational limits. The mandate for both reliable and least cost energy necessitates that the IESO produces multiple assessments leading up to the dispatch hour. This includes a Day-Ahead Commitment Process (DACP) which provides the first dependable view of the next day's available supply and anticipated Ontario demand.

The Day-Ahead Commitment Process (DACP) was introduced in 2006 as a temporary initiative to improve the reliability of Ontario's electricity market through a day-ahead import and generator commitment program. Based on the benefits derived from the DACP initiative, the IESO Board voted to continue the program. In October of 2011, several enhancements were implemented into the DACP, including the use of a 24-hour optimized scheduling engine and revised import and generator commitment guarantees.

The DACP mechanism is utilized to obtain economic commitment from certain dispatchable generators and scheduling of imports the day-ahead in return for a financial guarantee for eligible resources.

The Day-ahead Ahead Calculation Engine (DACE), which is the subject of this review, is the software program that is part of the DACP and runs the day-ahead dispatch algorithm. The day-ahead dispatch algorithm is used to optimize day-ahead schedules over a 24-hour period for energy and operating reserves for the Ontario Electricity Market.

The DACE and related processes and procedures are complex and specialized processes. Accordingly, we have written this report to provide:

- An overview of the software that models the day-ahead dispatch algorithm (the DACE);
- The specific scope of our review and review approach;
- Our formal report setting out the results of our review; and
- Appendices containing the relevant Market Rules that were reviewed.

A separate report provides the results of the independent review for DSO.

Overview of DACE

The DACE is a dedicated software program that optimizes energy and operating reserve schedules for the 24 hours of the next day by minimising the "total costs" from scheduled resources. The DACE produces commitments and schedules which take into account both limits (i.e. the economic and system limitations) and optimality (i.e. the least-cost security constrained solution for a 24-hour dispatch day based on the day-ahead bids and offers submitted by all resources).

Multiple runs of the DACE occur between 10:00 and 15:00 each day and the Schedule of Record is published by 15:00 based on the last set of published results. The schedules and commitments resulting from the DACP Schedule of Record are the basis for all day-ahead guarantees.

To give dispatchable generators and imports an incentive to perform in real time, the DACP offers two reliability guarantees:

- A day-ahead production cost guarantee (DA-PCG), offered to eligible dispatchable generators that receive a DACP schedule and meet certain qualification criteria; and
- A day-ahead intertie offer guarantee (DA-IOG), available to all imports that receive a schedule in the DACP.

Figure 1 provides a simple overview of the overall process for day-ahead scheduling and commitment. The inputs, processes and outputs of the DACE are described below. Further details on the inputs and outputs of DACE detail can be found in Appendix A.

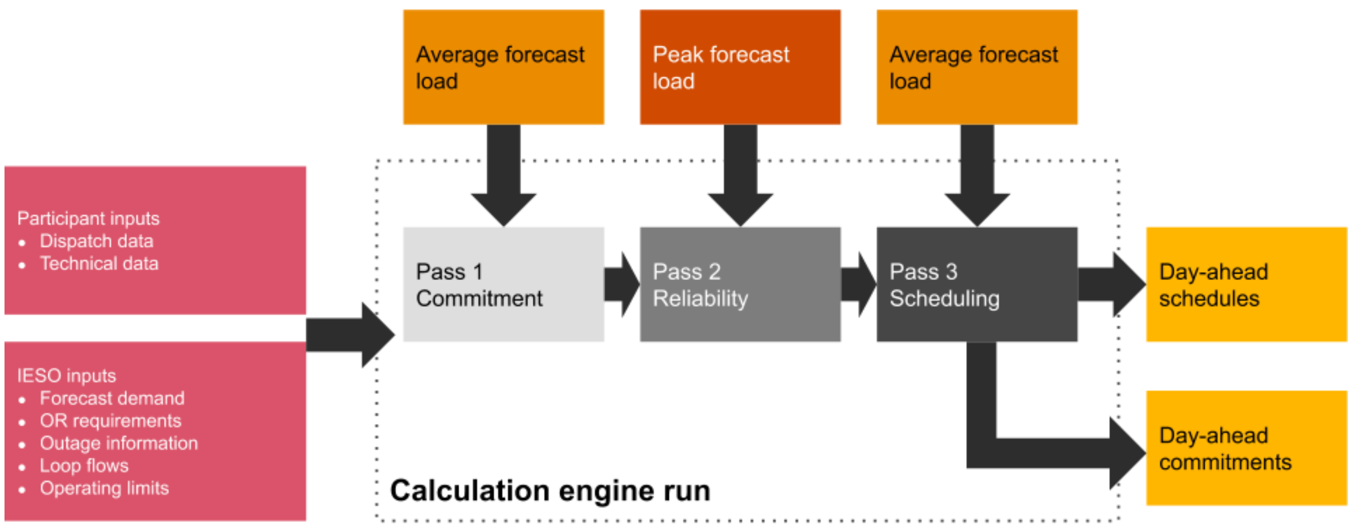


Figure 1: DACE overview[1]

Inputs to the DACE

Inputs to the DACE consist of generator offers, import offers, dispatchable load bids, export bids, technical data, outage information and forecasts from non-dispatchable resources.

Data sources include the Market Operations System (MOS), Energy Management System (EMS), Outage Scheduler (OS), Demand Forecast System (DFS), Resource Dispatch (RD), Dispatch Data Management System (DDMS), Centralized Forecasting System Database (CFSDB) and Tie-Breaking Modifier Database (TBMD). The mathematical formulation for the day-ahead dispatch algorithm is described in section 5.8 of Chapter 7 and specified in Appendix 7.5A of the Market Rules.

[1] Source: Guide to the Day-Ahead Commitment Process (DACP), IESO

Operation of the DACE

The DACE operates over three passes to determine the least-cost security-constrained solution for a dispatch day based on the day-ahead bids and offers submitted by all resources. The three passes of the DACE perform the following functions:

Pass 1: Commitment Pass – determines the initial set of schedules and commitments required to satisfy average hourly forecast demand.

Pass 2: Reliability Pass – commits additional resources to satisfy peak hourly forecast demand. Pass 2 uses the schedules and commitments from Pass 1 and chooses the lowest cost solution to cover peak.

Pass 3: Scheduling Pass – calculates the final day-ahead constrained schedules for all resources based on average hourly forecast demand and Pass 2 results.

Outputs of the DACE

The result of the DACE optimisation is a set of schedules and commitments for PCG-eligible generating resources and imports necessary to meet reliability requirements, along with constrained schedules for all resources to meet forecasted average demand. Day-ahead shadow prices for energy and operating reserve at different nodes internal to Ontario and at the interties are also a key output of the DACE.

2. Objective and scope of review

Objective

The purpose of this review is to confirm that the DACE and related dispatch processes and procedures are in compliance with section 5.8 of Chapter 7 and Appendix 7.5A of the Market Rules. This report communicates the results of the review.

Scope of review

Our review addressed the IESO's compliance with section 5.8 of Chapter 7 (The Day-Ahead Commitment Scheduling Process) and Appendix 7.5A (The DACP Calculation Engine Process) of the Market Rules.

The scope of our review for the DACE is outlined below. Further details can be found in Appendix A.

Scope inclusions

Our review was performed to assess the operation of the DACE to produce day-ahead schedules in the constrained mode for our test day, February 1, 2022. The dispatch day applicable to the results of the DACE was February 1, 2022. Our review considered the outputs of the DACE including:

- Day-ahead energy and operating reserve schedules; and
- Shadow prices at different nodes.

Scope exclusions

The completeness and accuracy of the inputs to the DACE was outside of the scope of this review.

Additionally, the internal processes of the DACE including the estimation of Non-Dispatchable Load (NDL), system losses (dynamic) and the Network Security Assessment (NSA) were outside the scope of our review as they are dependent on the network design model that represents the IESO grid.

The following outputs of the DACE were also out of scope:

- Obligation Indicator Index (OII)
- Flow-limited transmission circuits
- System operating reserve requirements

Limitations of review

We performed our review in accordance with CSAE 3530, of the Chartered Professional Accountants Canada Handbook "Attestation Engagements to Report on Compliance". In the case of the DACE review, Agreements and Regulations were section 5.8 of Chapter 7 and Appendix 7.5A of the IESO Market Rules. To gain clarity where required, PwC obtained IESO management's interpretations to the rules in order to clarify the requirements and interpretations of the Market Rules.

A review is substantially less in scope than an audit in accordance with generally accepted auditing standards, the objective of which is the expression of an opinion of whether the DACE is in compliance with the Market Rules. A review does not contemplate obtaining an understanding of internal control over the operation of the DACE or assessing control risk, tests of records provided and responses to inquiries by obtaining corroborating evidential matter, and certain other procedures ordinarily performed during an audit. Thus, a review does not provide assurance that we will become aware of significant matters that would normally be disclosed in an audit.

3. PwC's review approach

Our approach to the DACE review was to assess the outputs of the DACE for violations of the in-scope Market Rules. This approach allowed us to review all resources in the IESO controlled grid for all 24-hours intervals of our test day.

Specifically, our review of the DACE included the following activities:

Market rule review

We gained an understanding of the applicable Market Rules, and related processes and procedures by:

- Reviewing applicable IESO Market Rules and related Manuals;
- Reviewing the DACE procedural documentation; and
- Interviewing IESO personnel responsible for the use, operation, maintenance, and monitoring of the DACE.

Information validation

We validated the information provided by the IESO and used for testing (inputs and outputs of the DACE for our test day) by comparing a sample interval of the historical data obtained from the IESO to the save case within the DACE.

Where required, we obtained management's interpretations to clarify the requirements and interpretations of the Market Rules.

Automated testing

We developed and executed Automated Screening Tests tests to assess the DACE produced schedules for compliance with Market Rules related to limit violations and economic optimality. The key activities included:

- Developing and executing automated tests to assess compliance of the DACE output with the mathematical limits and representations in Appendix 7.5A of the Market Rules.
- Screening each of the DACE schedules (i.e. energy and operating reserve) for February 1, 2022 to identify individual dispatches that may be economically sub-optimal or in violation of the unit's limits or the security constraints. Screening of schedules was done for each of the 24-hour intervals in the dispatch day.

Scenario testing

For Market Rules that were not triggered on the test day or were not covered by automated testing, we developed and performed scenario tests using base case and save case data, as follows:

- Tests were performed in the IESO testing environment by manipulating inputs and observing whether the outputs produced by the tool were as expected.
- Performed scenario tests in the testing environment with IESO personnel executing the tests and PwC observing the effects of modifying inputs on the resulting DACE solution.

4. Results of review

June 24, 2022

To the IESO Board of Directors:

Independent Reviewer's Report

We have undertaken a limited assurance engagement of the accompanying statement of the Independent Electricity System Operator (IESO)'s compliance as at February 1, 2022, with:

- Chapter 7.5.8 (The Day-Ahead Commitment Scheduling Process) of the Market Rules, dated January 30, 2020 (Issue 40.0), and
- Appendix 7.5A (The DACP Calculation Engine Process) of the Market Rules, dated March 1, 2017 (Issue 21.0),

As interpreted by IESO Management and captured in the DACE tool including related processes and procedures.

Management's responsibility
Management is responsible for measuring and evaluating IESO's compliance with the specified requirements of the market rules and for preparing IESO's statement of compliance. Management is also responsible for such internal control as management determines necessary to enable IESO's compliance with the specified requirements.

Our responsibility
Our responsibility is to express a limited assurance conclusion on management's statement based on the evidence we have obtained. We conducted our limited assurance engagement in accordance with Canadian Standard on Assurance Engagements 3530, *Attestation Engagements to Report on Compliance*. This standard requires us to conclude whether anything has come to our attention that causes us to believe that management's statement that IESO complied with the specified requirements is not fairly stated, in all material respects.

A limited assurance engagement involves performing procedures (primarily consisting of making inquiries of management and others within the entity, as appropriate, and applying analytical procedures) and evaluating the evidence obtained. The procedures are selected based on our professional judgement, which includes identifying areas where the risks of material misstatement in management's statement of the entity's compliance with the specified requirements of the Market Rules are likely to arise.

The relevant sections of the Market Rules are attached in the Appendices of this report. Our review was made in accordance with Canadian generally accepted standards for review engagements and, accordingly, consisted primarily of enquiry, analytical procedures, and discussion related to information supplied to us by the IESO. Our review process and criteria are further described in Section 3 of the report.

The procedures performed in a limited assurance engagement vary in nature and timing from, and are less in extent than for a reasonable assurance engagement and, consequently, the level of assurance obtained is substantially lower than the assurance that would have been obtained had a reasonable assurance engagement been performed.

Our independence and quality control
We have complied with the relevant rules of professional conduct/code of ethics applicable to the practice of public accounting and related to assurance engagements, issued by various professional accounting bodies,

which are founded on fundamental principles of integrity, objectivity, professional competence and due care, confidentiality and professional behaviour.

The firm applies Canadian Standard on Quality Control 1, *Quality Control for Firms that Perform Audits and Reviews of Financial Statements, and Other Assurance Engagements* and, accordingly, maintains a comprehensive system of quality control, including documented policies and procedures regarding compliance with ethical requirements, professional standards and applicable legal and regulatory requirements.

Conclusion

Based on the procedures we have performed and the evidence we have obtained, nothing has come to our attention that causes us to believe that the DACE was not in compliance, as at February 1, 2022 with Chapter 7.5.8 (The Day-Ahead Commitment Scheduling Process) and Appendix 7.5A (The DACP Calculation Engine Process) of the Market Rules, in all material respects.

We do not provide a legal opinion on IESO's compliance with the specified requirements.

Purpose of statement and restriction on distribution and use of our report

Management's statement of compliance has been prepared to report IESO's compliance with the specified requirements, established in Chapter 7.5.8 (The Day-Ahead Commitment Scheduling Process) and Appendix 7.5A (The DACP Calculation Engine Process) of the Market Rules. As a result, management's statement of compliance may not be suitable for another purpose. Our report is intended solely for IESO.

PricewaterhouseCoopers LLP

Partnership of Chartered Professional Accountants, Licensed Public Accountants

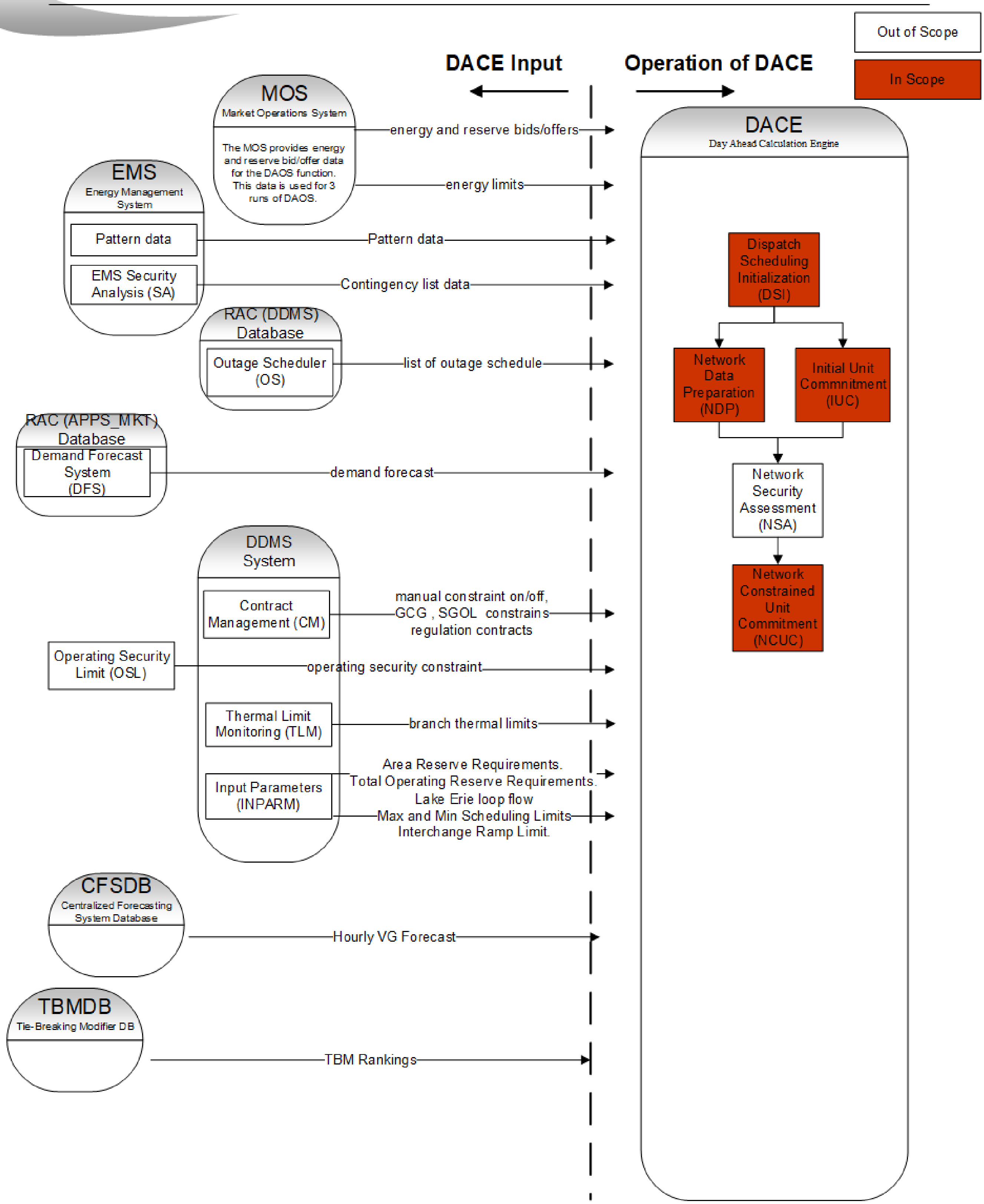
Toronto, Ontario, Canada

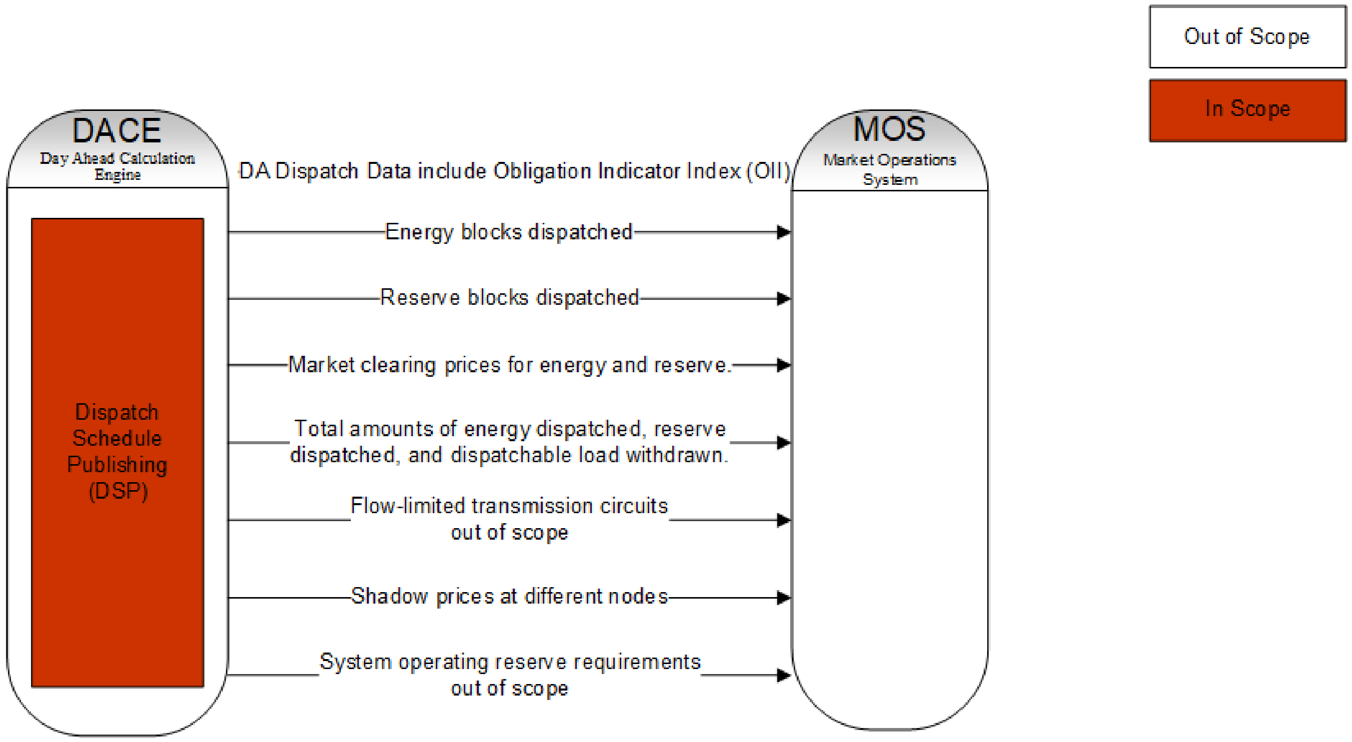
June 24 2022

Appendices

Appendix A – Day Ahead Calculation Engine (DACE) Inputs and Outputs

Day Ahead Calculation Engine (DACE) – Inputs System Interface




Out of Scope
In Scope
DACE
Day Ahead Calculation Engine
Dispatch Schedule Publishing (DSP)
DA Dispatch Data include Obligation Indicator Index (OII)
Energy blocks dispatched
Reserve blocks dispatched
Market clearing prices for energy and reserve.
Total amounts of energy dispatched, reserve dispatched, and dispatchable load withdrawn.
Flow-limited transmission circuits out of scope
Shadow prices at different nodes
System operating reserve requirements out of scope
MOS
Market Operations System

Appendix B – Section 5.8 of Chapter 7 – The Day Ahead Commitment Scheduling Process

5.8 The Day-Ahead Commitment Scheduling Process

5.8.1 Starting from 10:00 EST the IESO may in accordance with Appendix 7.5A determine the schedule of record.

5.8.2 Where the IESO determines the schedule of record in accordance with Section 5.8.1, it will be released by the IESO no later than 15:00 EST in accordance with the applicable market manual.

5.8.3 [Intentionally left blank – section deleted]

5.8.4 A registered market participant whose facility is eligible under section 2.2C for the day-ahead production cost guarantee and whose facility is included in the schedule of record is deemed to have accepted the guarantee for its facility.

5.8.5 Subject to sections 5.8.4 and 5.8.6, the IESO shall ensure that the scheduled output for a facility will meet or exceed its minimum loading point for all hours that it was included in the schedule of record in future iterations of the pre-dispatch schedule and in the real-time schedule.

5.8.6 The IESO may, to maintain the reliable operation of the IESO-controlled grid, require a generation facility that was included in the schedule of record to either de-synchronize from the IESO-controlled grid or to not synchronize to the IESO-controlled grid.

5.8.7 When determining the schedule of record applicable to the first hour of the next dispatch day, the IESO may disregard the net intertie scheduling limit.

5.8.8 [Intentionally left blank – section deleted]

Appendix C – Appendix 7.5A The DACP Calculation Engine Process

1.1 Interpretation

1.1.1 This appendix describes the DACP calculation engine process used to determine commitments, constrained schedules, and shadow prices.

1.1.1.1 Commitment refers to the availability of *generation facilities* and *imports* to provide *energy* and/or *operating reserve* and *dispatchable loads* and *exports* to provide *operating reserve*.

1.1.1.2 The constrained schedules of the *schedule of record* are assessed in the calculation of production cost guarantees.

1.1.1.3 The shadow price of a location indicates the price of meeting an infinitesimal amount of change in load at that location.

1.1.2 The mathematical description of the optimization algorithm of the DACP calculation engine process is also described in this appendix.

1.1.3 The DACP calculation engine "outputs" described in this appendix refer to data produced by DACP calculation engine and the *IESO* shall not be required to *publish* such data except where expressly required by these *market rules*.

2. DACP Calculation Engine

2.1 Overview

2.1.1 The DACP calculation engine is a core component of the DACP process that performs the functions of commitment and constrained scheduling over a 24-hour period for *energy* and *operating reserves,* and the calculation of shadow prices. The DACP calculation engine executes three passes to produce the final *schedule of record*.

2.1.1.1 Pass 1, the Commitment Pass determines the initial set of commitments and constrained schedules required to satisfy the average forecast *demand* of the next day. Details of Pass 1 are described in section 4.

2.1.1.2 Pass 2, the Reliability Pass ensures that if the resources committed by Pass 1 are insufficient to satisfy peak forecast *demand*, additional resources are committed and scheduled. Details of Pass 2 are described in section 5.

2.1.1.3 Pass 3, the Scheduling Pass uses the commitments made in Passes 1 and 2 to determine the *schedule of record* and the associated constrained schedules to meet average forecast *demand*. Details of Pass 3 are described in section 6.

2.1.2 Since each Pass provides constrained schedules, the DACP calculation engine will iterate the calculations for constrained schedules with *security* assessments until there are no *security* violations. The *security* assessment functionality is described in section 4.4.

3. Inputs into the DACP Calculation Engine

3.1 Demand Forecast

3.1.1 The *IESO* shall prepare forecasts of the total *demand* in Ontario for each hour of the next day. This hourly forecast will be modified by the DACP calculation engine so that the expected consumption associated with *dispatchable loads* will be removed. Average hourly *demand* forecasts will be used as inputs to Passes 1 and 3. Peak hourly *demand* forecasts will be used as inputs to Pass 2.

3.2 Energy Offers and Bids

3.2.1 A *registered market participant* may submit an *energy offer* or *energy bid* and associated *dispatch data* with respect to a given *registered facility* for each *dispatch hour* of the next day for DACP. *Energy offers, bids* and *dispatch data* shall be submitted in accordance to Chapter 7 and may be limited in accordance with section 2.2.1.15 of Appendix 7.5.

3.3 Operating Reserve Offers

3.3.1 A *registered market participant* may submit an *offer* and associated *dispatch data* to provide each class of *operating reserve* for each *dispatch hour* of the next day for DACP. *Operating reserve offers* and *dispatch data* shall be submitted in accordance to Chapter 7.

3.4 Forecasts from Self-Scheduling Generation Facilities, Transitional Scheduling Generators and Intermittent Generators

3.4.1 The DACP calculation engine will take into account the expected output of *self-scheduling generation facilities, transitional scheduling generators and intermittent generators* when committing resources to meet forecast *demand* for the next day. The *registered market participant* representing such generation at each location will inform the *IESO* of the amount of *energy* it expects to produce in each hour of the next day as a function of price in accordance with Chapter 7.

3.5 Ramp up to Minimum Loading Point

3.5.1 In order for the DACP calculation engine to determine constrained schedules in Pass 3 that account for the *energy* produced by *generation facilities* during ramping to their *minimum loading points*, an approximate value of this *energy* will be used. This *energy* will be represented by a fraction of the unit's *minimum loading point* in the hour prior to the first hour it is scheduled.

3.6 Energy Limited Resources

3.6.1 *Energy* limited resources constitute a subset of *generation facilities* that at times can be limited in the amount of *energy* they can provide during each day.

3.6.2 An *energy* limited resource shall designate the daily limit on the amount of *energy* it could be scheduled to generate over the course of the day.

3.7 Transmission Inputs

3.7.1. Transmission inputs are based on information prepared by the *IESO* for the *security* assessment function of the DACP calculation engine described in section 4.4. These inputs include:

3.7.1.1 Internal transmission constraints;

3.7.1.2 Limits on imports and exports;

3.7.1.3 Loop flows; and

3.7.1.4 Transmission losses.

3.8 Other Inputs

3.8.1 The *IESO* shall also provide other inputs into the DACP calculation engine that are necessary in order to ensure a solution that is consistent with system *reliability*. These include:

3.8.1.1 Distribution of internal *demand*;

3.8.1.2 Distribution of imports, exports and loop flows;

3.8.1.3 *Operating reserve* requirements;

3.8.1.4 Must-run resources for other reliability purposes;

3.8.1.5 Regulation *(AGC);*

3.8.1.6 Voltage constraints;

3.8.1.7 Initializing assumptions regarding resources in operation; and

3.8.1.8 Costs of violations.

4. Pass 1: Constrained Commitment to Meet Average Demand

4.1 Overview

4.1.1 Pass 1 performs a least cost, *security* constrained, unit commitment and constrained scheduling to meet the forecast average *demand* and *IESO*-specified *operating reserve* requirements for each hour of the next day.

4.1.2 This Pass will use *bids* and *offers* and associated *dispatch data* submitted by *registered market participants* to maximize the gains from trade (i.e., the difference between the total price of *bids* submitted by *market participants* whose *bids* were scheduled, and the total price of *offers* submitted by *market participants* whose *offers* were scheduled). The optimization is subject to the constraints accompanying those *bids* and *offers*, and constraints imposed by the *IESO* to ensure reliable service.

4.2 Inputs for Pass 1

4.2.1 Inputs for Pass 1 include those described in section 3.

4.3 Optimization Objective for Pass 1

4.3.1 The objective function of Pass 1 is to maximize the gains from trade. This is accomplished by maximizing the sum of the following quantities for each hour of the trade day:

The value of:

- Scheduled exports;

Less the *offered* costs of:

- Scheduled *operating reserve* from exports;
- The foregone opportunity due to scheduled load reductions;
- Scheduled *operating reserve* from *dispatchable load*;
- Scheduled hourly imports;
- Scheduled *operating reserve* from imports;
- Scheduled *operating reserve* from *generation facilities*;
- Scheduled generation;
- Hourly costs for speed no-load for committed *generation facilities*; and
- *Startup cost* for committed *generation facilities*.

Less the cost of:

- Scheduled violation variables.

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

- Projected load curtailment due to a supply deficit;
- Scheduling additional load to offset surplus must-run *generation facility* requirements (the minus sign is required since the violation price is negative);
- *Operating reserve* requirement deficits;
- All reserve area minimum *operating reserve* requirement deficits;
- All reserve area *operating reserve* excesses above maximum requirements;
- Pre-contingency and post-contingency limit violations for internal transmission facilities;

- Pre-contingency limit violations for import or export *interties*; and
- Exceeding the up or down ramp limits for the total net schedule change for imports and exports.

4.4 Security Assessment

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

4.4.2 The *security* assessment function used by Pass 1 is common to all passes of the DACP calculation engine process.

4.4.3 The *security* assessment function performs the following calculations and analyses:

4.4.3.1 Base case solution: A base case solution function prepares a power flow solution for each hour. This function automatically selects the power system model state (i.e., breaker/switch status, tap positions, desired voltages, etc) applicable to the forecast of conditions for the hour and input schedules. An AC load flow program is used; however, a DC load flow may be used should the AC load flow fail to converge.

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

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

4.4.3.4 Linear contingency analysis: A variation of the DC load flow is used to simulate all valid contingencies, calculate post contingency flows and check for limited time (i.e. emergency) thermal limit violations. Violated limits are linearized and incorporated as constraints for use by the scheduling function.

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

4.4.5 The *IESO* maintains sets of data as outlined in Appendix 7.5, section 2.4 for use in the *security* assessment processes for the *real-time market* and operation. The *security* assessment function will use this same set of data to obtain:

4.4.5.1 The power system model;

4.4.5.2 Status of power system equipment;

4.4.5.3 List of contingencies to be simulated;

4.4.5.4 List of monitored equipment;

4.4.5.5 Equipment thermal limits; and

4.4.5.6 Operating *security limits* (angular stability, voltage stability and voltage decline).

4.4.6 Constraint violation variables, when violated indicate the type of problem that is not allowing the optimization of the objective function to have a solution. The equivalent constraint violation variables and their values as used in the *real-time market* and described Appendix 7.5, section 4.12 are utilized by the DACP calculation engine. Further details of these inputs for the DACP calculation engine are described in section 4.6.2.4.

4.5 Outputs from Pass 1

4.5.1 The primary outputs of Pass 1 which are used in Pass 2 and other DACP processes include the following:

4.5.1.1 Commitments;

4.5.1.2 Constrained schedules for *energy*; and

4.5.1.3 Shadow prices for *energy*.

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

4.6.1 Fundamental Sets and Indices

A	The set of all *intertie zones a*.
B	The set of buses *b* within Ontario, corresponding to *bids* and offers at locations on the *IESO-controlled grid*.
C	The set of contingencies conditions *c* to be considered in the *security* assessment.
D	The set of buses *d* outside Ontario, corresponding to *bids* and offers at *intertie zones*.
F	The set of transmission *facilities* (or groups of transmission *facilities*) *f* in Ontario for which constraints have been identified.
J	The set of all *bids j*. Each *price-quantity pair* of a *bid* submitted by a *market participant* would be represented by a unique element *j* in the set.
J_b	The subset of those *bids j* consisting of *bids* for a *dispatchable load* resource at a bus *b*.
J_d	The subset of those *bids j* consisting of *bids* for an export to *intertie zone* sink bus *d*.
K	The set of all *offers*. Each *price-quantity pair* of an *offer* submitted by a *market participant* would be represented by a unique element *k* in the set.

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

4.6.2 Variables and Parameters

4.6.2.1 Bid and Offer Inputs

Dispatchable Loads:

$QPRL_{j,h,b}$	An incremental quantity of reduction in *energy* consumption that may be scheduled for a *dispatchable load* in hour *h* at bus *b* in association with *bid j.*
$PPRL_{j,h,b}$	The lowest *energy* price at which the incremental quantity of reduction in *energy* consumption specified in *bid j* should be scheduled in hour *h* at bus *b.*
$10SQPRL_{j,h,b}$	The synchronized *ten-minute operating reserve* quantity associated with *bid j* in hour *h* at bus *b* for *dispatchable loads* qualified to do so.

$10SPPRL_{j,h,b}$	The price of being scheduled to provided synchronized *ten-minute operating reserve* associated with *bid j* in hour *h* at bus *b*, for *dispatchable loads* qualified to do so.
$10NQPRL_{j,h,b}$	The non-synchronized *ten-minute operating reserve* quantity associated with *bid j* in hour *h* at bus *b* for *dispatchable loads* qualified to do so.
$10NPPRL_{j,h,b}$	The price of being scheduled to provide non-synchronized *ten-minute operating reserve* associated with *bid j* in hour *h* at bus *b*, for *dispatchable loads* qualified to do so.
$30RQPRL_{j,h,b}$	The *thirty-minute operating reserve* quantity associated with *bid j* in hour *h* at bus *b*, for *dispatchable loads* qualified to do so.
$30RPPRL_{j,h,b}$	The price of being scheduled to provide *thirty-minute operating reserve* associated with *bid j* in hour *h* at bus *b*, for *dispatchable loads* qualified to do so.
$ORRPRL_{b}$	The *operating reserve* ramp rate per minute for reductions in load consumption at bus *b*.
$URRPRL_{b}$	The maximum rate per minute at which a *dispatchable load* that wishes to consume *energy* at bus *b* can decrease its amount of energy consumption.
$DRRPRL_{b}$	The maximum rate per minute at which a *dispatchable load* that wishes to consume *energy* at bus *b* can increase its amount of load consumption.

Exports:

$QHXL_{j,h,d}$	The maximum quantity of *energy* for which an export to *intertie zone* sink bus *d* in hour *h* may be scheduled in association with *bid j.*
$PHXL_{j,h,d}$	The highest price at which *energy* should be scheduled for an export to *intertie zone* sink bus *d* in hour *h* in association with *bid j.*
$QX10N_{j,h,d}$	The non-synchronized *ten-minute operating reserve* quantity associated with *bid j* in hour *h* at *intertie zone* sink bus *d* for an export qualified to do so.
$PX10N_{j,h,d}$	The price of being scheduled to provide non-synchronized *ten-minute operating reserve* associated with *bid j* in hour *h* at *intertie zone* sink bus *d*, for an export qualified to do so.
$QX30R_{j,h,d}$	The *thirty-minute operating reserve* quantity associated with *bid j* in hour *h* at *intertie zone* sink bus *d*, for an export qualified to do so.
$PX30R_{j,h,d}$	The price of being scheduled to provide *thirty-minute operating reserve* associated with *bid j* in hour *h* at *intertie zone* sink bus *d*, for an export qualified to do so.
$ORRHXL_{d}$	The *operating reserve* ramp rate per minute for exports at *intertie zone* sink bus *d*, as specified by the *IESO*.

Dispatchable Generators:

$MinQPRG_{h,b}$	The *minimum loading point* which is the minimum amount of *energy* that a *generation facility* at bus *b* is willing to produce in hour *h*, if scheduled to operate.
$SUPRG_{h,b}$	The *offered start up cost* that a *generation facility* at bus *b* incurs in order to start and synchronize in hour *h*.
$SNL_{h,b}$	The *offered speed no-load cost* to maintain a *generation facility* synchronized with zero net *energy* injected into the system in hour *h*.
$MGOPRG_{h,b}$	The *offered* minimum generation cost for a *generation facility* at bus *b* in order to operate at its *minimum loading point* in hour *h.* This is calculated as the sum of $SNL_{h,b}$ and the incremental price, $PPRG_{k,h,b}$ for *energy* up to the *minimum loading point*, $MinQPRG_{h,b}$.
$QPRG_{k,h,b}$	An incremental quantity of *energy* generation (above and beyond the *minimum loading point*) that may be scheduled at bus *b* in hour *h* in association with *offer k.*
$PPRG_{k,h,b}$	The lowest *energy* price at which incremental generation should be scheduled at bus *b* in hour *h* in association with *offer k*.
$10SPPRG_{k,h,b}$	The *offered* price of being scheduled to provide synchronized *ten-minute operating reserve* in hour *h* at bus *b* in association with *offer k.*
$10SQPRG_{k,h,b}$	The *offered* quantity of synchronized *ten-minute operating reserve* in hour *h* at bus *b* in association with *offer k*.
$10NPPRG_{k,h,b}$	The *offered* price of being scheduled to provide *ten-minute operating* non-synchronized *ten-minute operating reserve* in hour *h* at bus *b* in association with *offer k*.
$10NQPRG_{k,h,b}$	The *offered* quantity of non-synchronized *ten-minute operating reserve* in association with *offer k*.
$30RPPRG_{k,h,b}$	The *offered* price of being scheduled to provide *thirty-minute operating reserve* in association with *offer k*.
$30RQPRG_{k,h,b}$	The *offered* quantity of *thirty-minute operating reserve* in hour *h* at bus *b* in association with *offer k*.
$ORRPRG_{b}$	The maximum *operating reserve* ramp rate per minute at bus *b*.
$MRTPRG_{b}$	The *minimum generation block run time* period for which a *generation facility* at bus *b* must be scheduled to operate if its *offer* to generate is accepted.
$MDTPRG_{b}$	The *minimum generation block down time* period between the end of one period when a *generation facility* at bus *b* is scheduled to operate and the beginning of the next period when it is scheduled to operate.
$MaxStartsPRG_{b}$	The maximum number of times per day a *generation facility* at bus *b* can be scheduled to start.
$URRPRG_{b}$	The maximum rate per minute at which a *generation facility offering* to produce at bus *b* can increase the amount of *energy* it supplies.

$DRRPRG_b$	The maximum rate per minute at which a *generation facility offering* to produce at bus *b* can decrease the amount of *energy* it supplies.
EL_b	The daily limit on the amount of *energy* that an *energy limited resource* at bus *b* may be scheduled to generate over the course of the day (*maximum daily energy limit*).

Imports:

$QHIG_{k,h,d}$	The maximum quantity of *energy* for which an import from *intertie zone* source bus *d* in hour *h* may be scheduled in association with *offer k*.
$PHIG_{k,h,d}$	The lowest price at which an import from *intertie zone* source bus *d* in hour *h* in association with *offer k* should be scheduled.
$QI10N_{k,h,d}$	The non-synchronized *ten-minute operating reserve* quantity associated with *offer k* in hour *h* at *intertie zone* source bus *d*.
$PI10N_{k,h,d}$	The price of being scheduled to provide non-synchronized *ten-minute operating reserve* associated with *offer k* in hour *h* at *intertie zone* source bus *d*.
$QI30R_{k,h,d}$	The non-synchronized *thirty-minute operating reserve* quantity associated with *offer k* in hour *h* at *intertie zone* source bus *d*.
$PI30R_{k,h,d}$	The price of being scheduled to provide non-synchronized *thirty-minute operating reserve* associated with *offer k* in hour *h* at *intertie zone* source bus *d*.
$ORRHIG_d$	The *operating reserve* ramp rate per minute for imports at *intertie zone* source bus *d*, as specified by the *IESO*.

4.6.2.2 Transmission and Security Inputs and Intermediate Variables

$EnCoeff_{a,z}$	The coefficient for calculating the contribution of scheduled *energy* flows (and *operating reserve*, in the case of inflows) over *intertie zone a* which is part of the *intertie* group *z*. $EnCoeff_{a,z}$ takes the value +1 to account for limits on scheduled flows into Ontario and the value -1 to account for limits on scheduled flows out of Ontario.
$MaxExtSch_{z,h}$	The maximum flow limit over an *intertie z* in hour *h*.
$ExtDSC_h$	The maximum decrease in total net flows over all *interties* from hour to hour, which limits the hour-to-hour decreases in net imports (calculated as imports less exports) from all the *intertie zones*.
$ExtUSC_h$	The maximum increase in total net flows over all *interties* from hour to hour, which limits the hour-to-hour increases in net imports (calculated as imports less exports) from all the *intertie zones*.

$PF_{h,a}$	The anticipated inflow into Ontario from *intertie zone a* in hour *h* that result from loop flows.
$MglLoss_{h,b}$	The marginal impact on transmission losses resulting from transmitting *energy* from the *reference bus* to serve an increment of additional load at the bus *b* in hour *h*.
$LossAdj_{h}$	The adjustment needed for hour *h* to correct for any discrepancy between actual Ontario total system losses using a base case power flow from the *security* assessment function and system losses that would be calculated using the marginal transmission loss factors.
$With^{1}_{h,b}$	The total amount of withdrawals scheduled in Pass 1 at each bus *b* in each hour *h*, for scheduled *dispatchable loads*.
$With^{1}_{h,d}$	The total amount of withdrawals scheduled in Pass 1 at each bus *d* in each hour *h*, for exports and outflows associated with loop flows for buses in *intertie zones*.
$Inj^{1}_{h,b}$	The total amount of injections scheduled in Pass 1 at each bus *b* in each hour *h*, for scheduled generation.
$Inj^{1}_{h,d}$	The total amount of injections scheduled in Pass 1 at each bus *d* in each hour *h*, for imports and inflows associated with loop flows for buses in *intertie zones*.
$PreConSF_{b,f,h}$	The fraction of *energy* injected at bus *b* which flows on transmission *facility f* during hour *h* under pre-contingency conditions.
$AdjNormMaxFlow_{f,h}$	The maximum flow allowed on transmission *facility f* in hour *h* as determined by the *security* assessment for pre-contingency conditions.
$SF_{b,f,c,h}$	The fraction of *energy* injected at bus *b* which flows on a transmission *facility f* during hour *h* under post-contingency conditions.
$AdjEmMaxFlow_{f,c,h}$	The maximum flow allowed on transmission *facility f* in hour *h* as determined by the *security* assessment for post-contingency condition *c*.

4.6.2.3 Other Inputs

Distribution of Load, Imports and Exports and Loop Flows

$LDF_{h,b}$	Load distribution factors, for loads which are distributed across Ontario, representing the proportion of the load at bus *b* in hour *h*. This is based on historical telemetry data.
AFL_{h}	Average Ontario *demand* forecast in hour *h* with the expected consumption associated with *dispatchable loads* removed.
PFL_{h}	Peak Ontario *demand* forecast in hour *h* with the expected consumption associated with *dispatchable loads* removed.

$ProxyUPIWt_{d,a}$	The proportion of inflows associated with loop flows from *intertie zone a* that shall be assigned to each bus *d* in the *control area* in which that *intertie zone* is located.
$ProxyUPOWt_{d,a}$	The proportion of outflows associated with loop flows from *intertie zone a* that shall be assigned to each bus *d* in the *control area* in which that *intertie zone* is located.
10ORConv	The factor applied to scheduled *ten-minute operating reserve* for *energy limited resources* to convert MW into MWh. This factor shall be 1.0.
30ORConv	The factor applied to scheduled *thirty-minute operating reserve* for *energy limited resources* to convert MW into MWh. This factor shall be 1.0.

Operating Reserve Requirements:

$TOT10R_h$	Minimum requirement for the total amount of *ten-minute operating reserve*.
$TOT10S_h$	The total amount of synchronized *ten-minute operating reserve* required in hour *h,* which is a percentage of the total *ten-minute operating reserve* requirement.
$TOT30R_h$	Minimum requirement for the total amount of *thirty-minute operating reserve*.
$REGMin10R_{r,h}$	The minimum requirement for *ten-minute operating reserve* in region *r* in hour *h*.
$REGMax10R_{r,h}$	The maximum amount of *ten-minute operating reserve* that may be provided in region *r* in hour *h.*
$REGMin30R_{r,h}$	The minimum requirement for *thirty-minute operating reserve* in region *r* in hour *h*.
$REGMax30R_{r,h}$	The maximum amount of *thirty-minute operating reserve* that may be provided in region *r* in hour *h.*

Other Ancillary Service and Resource Initializing Assumptions:

$MaxPRL_{h,b}$	The maximum amount of load reduction that a *dispatchable load* can achieve at bus *b* in hour *h*.
$MinPRG_{h,b}$	The minimum output for a *generation facility* at bus *b* in hour *h,* that is the most restrictive of the limits for *regulation* or voltage support, providing *AGC* or due to outages.
$MaxPRG_{h,b}$	The maximum output for a *generation facility* at bus *b* in hour *h,* that is the most restrictive of the limits for *regulation* or voltage support, providing *AGC* or due to outages.
$InitOperHrs_b$	The number of consecutive hours at the end of the previous day for which the *generation facility* or load at bus *b* was scheduled to operate.

4.6.2.4 Constraint Violation Price Inputs

PLdViol	The value that the DACP calculation engine will assign to scheduling the forecast load. As measured by the effect on the value of the objective function, if the cost of serving that load (in dollars per MWh) exceeds *PLdViol*, then that load would not be scheduled. This is not applicable to Pass 1 since *PLdViol* will exceed maximum *bid* price allowed and no *bid* load could be scheduled at this price. This equals the shortage cost for *energy* applied in the *real-time market*.
PGenViol	The price at which additional load will be included above the scheduled amount when the amount of *energy generation facilities* produce at their *minimum loading points* exceeds the amount of load scheduled on the system. This equals the negative of the shortage cost for *energy* applied in the *real-time market*.
P10SViol	The price at which the overall minimum synchronized *ten-minute operating reserve* requirement may be violated. This equals the shortage cost for synchronized *ten-minute operating reserve* applied in the *real-time market*.
P10RViol	The price at which the overall minimum *ten-minute operating reserve* requirement may be violated. This equals the shortage cost for total *ten-minute operating reserve* applied in the *real-time market*.
P30RViol	The price at which the overall minimum *thirty-minute operating reserve* requirement may be violated. This equals the shortage cost for total *thirty-minute operating reserve* applied in the *real-time market*.
PREG10RViol	The price at which the regional minimum *ten-minute operating reserve* requirements may be violated. This equals the shortage cost for the corresponding value applied in the *real-time market*.
PXREG10RViol	The price at which the regional maximum *ten-minute operating reserve* requirements may be violated. This equals the shortage cost for the corresponding value applied in the *real-time market*.
PREG30RViol	The price at which the regional minimum *thirty-minute operating reserve* requirements may be violated This equals the shortage cost for the corresponding value applied in the *real-time market*.
PXREG30RViol	The price at which the regional maximum *thirty-minute operating reserve* requirements may be violated. This equals the shortage cost for the corresponding value applied in the *real-time market*.
PPreConITLViol	The price at which pre-contingency flows over internal transmission may exceed that *facility*'s limit. This equals the shortage cost for base case *security limits* applied in the *real-time market*.

PITLViol	The price at which flows over an internal transmission *facility* following a contingency may exceed that *facility*'s limit. This equals the shortage cost for contingency constrained *security limits* applied in the *real-time market*.
PPreConXTLViol	The price at which the pre-contingency import and export *intertie* limits may be violated. This equals the shortage cost for inter *control area* scheduling limits applied in the *real-time market*.
PRmpXTLViol	The price at which the limit for hour to hour changes (up and down) of total net scheduled imports from *intertie zones* may be violated. This equals the shortage cost for inter *control area* scheduling limits applied in the *real-time market*.

4.6.2.5 Output Schedule and Commitment Variables

$SHXL^1_{j,h,d}$	The amount of exports scheduled in hour *h* in Pass 1 from *intertie zone* sink bus *d* in association with *bid j.*
$SX10N^1_{j,h,d}$	The amount of non-synchronized *ten-minute operating reserve* scheduled from the export in hour *h* in Pass 1 from *intertie zone* sink bus *d* in association with *bid j.*
$SX30R^1_{j,h,d}$	The amount of *thirty-minute operating reserve* scheduled from the export in hour *h* in Pass 1 from *intertie zone* sink bus *d* in association with *bid j.*
$SPRL^1_{j,h,b}$	The amount of *dispatchable load* reduction scheduled at bus *b* in hour *h* in Pass 1 in association with *bid j*.
$10SSPRL^1_{j,h,b}$	The amount of synchronized *ten-minute operating reserve* that a qualified *dispatchable load* is scheduled to provide at bus *b* in hour *h* in Pass 1 in association with *bid j*.
$10NSPRL^1_{j,h,b}$	The amount of non-synchronized *ten-minute operating reserve* that a qualified *dispatchable load* is scheduled to provide at bus *b* in hour *h* in Pass 1 in association with *bid j*.
$30RSPRL^1_{j,h,b}$	The amount of *thirty-minute operating reserve* that a qualified *dispatchable load* is scheduled to provide at bus *b* in hour *h* in Pass 1 in association with *bid j*.
$SHIG^1_{k,h,d}$	The amount of hourly imports scheduled in hour *h* from *intertie zone* source bus *d* in Pass 1 in association with *offer k.*
$SI10N^1_{k,h,d}$	The amount of imported *ten-minute operating reserve* scheduled in hour *h* from *intertie zone* source bus *d* in Pass 1 in association with *offer k.*
$SI30R^1_{k,h,d}$	The amount of imported *thirty-minute operating reserve* scheduled in hour *h* from *intertie zone* source bus *d* in Pass 1 in association with *offer k.*
$SPRG^1_{k,h,b}$	The amount of *energy* scheduled for the *generation facility* at bus *b* in hour *h* in Pass 1 in association with *offer k*. This is in addition to any $MinQPRG_{h,b}$, the *minimum loading point*, which must also be committed.

$OPRG^1_{h,b}$	Represents whether the *generation facility* at bus *b* has been scheduled in hour *h* in Pass 1.
$IPRG^1_{h,b}$	Represents whether the *generation facility* at bus *b* has been scheduled to start in hour *h* in Pass 1.
$10SSPRG^1_{k,h,b}$	The amount of synchronized *ten-minute operating reserve* that a qualified *generation facility* at bus *b* is scheduled to provide in hour *h* in Pass 1 in association with *offer k*.
$10NSPRG^1_{k,h,b}$	The amount of non-synchronized *ten-minute operating reserve* that a qualified *generation facility* at bus *b* is scheduled to provide in hour *h* in Pass 1 in association with *offer k*.
$30RSPRG^1_{k,h,b}$	The amount of *thirty-minute operating reserve* that a qualified *generation facility* at bus *b* is scheduled to provide in hour *h* in Pass 1 in association with *offer k*.

4.6.2.6 Output Violation Variables

$ViolCost^1_h$	The cost incurred in order to avoid having the Pass 1 schedules for hour *h* violate specified constraints.
$SLdViol^1_h$	Projected load curtailment, that is, the amount of load that cannot be met using *offers* scheduled or committed in hour *h* in Pass 1.
$SGenViol^1_h$	The amount of additional load that must be scheduled in hour *h* in Pass 1 to ensure that there is enough load on the system to offset the must-run requirements of *generation facilities*.
$S10SViol^1_h$	The amount by which the overall synchronized *ten-minute operating reserve* requirement is not met in hour *h* of Pass 1 because the cost of meeting that portion of the requirement was greater than or equal to *P10SViol.*
$S10RViol^1_h$	The amount by which the overall *ten-minute operating reserve* requirement is not met in hour *h* of Pass 1 (above and beyond any failure to meet the synchronized *ten-minute operating reserve* requirement) because the cost of meeting that portion of the requirement was greater than or equal to *P10RViol.*
$S30RViol^1_h$	The amount by which the overall *thirty-minute operating reserve* requirement is not met in hour *h* of Pass 1 (above and beyond any failure to meet the *ten-minute operating reserve* requirement) because the cost of meeting that portion of the requirement was greater than or equal to *P30RViol.*
$SREG10RViol^1_{r,h}$	The amount by which the minimum *ten-minute operating reserve* requirement for region *r* is not met in hour *h* of Pass 1 because the cost of meeting that portion of the requirement was greater than or equal to *PREG10RViol.*

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

4.6.2.7 Output Shadow Prices

Shadow Prices of Constraints:

SPL^{1}_{h}	The Pass 1 shadow price measuring the rate of change of the objective function for a change in load at the *reference bus* in hour *h*.
$SPNormT^{1}_{f,h}$	The Pass 1 shadow price measuring the rate of change of the objective function for a change in the limit, $AdjNormMaxFlow_{f,h}$, on flows over transmission *facilities* in normal conditions for *facility f* in hour *h*.

$SPEmT^1_{f,c,h}$	The Pass 1 shadow price measuring the rate of change of the objective function for a change in the limit, $AdjEmMaxFlow_{f,c,h}$, on flows over transmission *facilities* in emergency conditions for *facility f* in monitored contingency *c* in hour *h*.

Shadow Price for Energy:

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

4.6.2.8 Energy Ramp Rates

$RmpRngMaxPRL_{j,b}$	The maximum load reduction to which the ramp rates $URRPRL_{j,b}$ and $DRRPRL_{j,b}$ apply for a *dispatchable load* at bus *b*. The largest $RmpRngMaxPRL_{j,b}$ must be greater than or equal to maximum load reduction bid.
$URRPRL_{j,b}$	The maximum rate per minute at which a *dispatchable load* at bus *b* can decrease its consumption of energy while operating in the range between $RmpRngMaxPRL_{j-1,b}$ and $RmpRngMaxPRL_{j,b}$.
$DRRPRL_{j,b}$	The maximum rate per minute at which a *dispatchable load* at bus *b* can increase its consumption of energy while operating in the range between $RmpRngMaxPRL_{j-1,b}$ and $RmpRngMaxPRL_{j,b}$.
$RmpRngMaxPRG_{k,b}$	The maximum output level to which the ramp rates $URRPRG_{k,b}$ and $DRRPRG_{k,b}$ apply for a *generation facility* at bus *b*. The largest $RmpRngMaxPRG_{k,h,b}$ must be greater than or equal to maximum *energy offered*.
$URRPRG_{k,b}$	The maximum rate per minute at which a *generation facility* at bus *b* can increase its output while operating in the range between $RmpRngMaxPRG_{k-1,b}$ and $RmpRngMaxPRG_{k,b}$.
$DRRPRG_{k,b}$	The maximum rate per minute at which a *generation facility* at bus *b* can decrease its output in hour *h* while operating in the range between $RmpRngMaxPRG_{k-1,b}$ and $RmpRngMaxPRG_{k,b}$.

4.7 Objective Function

4.7.1 The optimization of the objective function in Pass 1 is to maximize the expression:

$$\sum_{h=1,\ldots,24}\left\{\begin{array}{l}\displaystyle\sum_{d\in DX,j\in J_d}(SHXL^1_{j,h,d}\cdot PHXL_{j,h,d}-SX10N^1_{j,h,d}\cdot PX10N_{j,h,d}-SX30R^1_{j,h,d}\cdot PX30R_{j,h,d})\\ \displaystyle-\sum_{b\in B}\left[\begin{array}{l}\displaystyle\sum_{j\in J_b}SPRL^1_{j,h,b}\cdot PPRL_{j,h,b}\\ \displaystyle+\sum_{j\in J_b}\begin{array}{l}10SSPRL^1_{j,h,b}\cdot 10SPPRL_{j,h,b}+10NSPRL^1_{j,h,b}\cdot 10NPPRL_{j,h,b}+\\ 30RSPRL^1_{j,h,b}\cdot 30RPPRL_{j,h,b}\end{array}\end{array}\right]\\ \displaystyle-\sum_{d\in DI,k\in K_d}\left(SHIG^1_{k,h,d}\cdot PHIG_{k,h,d}+SI10N^1_{k,h,d}\cdot PI10N_{k,h,d}+SI30R^1_{k,h,d}\cdot PI30R_{k,h,d}\right)\\ \displaystyle-\sum_{b\in B}\left[\begin{array}{l}\displaystyle\sum_{k\in K_b}\left(SPRG^1_{k,h,b}\cdot PPRG_{k,h,b}\right)\\ +OPRG^1_{h,b}\cdot MGOPRG_{h,b}+IPRG^1_{h,b}\cdot SUPRG_{h,b}\\ \displaystyle+\sum_{k\in K_b}\begin{array}{l}10SSPRG^1_{k,h,b}\cdot 10SPPRG_{k,h,b}+10NSPRG^1_{k,h,b}\cdot 10NPPRG_{k,h,b}\\ +30RSPRG^1_{k,h,b}\cdot 30RPPRG_{k,h,b}\end{array}\end{array}\right]\\ -ViolCost^1_h\end{array}\right\};$$

where $ViolCost^1_h$ is calculated as follows:

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

4.7.2 The Pass 1 maximization is subject to the constraints described in the next section.

4.8 Constraints Overview

4.8.1 The constraints that apply to the optimization above can be broken into the categories:

a) Single hour constraints to ensure that the schedules determined in the optimization do not violate the parameters specified in the *bids* and *offers* submitted by *registered market participants*;

b) Inter-hour and multi-hour constraints to ensure that the schedules determined in the optimization do not violate the parameters specified in the *bids* and *offers* submitted by *registered market participants*; and

c) Constraints to ensure that those schedules do not violate *reliability* criteria established by the *IESO*.

4.9 Bid/Offer Constraints Applying to Single Hours

4.9.1 Status Variables and Capacity Constraints

4.9.1.1 A Boolean variable, $OPRG^1_{h,b}$ indicates whether a *dispatchable generation facility* at bus *b* is committed in hour *h*. A value of zero indicates that a resource is not committed, while a value of one indicates that it is committed. Therefore:

$OPRG_{h,b}^1 = 0 \text{ or } 1,$ for all hours *h* and buses *b.*

4.9.1.2 Must-run resources will be considered committed for all must-run hours. Regulating units will be considered committed for all the hours that they are regulating. *Generation facilities* with zero commitment cost (i.e., their *minimum loading point*s, *start-up costs minimum generation block run-times* and *minimum generation block down times* are zero) and hourly *loads,* imports and exports will be considered committed for all the hours.

4.9.1.3 No schedule can be negative, nor can any schedule exceed the amount of capacity *offered* for that service (*energy* and *operating reserve*). Therefore:

$$0 \leq SPRL^1_{j,h,b} \leq QPRL_{j,h,b};$$

$$0 \leq 10SSPRL^1_{j,h,b} \leq 10SQPRL_{j,h,b};$$

$$0 \leq 10NSPRL^1_{j,h,b} \leq 10NQPRL_{j,h,b};$$

$$0 \leq 30RSPRL^1_{j,h,b} \leq 30RQPRL_{j,h,b};$$

$$0 \leq SHXL^1_{j,h,d} \leq QHXL_{j,h,d};$$

$$0 \leq SX10N^1_{j,h,d} \leq QX10N_{j,h,d};$$

$$0 \leq SX30R^1_{j,h,d} \leq QX30R_{j,h,d};$$

$$0 \leq SHIG^1_{k,h,d} \leq QHIG_{k,h,d};$$

$$0 \leq SI10N^1_{k,h,d} \leq QI10N_{k,h,d}; \text{ and}$$

$$0 \leq SI30R^1_{k,h,d} \leq QI30R_{k,h,d}$$

for all *bids j*, *offers k*, hours *h*, buses *b* and *intertie zones* sink/source bus *d*.

4.9.1.4 In the case of *generation facilities*, in addition to restrictions on their schedules similar to those above, their schedules must be consistent with their operating status as described above. *Generation facilities* can be scheduled to produce *energy* and/or *operating reserve* only if they are committed. Therefore:

$$0 \leq SPRG^1_{k,h,b} \leq OPRG^1_{h,b} \cdot QPRG_{k,h,b};$$

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

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

$$0 \le 30RSPRG^{1}_{k,h,b} \le OPRG^{1}_{h,b} \cdot 30RQPRG_{k,h,b}$$

for all *offers* k, hours h, and buses b.

4.9.1.5 In the case of linked wheeling transactions (the export *bid* and the import *offer* have the same *NERC* tag identifier), the amount of scheduled export *energy* must be equal to the amount of scheduled import *energy*. Therefore:

$$\sum_{j \in J_d} SHXL^{1}_{j,h,dx} = \sum_{k \in k_d} SHIG^{1}_{k,h,di}$$

where *dx* and *di* are the respective buses of the export and import schedules associated with the wheeling transactions.

4.9.1.6 The minimum and/or maximum output of internal resources may be limited because of *outages* and/or de-ratings or in order for the units to provide *regulation* or voltage support. These constraints will take the form:

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

4.9.1.7 Similarly, the maximum level of load reduction is the mechanism by which a *dispatchable load* indicates any de-rating to its registered maximum load reduction level due to mechanical or operational adjustments to their equipment. The constraint will take the form:

$$\sum_{j \in J_b} SPRL^{1}_{j,h,b} \le MaxPRL_{h,b}.$$

4.9.2 Operating Reserve Constraints

4.9.2.1 The total reserve (10-minute synchronized, 10-minute non-synchronized and 30-minute) from committed *dispatchable load* cannot exceed its ramp capability over 30 minutes. It cannot exceed the total scheduled load (maximum load *bid* minus the load reductions). These conditions can be enforced by the following two constraints:

$$\sum_{j \in J_b} (10SSPRL^{1}_{j,h,b} + 10NSPRL^{1}_{j,h,b} + 30RSPRL^{1}_{j,h,b}) \le 30 \cdot ORRPRL_b; \text{ and}$$

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

4.9.2.2 In addition, this next constraint ensures that the total (10-minute synchronized, 10-minute non-synchronized and 30-minute) from committed *dispatchable load* cannot exceed the *dispatchable load's* ramp capability to increase load reduction (schedules for hour, h=0 are obtained from the initializing inputs listed in section 3.8):

$$\sum_{j \in J_b} (10SSPRL^1_{j,h,b} + 10NSPRL^1_{j,h,b} + 30RSPRL^1_{j,h,b})$$
$$\le -\sum_{j \in J_b} \left[\left(QPRL_{j,h-1,b} - SPRL^1_{j,h-1,b}\right) - \left(QPRL_{j,h,b} - SPRL^1_{j,h,b}\right)\right]$$
$$+ 60 \cdot URRPRL_b.$$

4.9.2.3 Finally, the total 10-minute synchronized, 10-minute non-synchronized and 30-minute *operating reserve* from committed *dispatchable load* cannot exceed the *dispatchable load's* Pass 1 scheduled consumption:

$$\sum_{j \in J_b} (10SSPRL^1_{j,h,b} + 10NSPRL^1_{j,h,b} + 30RSPRL^1_{j,h,b})$$
$$\le MaxPRL_{h,b} - \sum_{j \in J_b} SPRL^1_{j,h,b}.$$

4.9.2.4 The amount of 10-minute synchronized reserve plus the 10-minute non-synchronized reserve that a *dispatchable load* is scheduled to provide cannot exceed the amount by which it can decrease its load over 10 minutes, as limited by its *operating reserve* ramp rate. This condition can be enforced by the following constraint:

$$\sum_{j \in J_b} 10SSPRL^1_{j,h,b} + 10NSPRL^1_{j,h,b} \le 10 \cdot ORRPRL_b.$$

4.9.2.5 The total reserve (10-minute synchronized, 10-minute non-synchronized and 30-minute) from committed *generation facility* cannot exceed its ramp capability over 30 minutes. It cannot exceed the remaining capacity (maximum *offered* generation minus the *energy* schedule). These conditions can be enforced by the following two constraints:

$$\sum_{k \in K_b} (10SSPRG^1_{k,h,b} + 10NSPRG^1_{k,h,b} + 30RSPRG^1_{k,h,b})$$
$$\le 30 \cdot ORRPRG_b \text{; and}$$

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

4.9.2.6 In addition, this next constraint ensures that the total (10-minute synchronized, 10-minute non-synchronized and 30-minute) from committed *dispatchable generation facility* cannot exceed the *generation facility's* ramp capability (schedules for hour, *h*=0 are obtained from the initializing inputs listed in section 3.8). Ramping considerations from start-ups or shut downs are not carried forward from one day to the next:

$$\sum_{k \in K_b} (10SSPRG^1_{k,h,b} + 10NSPRG^1_{k,h,b} + 30RSPRG^1_{k,h,b}) \le \sum_{k \in K_b} \left(SPRG^1_{k,h-1,b} - SPRG^1_{k,h,b}\right) + 60 \times URRPRG_b$$

and

$$\sum_{k \in K_b}\left(10SSPRG^1_{k,h,b} + 10NSPRG^1_{k,h,b} + 30RSPRG^1_{k,h,b}\right) + \sum_{k \in K_b}\left(SPRG^1_{kh,b}\right) \leq [(h - n) * 60 + 30] \times URRPRG_b \times OPRG^1_{h,b}$$

where n is the hour of the last start before or in hour h

and

$$\sum_{k \in K_b}\left(10SSPRG^1_{k,h,b} + 10NSPRG^1_{k,h,b} + 30RSPRG^1_{k,h,b}\right) + \sum_{k \in K_b}\left(SPRG^1_{k,h,b}\right) \leq [(m - h) * 60 + 30] \times DRRPRG_b \times OPRG^1_{h,b}$$

where m is the hour of the last shut down in or after hour h.

4.9.2.7 Finally, the total (10-minute synchronized, 10-minute non-synchronized and 30-minute) from committed *generation facility* cannot exceed its Pass 1 unscheduled capacity:

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

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

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

4.9.2.9 The total reserve (10-minute non-synchronized and 30-minute) from hourly exports cannot exceed its ramp capability over 30 minutes. It cannot exceed the total scheduled export. These conditions can be enforced by the following two constraints:

$$\sum_{j \in J_d}(SX10N^1_{j,h,d} + SX30R^1_{j,h,d}) \leq 30 \cdot ORRHXL_d; \text{ and}$$

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

4.9.2.10 The amount of 10-minute non-synchronized reserve that hourly export is scheduled to provide cannot exceed the amount by which it can decrease its load over 10 minutes, as limited by its *operating reserve* ramp rate. This condition can be enforced by the following constraint:

$$\sum_{j \in J_d}(SX10N^1_{j,h,d}) \leq 10 \cdot ORRHXL_d.$$

4.9.2.11 The total reserve (10-minute non-synchronized and 30-minute) from hourly imports cannot exceed its ramp capability over 30 minutes. It cannot exceed the remaining capacity (maximum import *offer* minus scheduled *energy* import). These conditions can be enforced by the following two constraints:

$$\sum_{k \in K_d} (SI10N^1_{k,h,d} + SI30R^1_{k,h,d}) \le 30 \cdot ORRHIG_d \text{; and}$$

$$\sum_{k \in K_d} (SI10N^1_{k,h,d} + SI30R^1_{k,h,d}) \le \sum_{k \in K_d} (QHIG_{k,h,d} - SHIG^1_{k,h,d}).$$

4.9.2.12 The amount of 10-minute non-synchronized reserve that hourly import is scheduled to provide cannot exceed the amount by which it can increase the output over 10 minutes, as limited by its *operating reserve* ramp rate. This condition can be enforced by the following constraint:

$$\sum_{k \in K_d} SI10N^1_{k,h,d} \le 10 \cdot ORRHIG_d.$$

4.10 Bid/Offer Inter-Hour/Multi-Hour Constraints

4.10.1 Status Variables

4.10.1.1 A Boolean variable, $IPRG^1_{h,b}$, indicates that a *generation facility* at bus *b* are scheduled to start up on hour *h*. A value of zero indicates that a resource is not scheduled to start up, while a value of one indicates that it is scheduled to start up. Therefore, for *h* > 1:

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

4.10.1.2 For *h* = 1, the determination of whether a resource was previously operating must make reference to the initial conditions:

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

4.10.2 Ramping

4.10.2.1 *Energy* schedules for each resource cannot vary by more than an hour's ramping capacity for that resource. The *energy* schedule change in the hour in which the unit is scheduled to start or shut down depends on the unit ramp rate below its *minimum loading point*. Almost all non-quick start units will need one or more hours to reach their *minimum loading point* and to go down from *minimum loading point* to zero. Since non-committed units must be assigned zero output and committed units must operate at or above their *minimum loading point*, it is assumed that these units will be at their *minimum loading point* at the beginning of the first commitment hour and at the end of the hour before shut down.

4.10.2.2 The following three part constraint ensures that *energy* schedules do not exceed the *generation facility's* ramp capability in the hours where the *generation facility* starts, stays on and shuts down.

Start Up Scenario ($OPRG^1_{h,b} = 1$, and $OPRG^1_{h-1,b} = 0$)

$$0 \le \sum_{k \in K_b} SPRG^1_{k,h,b} \le \sum_{k \in K_b} 30 \times URRPRG_b$$

Continued On Scenario ($OPRG^1_{h-1,b} = OPRG^1_{h,b} = 1$)

$$\sum_{k \in K_b} \left(SPRG^1_{k,h-1,b} \right) - 60 \times DRRPRG_b \le \sum_{k \in K_b} SPRG^1_{k,h,b} \le \sum_{k \in K_b} \left(SPRG^1_{k,h-1,b} \right) + 60 \times URRPRG_b$$

Shut Down Scenario ($OPRG^1_{h,b} = 1$, and $OPRG^1_{h+1,b} = 0$)

$$0 \le \sum_{k \in K_b} SPRG^1_{k,h,b} \le \sum_{k \in K_b} 30 \times DRRPRG_b$$

4.10.2.3 It should be noted that this ramp up/down is in addition to the *minimum loading point*. The unit commitment process handles the *minimum loading point* change. This ramp only affects the incremental change above the *minimum loading point*.

4.10.2.4 The *dispatchable loads* are considered committed in all hours. Similar logic is applied to *dispatchable loads* to arrive at the following constraint:

$$\begin{aligned} &\sum_{j \in J_b} \left(QPRL_{j,h-1,b} - SPRL^1_{j,h-1,b} \right) - 60 \cdot URRPRL_{h,b} \\ &\quad \le \sum_{j \in J_b} \left(QPRL_{j,h,b} - SPRL^1_{j,h,b} \right) \\ &\quad \le \sum_{j \in J_b} \left(QPRL_{j,h-1,b} - SPRL^1_{j,h-1,b} \right) + 60 \cdot DRRPRL_{h,b}. \end{aligned}$$

4.10.2.5 The above two constraints apply for all hours from 1 to 24. In the above two constraints the variables related to hour zero belong to the last hour of the previous day and are obtained from the initializing assumptions.

4.10.2.6 The ramping rates in the ramping constraints must be adjusted to allow the resource to:

a) Ramp down from its lower limit in hour (*h-1*) to its upper limit in hour *h*.

b) Ramp up from its upper limit in hour (*h-1*) to its lower limit in hour *h*.

4.10.2.7 This will allow a solution to be obtained when changes to the upper and lower limits between hours are beyond the ramping capability of the resources.

4.10.2.8 In the above ramping constraints, a single ramp up and a single ramp down, $URRPRG_b$ and $DRRPRG_b$ for *generation facilities* and $URRPRL_b$ and $DRRPRL_b$ for *dispatchable loads* are used. The ramp rate is assumed constant over the full operating range of the *dispatchable load* and *generation facility*. However, this is not the case. *Dispatchable load bids* and *generator offers* will include multi-*energy* ramp rates.

4.10.2.9 In the *dispatchable load bids*, multi-*energy* ramp rates would be specified as:

a) $RmpRngMaxPRL_{j,\,b}$ shall designate the level of maximum load reduction to which the ramp rates $URRPRL_{j,b}$ and $DRRPRL_{j,b}$ shall apply. $RmpRngMaxPRL_{5,b}$ must be greater than or equal to maximum load reduction *bid*.

b) $URRPRL_{j,b}$ shall designate the maximum rate per minute at which a *dispatchable load* at bus *b* can increase load reduction while operating in the range between $RmpRngMaxPRL_{j-1,b}$ and $RmpRngMaxPRL_{j,b.}$ $RmpRngMaxPRL_{0,b}$ is equal to the minimum load reduction.

c) $DRRPRL_{j,b}$ shall designate the maximum rate per minute at which a *dispatchable load* at bus *b* can decrease load reduction while operating in the range between $RmpRngMaxPRL_{j-1,b}$ and $RmpRngMaxPRL_{j,b.}$ $RmpRngMaxPRL_{0,b}$ is equal to the minimum load reduction.

4.10.2.10 The multi-*energy* ramp rates would be specified for *generation facilities* as:

a) $RmpRngMaxPRG_{k,b}$ shall designate the maximum generation output level to which the ramp rates $URRPRG_{k,b}$ and $DRRPRG_{k,b}$ shall apply. $RmpRngMaxPRG_{5,b}$ must be greater than or equal to maximum generation output *offered*.

b) $URRPRG_{k,b}$ shall designate the maximum rate per minute at which a *generation facility* at bus *b* can increase its output while operating in the range between $RmpRngMaxPRG_{k-1,b}$ and $RmpRngMaxPRG_{k,b.}$ $RmpRngMaxPRG_{0,b}$ is equal to its *minimum loading point*.

c) $DRRPRG_{k,b}$ shall designate the maximum rate per minute at which a *generation facility* at bus *b* can decrease its output while operating in the range between $RmpRngMaxPRG_{k-1,b}$ and $RmpRngMaxPRG_{k,b.}$ $RmpRngMaxPRG_{0,b}$ is equal to its *minimum loading point*.

4.10.3 Minimum Generation Block Run Time and Minimum Generation Block Down Time

4.10.3.1 Schedules for *generators* must observe *minimum generation block run times* and *minimum generation block down times*. At the beginning of the day, a *generation facility*'s previous day schedule is considered,

if $0 < InitOperHrs_b < MRTPRG_b$, then that *generation facility* has yet to complete its *minimum generation block run time*, and:

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

4.10.3.2 During the day,

if $OPRG^1_{h,b} = 1$, $OPRG^1_{h+1,b} = 0$, and $MDTPRG_b > 1$, then the *generation facility* at bus *b* has been scheduled to shut down during hour *h* + 1. It must be scheduled to remain off until it has completed its *minimum generation block down time* or we reach the end of the day. Therefore:

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

And if $OPRG^1_{h,b} = 0$, $OPRG^1_{h+1,b} = 1$, and $MRTPRG_b > 1$, then the *generation facility* at bus *b* has been scheduled to start up during hour *h* + 1. It must be scheduled to remain in operation until it has completed its *minimum generation block run time* or we reach the end of the day, so:

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

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

4.10.4 Energy Limited Resources

4.10.4.1 A constraint must be added in order to ensure that *energy*-limited units are not scheduled to provide more *energy* than they have indicated they are capable of providing. In addition to limiting *energy* schedules over the course of the day to the *energy* limit specified for a unit, this constraint must also ensure that units are not scheduled to provide *energy* in amounts that would preclude them from providing reserve when activated. Given these factors, therefore:

$$\sum_{h=1}^{1}\left(OPRG_{h,b}^{1}\cdot MinQPRG_{h,b}+\sum_{k\in K_b}SPRG_{k,h,b}^{1}\right)$$
$$+10ORConv\left(\sum_{k\in K_b}10SSPRG_{k,1,b}^{1}+\sum_{k\in K_b}10NSPRG_{k,1,b}^{1}\right)$$
$$+30ORConv\sum_{k\in K_b}30RSPRG_{k,1,b}^{1}\leq EL_b;$$
$$\sum_{h=1}^{2}\left(OPRG_{h,b}^{1}\cdot MinQPRG_{h,b}+\sum_{k\in K_b}SPRG_{k,h,b}^{1}\right)$$
$$+10ORConv\left(\sum_{k\in K_b}10SSPRG_{k,2,b}^{1}+\sum_{k\in K_b}10NSPRG_{k,2,b}^{1}\right)$$
$$+30ORConv\sum_{k\in K_b}30RSPRG_{k,2,b}^{1}\leq EL_b;$$
$$\vdots$$
$$\sum_{h=1}^{24}\left(OPRG_{h,b}^{1}\cdot MinQPRG_{h,b}+\sum_{k\in K_b}SPRG_{k,h,b}^{1}\right)$$
$$+10ORConv\left(\sum_{k\in K_b}10SSPRG_{k,24,b}^{1}+\sum_{k\in K_b}10NSPRG_{k,24,b}^{1}\right)$$
$$+30ORConv\sum_{k\in K_b}30RSPRG_{k,24,b}^{1}\leq EL_b$$

for all buses *b* at which *energy*-limited resources are located. The factors *10ORConv* and *30ORConv* are applied to scheduled *ten-minute* and *thirty-minute operating reserves* for *energy*-limited resources to convert MW into MWh. This factor is initially set to unity.

4.10.5 Maximum Number of Starts

4.10.5.1 To ensure that *generation facilities* are not scheduled to be cycled on and off more than their specified maximum number in a day, the following constraint is defined:

$$\sum_{h=1}^{24}IPRG_{h,b}^{1}\leq MaxStartsPRG_b.$$

4.11 Constraints to Ensure Schedules Do Not Violate Reliability Requirements

4.11.1 Load

4.11.1.1 For each hour of the DACP, the total amount of *energy* generated in the DACP schedule, plus scheduled imports must be sufficient to meet forecast *demand*, scheduled exports, and transmission losses consistent with these schedules. It will be easiest to break the derivation of the constraint that will ensure this occurs into several steps.

4.11.1.2 The total amount of withdrawals scheduled in Pass 1 at each bus *b* in each hour *h*, $With^1_{h,b}$, is the sum of:

- The portion of the load forecast for that hour that has been allocated to that bus; and
- All *dispatchable load bid*, net of the amount of load reduction scheduled (since the *dispatchable load* is excluded from the *demand* forecast by the DACP calculation engine), yielding:

$$With^1_{h,b} = LDF_{h,b} \cdot AFL_h + \left[\sum_{j \in J_b} \left(QPRL_{j,h,b} - SPRL^1_{j,h,b} \right) \right]; \text{and}$$

the total amount of withdrawals scheduled in Pass 1 at each *intertie zone* sink bus *d* in each hour *h*, $With^1_{h,d}$, is the sum of:

- Exports from Ontario to each *intertie zone* sink bus; and
- Outflows from Ontario associated with loop flows between Ontario and each *intertie zone*, allocated among the buses in the *intertie zones* using the distribution factors developed for that purpose, yielding:

$$With^1_{h,d} = \sum_{j \in J_d} (SHXL^1_{j,h,d}) - \sum_{a \in A} ProxyUPOWt_{d,a} \cdot \min(0, PF_{h,a}).$$

4.11.1.3 The total amount of injections scheduled in Pass 1 at each bus *b* in each hour *h*, $Inj^1_{h,b}$, is the sum of

- *Generation facilities* scheduled at that bus, yielding:

$$Inj^1_{h,b} = OPRG^1_{h,b} \cdot MinQPRG_{h,b} + \sum_{k \in K_b} SPRG^1_{k,h,b}; \text{and}$$

the total amount of injections scheduled in Pass 1 at each *intertie zone* source bus *d* in each hour *h*, $Inj^1_{h,b}$, is the sum of:

- Imports into Ontario from each *intertie zone* source bus; and

- Inflows from Ontario associated with loop flows between Ontario and each *intertie zone*, allocated among the buses in the *intertie zones* using the distribution factors developed for that purpose:

$$Inj_{h,d}^{1} = \sum_{k \in K_d} SHIG_{k,h,d}^{1} + \sum_{a \in A} ProxyUPIWt_{d,a} \cdot \max(0, PF_{h,a}).$$

4.11.1.4 Injections and withdrawals at each bus must 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 actual and marginal losses. Load reduction associated with the *demand* constraint violation will be subtracted from the total load and generation reduction will be subtracted from total generation associated with the *demand* constraint violation to ensure that the DACP calculation engine will always produce a solution. These violation variables are assigned a very high cost to limit their use to infeasible cases.

$$\begin{aligned}
&\sum_{b \in B}(1 + MglLoss_{h,b})With_{h,b}^{1} + \sum_{d \in D}(1 + MglLoss_{h,d})With_{h,d}^{1} - SLdViol_{h}^{1} \\
&\quad = \sum_{b \in B}(1 + MglLoss_{h,b})Inj_{h,b}^{1} \\
&\quad\quad + \sum_{d \in D}(1 + MglLoss_{h,d})Inj_{h,d}^{1} - SGenViol_{h}^{1} + LossAdj_{h}.
\end{aligned}$$

4.11.2 Operating Reserve

4.11.2.1 Sufficient *operating reserve* must be provided on the system to meet system wide requirements for 10-minute synchronized reserve, *ten-minute operating reserve* and *thirty-minute operating reserve*, as well as all applicable regional minimum and maximum requirements for *operating reserve*.

4.11.2.2 Therefore, taking into consideration the potential not to meet these minimum and maximum requirements if the cost of meeting those requirements becomes too high:

$$\begin{aligned}
&\sum_{b \in B}\left(\sum_{k \in K_b} 10SSPRG_{k,h,b}^{1}\right) + \sum_{b \in B}\left(\sum_{j \in J_b} 10SSPRL_{j,h,b}^{1}\right) + S10SViol_{h}^{1} \\
&\quad \geq TOT10S_{h};
\end{aligned}$$

$$\begin{aligned}
&\sum_{b \in B}\left(\sum_{j \in J_b} 10SSPRL_{j,h,b}^{1}\right) + \sum_{b \in B}\left(\sum_{k \in K_b} 10SSPRG_{k,h,b}^{1}\right) + S10RViol_{h}^{1} \\
&\quad + \sum_{b \in B}\left(\sum_{k \in K_b} 10NSPRG_{k,h,b}^{1}\right) + \sum_{b \in B}\left(\sum_{j \in J_b} 10NSPRL_{j,h,b}^{1}\right) \\
&\quad + \sum_{d \in D}\left(\sum_{k \in K_d} SI10N_{k,h,d}^{1}\right) + \sum_{d \in D}\left(\sum_{j \in J_d} SX10N_{j,h,d}^{1}\right) \geq TOT10R_{h}; \text{ and}
\end{aligned}$$

$$\sum_{b\in B}\left(\sum_{j\in J_b} 10SSPRL^1_{j,h,b}\right)+\sum_{b\in B}\left(\sum_{k\in K_b} 10SSPRG^1_{k,h,b}\right)+S30RViol^1_h$$
$$+\sum_{b\in B}\left(\sum_{k\in K_b}(10NSPRG^1_{k,h,b}+30RSPRG^1_{k,h,b})\right)$$
$$+\sum_{b\in B}\left(\sum_{j\in J_b}(10NSPRL^1_{j,h,b}+30RSPRL^1_{j,h,b})\right)$$
$$+\sum_{d\in D}\left(\sum_{k\in K_d}(SI10N^1_{k,h,d}+SI30R^1_{k,h,d})\right)$$
$$+\sum_{d\in D}\left(\sum_{j\in J_d}(SX10N^1_{j,h,d}+SX30R^1_{j,h,d})\right)\geq TOT30R_h$$

for all hours *h*, and

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

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

$$\sum_{b\in r}\left(\sum_{j\in J_b} 10SSPRL^1_{j,h,b}\right)+\sum_{b\in r}\left(\sum_{k\in K_b} 10SSPRG^1_{k,h,b}\right)+SREG30RViol^1_{r,h}$$
$$+\sum_{b\in r}\left(\sum_{k\in K_b}(10NSPRG^1_{k,h,b}+30RSPRG^1_{k,h,b})\right)$$
$$+\sum_{b\in r}\left(\sum_{j\in J_b}(10NSPRL^1_{j,h,b}+30RSPRL^1_{j,h,b})\right)$$
$$\geq REGMin30R_{r,h};\text{ and}$$

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

for all hours *h*, and for all regions *r* in the set *ORREG*.

4.11.3 Internal Transmission Limits

4.11.3.1 The *IESO* must ensure that the set of DACP schedules produced by Pass 1 of the DACP calculation engine would not violate any *security limits* in either the pre-contingency state or after any contingency.

4.11.3.2 To develop the constraints to ensure that this occurs, the total amount of *energy* scheduled to be injected at each bus and the total amount of *energy* scheduled to be withdrawn at each bus will be used.

4.11.3.3 The *security* assessment function of the DACP calculation engine will linearize binding (violated) pre-contingency limits on transmission *facilities* within Ontario. The linearized constraints will take the form:

$$\sum_{b\in B} PreConSF_{b,f,h}(Inj^1_{h,b}-With^1_{h,b})+\sum_{d\in D} PreConSF_{d,f,h}(Inj^1_{h,d}-With^1_{h,d})$$
$$-SPreConITLViol^1_{f,h}\leq AdjNormMaxFlow_{f,h}$$

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

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

$$\sum_{b\in B} SF_{b,f,c,h}(Inj^1_{h,b}-With^1_{h,b})+\sum_{d\in D} SF_{d,f,c,h}(Inj^1_{h,d}-With^1_{h,d})$$
$$-SITLViol^1_{f,c,h}\leq AdjEmMaxFlow_{f,c,h}$$

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

4.11.4 Intertie Limits and Constraints on Net Imports

4.11.4.1 The *IESO* must ensure that the set of DACP schedules produced by Pass 1 of the DACP calculation engine would not violate any *security limits* associated with *interties* between Ontario and *intertie zones*. To ensure this, we must calculate the net amount of *energy* scheduled to flow over each *intertie* in each hour and the amount of *operating reserve* scheduled to be provided by resources in that *control area*. This will be summed over all affected *interties*. The result will be compared to the limit associated with that constraint. Consequently:

$$\sum_{a\in A}\left[\begin{array}{l} EnCoeff_{a,z}\left(\sum_{d\in DI_a,k\in K_d}(SHIG^1_{k,h,d})+PF_{h,a}-\sum_{d\in DX_a,j\in J_d}(SHXL^1_{j,h,d})\right)+ \\ 0.5(EnCoeff_{a,z}+1)\left[\begin{array}{l}\sum_{d\in DI_a,k\in K_d}\left(SI10N^1_{k,h,d}+SI30R^1_{k,h,d}\right) \\ +\sum_{d\in DX_a,j\in J_d}\left(SX10N^1_{j,h,d}+SX30R^1_{j,h,d}\right)\end{array}\right]\end{array}\right]$$
$$\leq MaxExtSch_{z,h}$$

for all hours *h*, for all *intertie zones a* relevant to the constraint *z* ($EnCoeff_{a,z}\neq 0$), and for all constraints *z* in the set Z_{sch}.

4.11.4.2 In addition, changes in the net *energy* schedule over all *interties* cannot exceed the limits set forth by the *IESO* for hour-to-hour changes in those schedules. The net import schedule is summed over all *interties* for a given hour. It cannot exceed the sum of net import schedule for all *interties* for the previous hour plus the maximum permitted hourly increase. It cannot be less than the sum of the net import schedule for all *interties* for the previous hour minus the maximum permitted hourly decrease. Violation variables are provided for both the up and down ramp limits to ensure that the DACP calculation engine will always find a solution. Therefore:

$$\sum_{d\in D}\left(\sum_{k\in K_d}(SHIG^1_{k,h-1,d})-\sum_{j\in J_d}(SHXL^1_{j,h-1,d})\right)-ExtDSC_h-SDRmpXTLViol^1_h$$
$$\leq\sum_{d\in D}\left(\sum_{k\in K_d}(SHIG^1_{k,h,a})-\sum_{j\in J_d}(SHXL^1_{j,h,d})\right)$$
$$\leq\sum_{d\in D}\left(\sum_{k\in K_d}(SHIG^1_{k,h-1,d})-\sum_{j\in J_d}(SHXL^1_{j,h-1,d})\right)+ExtUSC_h+SURmpXTLViol^1_h$$

for all hours *h* (schedules for hour, *h*=0 are obtained from the initializing inputs listed in section 3.8).

4.12 Shadow Prices for Energy

4.12.1 The Pass 1 shadow price at each bus *b* in each hour *h* measures the *offered* price of meeting an infinitesimal change in the amount of load at that bus in that hour, or equivalently, measures the value of an incremental amount of generation at that bus in that hour in Pass 1. The Pass 1 shadow price at each bus *b* in each hour *h,* given the inputs and constraints into Pass 1, shall be calculated at internal locations as:

$$LMP^1_{h,b}=\left(1+MglLoss_{h,b}\right)\cdot SPL^1_h+\sum_f\left(\begin{array}{l}PreConSF_{b,f,h}\cdot SPNormT^1_{f,h} \\ +\sum_c SF_{b,f,c,h}\cdot SPEmT^1_{f,c,h}\end{array}\right).$$

4.12.2 The first portion of the right-hand side of this equation measures the cost of meeting load at bus *b*, incorporating the effect of marginal losses. It reflects the quantity of *energy* that must be injected at the *reference bus* to meet additional load at each bus *b*. The term in the summation reflects the cost of transmission congestion resulting from an infinitesimal increase in withdrawals at each bus *b* on each pre- and post-contingency internal transmission constraint. It is calculated as the product of each:

a) Shadow price, which measures the impact on the cost on that constraint if there were a one-to-one correspondence between increases in load and flows on the constraint (i.e., if each MW of increased load caused an increase in 1 MW inflows over the constraint); and

b) The shift factor for that bus and that constraint, which measures the actual impact of additional withdrawals at each bus on flows over that constraint.

4.12.3 [Intentionally left blank – section deleted]

5. Pass 2: Constrained Commitment to Meet Peak Demand

5.1 Overview

5.1.1 Pass 2 performs a least cost, *security* constrained unit commitment and constrained scheduling to meet the forecast peak *demand* and *IESO*-specified *operating reserve* requirements.

5.1.2 In each hour, peak *demand* occurs for a fraction of that hour. If additional commitment of *generation facilitie*s above those made in Pass 1 are required to meet peak *demand*, these *generation facilities* would only need to be operating for a fraction of the hour. Therefore, in Pass 2, the DACP calculation engine performs least cost optimization with respect to minimizing commitment costs to satisfy peak *demand*.

5.1.3 Imports and exports can only be scheduled on an hourly basis and *generation facilities* and *dispatchable load*s can follow 5-minute dispatches to meet peak *demand*. To account for this difference in scheduling, the incremental prices of *generator offer*s and *dispatchable load bids* will be evaluated on this basis against import *offer*s and export *bids*. This evaluation of *generator offer*s and *dispatchable load bids* is explained in detail in section 5.7.

5.1.4 *Generation facilities* already committed in Pass 1 is taken as committed in Pass 2. These resources will be scheduled to no less than their *minimum loading points*. Additional commitments of *offers* from *generators* are allowed.

5.1.5 Imports scheduled in Pass 1 must be scheduled to at least that value in Pass 2. Additional hourly imports may be scheduled. Hourly exports may be scheduled to a lower but not higher value than that determined in Pass 1. The import and export components of linked wheel transactions can be scheduled higher or lower than the schedules produced in Pass 1. The commitments and schedules calculated in Pass 2 will be used in Pass 3.

5.2 Inputs into Pass 2

5.2.1 All inputs identified in section 3 will be used in Pass 2. In addition, Pass 1 *generation facility* commitments, import schedules, exports schedules and shadow prices will also be used as input into Pass 2.

5.3 Optimization Objective for Pass 2

5.3.1 As for Pass 1, the gains from trade shall be maximized for Pass 2. This is accomplished by maximizing the same objective function described in section 4.3 used for Pass 1.

5.4 Security Assessment

5.4.1 The same *security* assessment is performed as described in section 4.4.

5.5 Outputs from Pass 2

5.5.1 The primary outputs of Pass 2 which are used in Pass 3 and other DACP processes include the following:

5.5.1.1 Commitments; and

5.5.1.2 Constrained schedules for *energy*.

5.6 Glossary of Sets, Indices, Variables and Parameters for Pass 2

5.6.1 Fundamental Sets and Indices

5.6.1.1 Same as those described in section 4.6.1.

5.6.2 Variables and Parameters

5.6.2.1 Bid and Offer Inputs

Same as those described in 4.6.2.1. In addition, the variables below are used to account for the fact that *generation facilities* and *dispatchable loads* are able to follow 5-minute dispatches to meet peak *demand* but imports and exports are only scheduled on an hourly basis:

$PmtPRG_{k,h,b}$	The lowest incremental *energy price* at which an incremental amount of *energy* should be scheduled at bus *b* in hour *h* in association with offer *k* to meet peak *demand*.
$PmtPRL_{j,h,b}$	The lowest incremental *energy price* at which an incremental quantity of reduction in *energy* consumption should be scheduled at bus *b* in hour *h* in association with bid *j* to meet peak *demand*.
PriceMultiplier	A *bid* and *offer* adjustment factor to account for the value of energy from *dispatchable loads* and *generation facilities* dispatched on a 5-minute basis to meet peak *demand* of any hour. This factor shall be 12.

5.6.2.2 Transmission and Security Inputs and Intermediate Variables

Same as those described in 4.6.2.2.

5.6.2.3 Other Inputs

Same as those described in 4.6.2.3.

5.6.2.4 Constraint Violation Price Inputs

Same as those described in 4.6.2.4.

5.6.2.5 Variables determined in Pass 1 and Used in Pass 2

$SHXL^{1}_{j,h,d}$	The amount of exports scheduled in hour *h* in Pass 1 from *intertie zone* sink bus *d* in association with *bid j*.
$SHIG^{1}_{k,h,d}$	The amount of imports scheduled in hour *h* in Pass 1 from *intertie zone* source bus *d* in associate with *offer k*.
$OPRG^{1}_{h,b}$	Indication of whether a *generation facility* at bus *b* was scheduled to operate in hour *h* in Pass 1.
$LMP^{1}_{h,b}$	The Pass 1 locational marginal price for *energy* at each bus *b* in each hour *h.*

5.6.2.6 Output Schedule and Commitment Variables

$SHXL^{2}_{j,h,d}$	The amount of exports scheduled in hour *h* in Pass 2 from *intertie zone* sink bus *d* in association with *bid j.*
$SX10N^{2}_{j,h,d}$	The amount of non-synchronized *ten-minute operating reserve* scheduled from the export in hour *h* in Pass 2 from *intertie zone* sink bus *d* in association with *bid j.*
$SX30R^{2}_{j,h,d}$	The amount of *thirty-minute operating reserve* scheduled from the export in hour *h* in Pass 2 from *intertie zone* sink bus *d* in association with *bid j.*
$SPRL^{2}_{j,h,b}$	The amount of *dispatchable load* reduction scheduled at bus *b* in hour *h* in Pass 2 in association with *bid j*.
$10SSPRL^{2}_{j,h,b}$	The amount of synchronized *ten-minute operating reserve* that a qualified *dispatchable load* is scheduled to provide at bus *b* in hour *h* in Pass 2 in association with *bid j*.
$10NSPRL^{2}_{j,h,b}$	The amount of non-synchronized *ten-minute operating reserve* that a qualified *dispatchable load* is scheduled to provide at bus *b* in hour *h* in Pass 2 in association with *bid j*.
$30RSPRL^{2}_{j,h,b}$	The amount of *thirty-minute operating reserve* that a qualified *dispatchable load* is scheduled to provide at bus *b* in hour *h* in Pass 2 in association with *bid j*.
$SHIG^{2}_{k,h,d}$	The amount of hourly imports scheduled in hour *h* from *intertie zone* source bus *d* in Pass 2 in association with *offer k.*

$SI10N^2_{k,h,d}$	The amount of imported *ten-minute operating reserve* scheduled in hour *h* from *intertie zone* source bus *d* in Pass 2 in association with *offer k.*
$SI30R^2_{k,h,d}$	The amount of imported *thirty-minute operating reserve* scheduled in hour *h* from *intertie zone* source bus *d* in Pass 2 in association with *offer k.*
$SPRG^2_{k,h,b}$	The amount of *energy* scheduled for the *generation facility* at bus *b* in hour *h* in Pass 2 in association with *offer k*. This is in addition to any $MinQPRG_{h,b}$, the *minimum loading point*, which must also be committed.
$OPRG^2_{h,b}$	Represents whether the *generation facility* at bus *b* has been scheduled in hour *h* in Pass 2.
$IPRG^2_{h,b}$	Represents whether *generation facility* at bus *b* has been scheduled to start in hour *h* in Pass 2.
$10SSPRG^2_{k,h,b}$	The amount of synchronized *ten-minute operating reserve* that a qualified *generation facility* at bus *b* is scheduled to provide in hour *h* in Pass 2 in association with *offer k*.
$10NSPRG^2_{k,h,b}$	The amount of non-synchronized *ten-minute operating reserve* that a qualified *generation facility* at bus *b* is scheduled to provide in hour *h* in Pass 2 in association with *offer k*.
$30RSPRG^2_{k,h,b}$	The amount of *thirty-minute operating reserve* that a qualified *generation facility* at bus *b* is scheduled to provide in hour *h* in Pass 2 in association with *offer k*.

5.6.2.7 Output Violation Variables

$ViolCost^2_h$	The cost incurred in order to avoid having the Pass 2 schedules for hour *h* violate specified constraints.
$SLdViol^2_h$	Projected load curtailment, that is, the amount of load that cannot be met using *offers* scheduled or committed in hour *h* in Pass 2.
$SGenViol^2_h$	The amount of additional load that must be scheduled in hour *h* in Pass 2 to ensure that there is enough load on the system to offset the must-run requirements of *generation facilities*.
$S10SViol^2_h$	The amount by which the overall synchronized *ten-minute operating reserve* requirement is not met in hour *h* of Pass 2 because the cost of meeting that portion of the requirement was greater than or equal to *P10SViol.*
$S10RViol^2_h$	The amount by which the overall *ten-minute operating reserve* requirement is not met in hour *h* of Pass 2 (above and beyond any failure to meet the synchronized *ten-minute operating reserve* requirement) because the cost of meeting that portion of the requirement was greater than or equal to *P10RViol.*

$S30RViol^2_h$	The amount by which the overall *thirty-minute operating reserve* requirement is not met in hour *h* of Pass 2 (above and beyond any failure to meet the *ten-minute operating reserve* requirement) because the cost of meeting that portion of the requirement was greater than or equal to *P30RViol.*
$SREG10RViol^2_{r,h}$	The amount by which the minimum *ten-minute operating reserve* requirement for region *r* is not met in hour *h* of Pass 2 because the cost of meeting that portion of the requirement was greater than or equal to *PREG10RViol.*
$SREG30RViol^2_{r,h}$	The amount by which the minimum *thirty-minute operating reserve* requirement for region *r* is not met in hour *h* of Pass 2 because the cost of meeting that portion of the requirement was greater than or equal to *PREG30RViol.*
$SXREG10RViol^2_{r,h}$	The amount by which the *ten-minute operating reserve* scheduled for region *r* exceeds the maximum required in hour *h* of Pass 2 because the cost of meeting that the maximum requirement limit was greater than or equal to *PXREG10RViol.*
$SXREG30RViol^2_{r,h}$	The amount by which the *thirty-minute operating reserve* scheduled for region *r* exceeds the maximum required in hour *h* of Pass 2 because the cost of meeting the maximum requirement limit was greater than or equal to *PXREG30RViol.*
$SPreConITLViol^2_{f,h}$	The amount by which pre-contingency flows over *facility f* in hour *h* of Pass 2 exceed the normal limit for flows over that *facility*, because the cost of alternative solutions that would not result in such an overload was greater than or equal to *PPreConITLViol.*
$SITLViol^2_{f,c,h}$	The amount by which flows over *facility f* that would follow the occurrence of contingency *c* in hour *h* of Pass 2 exceed the emergency limit for flows over that *facility*, because the cost of alternative solutions that would not result in such an overload was greater than or equal to *PITLViol.*
$SPreConXTLViol^2_{z,h}$	The amount by which *intertie* flows over *facility z* in hour *h* of Pass 2 exceed the normal limit for flows over that *facility*, because the cost of alternative solutions that would not result in such an overload was greater than or equal to *PPreConXTLViol.*
$SURmpXTLViol^2_h$	The amount by which the total net scheduled import increase for hour *h* in Pass 2 exceeds the up ramp limits, because the cost of alternative solutions that would not result in violation was greater than or equal to *PRmpXTLViol.*

$SDRmpXTLViol^2_h$ The amount by which the total net scheduled import decrease in hour *h* of Pass 2 exceed the down ramp limits, because the cost of alternative solutions that would not result in violation was greater than or equal to *PRmpXTLViol.*

5.6.2.8 Energy Ramp Rates

Same as those in section 4.6.2.8.

5.7 Evaluation of Generator Offers and Dispatchable Load Bids

5.7.1 All *offer*s for *generation facilities* that were committed in Pass 1 will be evaluated in Pass 2 as such:

5.7.1.1 $PmtPRG_{k,h,b}$, designates the lowest incremental *energy* price at which an incremental amount of *energy* should be scheduled at bus *b* in hour *h* in association with *offer k.* It shall be set to:

$$PmtPRG_{k,h,b} = LMP^1_{h,b} + \frac{PPRG_{k,h,b} - LMP^1_{h,b}}{PriceMultiplier}$$

for $PPRG_{k,h,b} > LMP^1_{h,b}$ and

$$PmtPRG_{k,h,b} = PPRG_{h,b}$$

for $PPRG_{k,h,b} \leq LMP^1_{h,b}$.

5.7.1.2 All other elements of the *offer*s will be used in Pass 2 as submitted.

5.7.2 All *dispatchable load bids* will be evaluated in Pass 2 as such:

5.7.2.1 $PmtPRL_{j,h,b}$, designates the lowest incremental *energy price* at which an incremental quantity of reduction in *energy* consumption specified in *bid j* should be scheduled in hour *h* at bus *b.* It shall be set to:

$$PmtPRL_{j,h,b} = LMP^1_{h,b} + \frac{PPRL_{j,h,b} - LMP^1_{h,b}}{PriceMultiplier}$$

for $PPRL_{j,h,b} > LMP^1_{h,b}$ and

$$PmtPRL_{j,h,b} = PPRL_{h,b}$$

for $PPRL_{j,h,b} \leq LMP^1_{h,b}$.

5.7.2.2 Other elements of the *dispatchable load bids* will be used in Pass 2 as submitted.

5.8 Function

5.8.1 The optimization of the objective function in Pass 2 is to maximize the expression:

$$\sum_{h=1,\dots,24}\left\{\begin{array}{l}\sum_{d\in DX,j\in J_d}(SHXL^2_{j,h,d}\cdot PHXL_{j,h,d}-SX10N^2_{j,h,d}\cdot PX10N_{j,h,d}-SX30R^2_{j,h,d}\cdot PX30R_{j,h,d})\\ -\sum_{b\in B}\left[\begin{array}{l}\sum_{j\in J_b}SPRL^2_{j,h,b}\cdot PmtPRL_{j,h,b}\\ +\sum_{j\in J_b}\begin{array}{l}10SSPRL^2_{j,h,b}\cdot 10SPPRL_{j,h,b}+10NSPRL^2_{j,h,b}\cdot 10NPPRL_{j,h,b}+\\ 30RSPRL^2_{j,h,b}\cdot 30RPPRL_{j,h,b}\end{array}\end{array}\right]\\ -\sum_{d\in DI,k\in K_d}\left(SHIG^2_{k,h,d}\cdot PHIG_{k,h,d}+SI10N^2_{k,h,d}\cdot PI10N_{k,h,d}+SI30R^2_{k,h,d}\cdot PI30R_{k,h,d}\right)\\ -\sum_{b\in B}\left[\begin{array}{l}\sum_{k\in K_b}\left(SPRG^2_{k,h,b}\cdot PmtPRG_{k,h,b}\right)\\ +OPRG^2_{h,b}\cdot MGOPRG_{h,b}+IPRG^2_{h,b}\cdot SUPRG_{h,b}\\ +\sum_{k\in K_b}\begin{array}{l}10SSPRG^2_{k,h,b}\cdot 10SPPRG_{k,h,b}+10NSPRG^2_{k,h,b}\cdot 10NPPRG_{k,h,b}\\ +30RSPRG^2_{k,h,b}\cdot 30RPPRG_{k,h,b}\end{array}\end{array}\right]\\ -ViolCost^2_h\end{array}\right\};$$

where $ViolCost^2{}_h$ is calculated as follows:

$$
\begin{aligned}
ViolCost_h^2 &= SLdViol_h^2 \cdot PLdViol - SGenViol_h^2 \cdot PGenViol \\
&+ S10SViol_h^2 \cdot P10SViol + S10RViol_h^2 \cdot P10RViol \\
&+ S30RViol_h^2 \cdot P30RViol \\
&+ \sum_{r \in ORREG} \begin{pmatrix} SREG10RViol_{r,h}^2 \cdot PREG10RViol \\ + SREG30RViol_{r,h}^2 \cdot PREG30RViol \\ + SXREG10RViol_{r,h}^2 \cdot PXREG10RViol \\ + SXREG30RViol_{r,h}^2 \cdot PXREG30RViol \end{pmatrix} \\
&+ \sum_{z \in Z} \left(SPreConXTLViol_{z,h}^2 \cdot PPreConXTLViol \right) \\
&+ SURmpXTLViol^2 \cdot PRmpXTLViol + SDRmpXTLViol^2 \cdot PRmpXTLViol \\
&+ \sum_{f \in F} SPreConITLViol_{f,h}^2 \cdot PPreConITLViol \\
&+ \sum_{f \in F, c \in C} SITLViol_{f,c,h}^2 \cdot PITLViol.
\end{aligned}
$$

5.8.2 The Pass 2 maximization is subject to the constraints described in the next section.

5.9 Constraints Overview

5.9.1 The constraints applied to the Pass 2 optimization mirror those used in Pass 1 and described in sections 4.8 through 4.11. They must be modified to:

a) Apply to schedules determined in Pass 2;

b) Reflect peak *demand* forecast compared to average *demand* forecast used in Pass 1; and

c) Reflect additional constraints limiting changes in internal resource (*generation facilities* and *dispatchable loads*) commitments, import and export schedules determined in Pass 1.

5.10 Bid/Offer Constraints Applying to Single Hours

5.10.1 Status Variables and Capacity Constraints

5.10.1.1 For the same reasons as discussed in section 4.9 for Pass 1:

$OPRG_{h,b}^2 = 0 \text{ or } 1,$ for all hours *h* and buses *b*;

$$0 \le SPRL_{j,h,b}^2 \le QPRL_{j,h,b};$$

$$0 \le 10SSPRL_{j,h,b}^2 \le 10SQPRL_{j,h,b};$$

$$0 \le 10NSPRL_{j,h,b}^2 \le 10NQPRL_{j,h,b};$$

$$0 \leq 30RSPRL^2_{j,h,b} \leq 30RQPRL_{j,h,b};$$

$$0 \leq SI10N^2_{k,h,d} \leq QI10N_{k,h,d};$$

$$0 \leq SI30R^2_{k,h,d} \leq QI30R_{k,h,d};$$

$$0 \leq SHIG^2_{k,h,d} \leq QHIG_{k,h,d};$$

$$0 \leq SHXL^2_{j,h,d} \leq QHXL_{j,h,d};$$

$$0 \leq SX10N^2_{j,h,d} \leq QX10N_{j,h,d};$$

$$0 \leq SX30R^2_{j,h,d} \leq QX30R_{j,h,d};$$

$$0 \leq SPRG^2_{k,h,b} \leq OPRG^2_{h,b} \cdot QPRG_{k,h,b};$$

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

$$0 \leq 10NSPRG^2_{k,h,b} \leq OPRG^2_{h,b} \cdot 10NQPRG_{k,h,b};$$ and

$$0 \leq 30RSPRG^2_{k,h,b} \leq OPRG^2_{h,b} \cdot 30RQPRG_{k,h,b}$$

for all modified *bids j*, modified *offers k*, hours *h*, and buses *b,* and *intertie zones* source/sink bus *d*.

5.10.1.2 In the case of linked wheeling transactions (the export *bid* and the import *offer* have the same *NERC* tag identifier), the amount of scheduled export *energy* must be equal to the amount of scheduled import *energy*. Therefore:

$$\sum_{j \in J_d} SHXL^2_{j,h,dx} = \sum_{k \in k_d} SHIG^2_{k,h,di}$$

where *dx* and *di* are the respective buses of the export and import schedules associated with the wheeling transactions.

5.10.1.3 The minimum and/or maximum output of the *generation facilities* may be limited because of *outages* and/or de-ratings or in order for the units to provide *regulation* or voltage support. These constraints will take the form:

$$MinPRG_{h,b} \leq MinQPRG_{h,b} \cdot OPRG^2_{h,b} + \sum_{k \in K_b} (SPRG^2_{k,h,b}) \leq MaxPRG_{h,b}.$$

5.10.1.4 Similarly, the maximum level of load reduction is the mechanism by which a *dispatchable load* indicates any de-rating to its registered maximum load reduction level due to mechanical or operational adjustments to their *facility*. The constraint will take the form:

$$\sum_{j \in J_b} SPRL^2_{j,h,b} \le MaxPRL_{h,b}.$$

5.10.2 Operating Reserve Constraints

5.10.2.1 The total reserve (10-minute synchronized and non-synchronized and 30-minute) from committed *dispatchable load* cannot exceed its ramp capability over 30 minutes. It cannot exceed the total scheduled load (maximum load *bid* minus the load reductions). These conditions can be enforced by the following two constraints:

$$\sum_{j \in J_b} (10SSPRL^2_{j,h,b} + 10NSPRL^2_{j,h,b} + 30RSPRL^2_{j,h,b}) \le 30 \cdot ORRPRL_b; \text{ and}$$

$$\sum_{j \in J_b} (10SSPRL^2_{j,h,b} + 10NSPRL^2_{j,h,b} + 30RSPRL^2_{j,h,b}) \le \sum_{j \in J_b} (QPRL_{j,h,b} - SPRL^2_{j,h,b}).$$

5.10.2.2 In addition, this next constraint ensures that the total (10-minute synchronized, 10-minute non-synchronized and 30-minute) from committed *dispatchable load* cannot exceed the *dispatchable load's* ramp capability to increase load reduction (schedules for hour, *h*=0 are obtained from the initializing inputs listed in section 3.8):

$$\sum_{j \in J_b} (10SSPRL^2_{j,h,b} + 10NSPRL^2_{j,h,b} + 30RSPRL^2_{j,h,b}) \le -\sum_{j \in J_b} \left[\left(QPRL_{j,h-1,b} - SPRL^2_{j,h-1,b}\right) - \left(QPRL_{j,h,b} - SPRL^2_{j,h,b}\right)\right] + 60 \cdot URRPRL_b.$$

5.10.2.3 Finally, the total (10-minute synchronized, 10-minute non-synchronized; and 30-minute) from committed *dispatchable load* cannot exceed the *dispatchable load's* Pass 2 scheduled consumption:

$$\sum_{j \in J_b} (10SSPRL^2_{j,h,b} + 10NSPRL^2_{j,h,b} + 30RSPRL^2_{j,h,b}) \le MaxPRL_{h,b} - \sum_{j \in J_b} SPRL^2_{j,h,b}.$$

5.10.2.4 The amount of 10-minute synchronized and non-synchronized reserve that a *dispatchable load* is scheduled to provide cannot exceed the amount by which it can decrease its load over 10 minutes, as limited by its *operating reserve* ramp rate. This condition can be enforced by the following constraint:

$$\sum_{j \in J_b} 10SSPRL^2_{j,h,b} + 10NSPRL^2_{j,h,b} \leq 10 \cdot ORRPRL_b.$$

5.10.2.5 The total reserve (10-minute synchronized, 10-minute non-synchronized and 30-minute) from committed *generation facility* cannot exceed its ramp capability over 30 minutes. It cannot exceed the remaining capacity (maximum *offered* generation minus the *energy* schedule). These conditions can be enforced by the following two constraints:

$$\sum_{k \in K_b} (10SSPRG^2_{k,h,b} + 10NSPRG^2_{k,h,b} + 30RSPRG^2_{k,h,b})$$
$$\leq 30 \cdot ORRPRG_b \text{; and}$$

$$\sum_{k \in K_b} (10SSPRG^2_{k,h,b} + 10NSPRG^2_{k,h,b} + 30RSPRG^2_{k,h,b})$$
$$\leq \sum_{k \in K_b} (QPRG_{k,h,b} - SPRG^2_{k,h,b}).$$

5.10.2.6 In addition, this next constraint ensures that the total(10-minute synchronized, 10-minute non-synchronized and 30-minute) from the committed *generation facility* cannot exceed its ramp capability (schedules for hour, *h*=0 are obtained from the initializing inputs listed in section 3.8). Ramping considerations from start ups or shut downs are not carried forward from one day to the next:

$$\sum_{k \in K_b} (10SSPRG^2_{k,h,b} + 10NSPRG^2_{k,h,b} + 30RSPRG^2_{k,h,b}) \leq \sum_{k \in K_b} \left(SPRG^2_{k,h-1,b} - SPRG^2_{k,h,b} \right) + 60 \times URRPRG_b$$

and

$$\sum_{k \in K_b} \left(10SSPRG^2_{k,h,b} + 10NSPRG^2_{k,h,b} + 30RSPRG^2_{k,h,b} \right) + \sum_{k \in K_b} \left(SPRG^2_{k,h,b} \right) \leq [(h - n) * 60 + 30] \times URRPRG_b \times OPRG^2_{h,b}$$

where *n* is the hour of the last start before or in hour *h*

and

$$\sum_{k \in K_b} \left(10SSPRG^2_{k,h,b} + 10NSPRG^2_{k,h,b} + 30RSPRG^2_{k,h,b} \right) + \sum_{k \in K_b} \left(SPRG^2_{k,h,b} \right) \leq [(m - h) * 60 + 30] \times DRRPRG_b \times OPRG^2_{h,b}$$

where *m* is the hour of the last shut down in or after hour *h*.

5.10.2.7 Finally, the total (10-minute synchronized, 10-minute non-synchronized and 30-minute) from the committed *generation facility* cannot exceed its Pass 2 unscheduled capacity:

$$\sum_{k \in K_b} (10SSPRG^2_{k,h,b} + 10NSPRG^2_{k,h,b} + 30RSPRG^2_{k,h,b})$$
$$\leq MaxPRG_{h,b} - \sum_{k \in K_b} SPRG^2_{k,h,b} - MinQPRG_{h,b}.$$

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

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

5.10.2.9 The total reserve (10-minute non-synchronized and 30-minute) from hourly exports cannot exceed its ramp capability over 30 minutes. It cannot exceed the total scheduled export. These conditions can be enforced by the following two constraints:

$$\sum_{j \in J_d} (SX10N^2_{j,h,d} + SX30R^2_{j,h,d}) \leq 30 \cdot ORRHXL_d; \text{ and}$$

$$\sum_{j \in J_d} (SX10N^2_{j,h,d} + SX30R^2_{j,h,d}) \leq \sum_{j \in J_d} SHXL^2_{j,h,d}.$$

5.10.2.10 The amount of 10-minute non-synchronized reserve that an hourly export is scheduled to provide cannot exceed the amount by which it can decrease its load over 10 minutes, as limited by its *operating reserve* ramp rate. This condition can be enforced by the following constraint:

$$\sum_{j \in J_d} SX10N^2_{j,h,d} \leq 10 \cdot ORRHXL_d.$$

5.10.2.11 The total reserve (10-minute non-synchronized and 30-minute) from hourly imports cannot exceed its ramp capability over 30 minutes. It cannot exceed the remaining capacity (maximum import *offer* minus scheduled *energy* import). These conditions can be enforced by the following two constraints:

$$\sum_{k \in K_d} (SI10N^2_{k,h,d} + SI30R^2_{k,h,d}) \leq 30 \cdot ORRHIG_d; \text{ and}$$

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

5.10.2.12 The amount of 10-minute non-synchronized reserve that hourly import is scheduled to provide cannot exceed the amount by which it can increase the output over 10 minutes, as limited by its *operating reserve* ramp rate. This condition can be enforced by the following constraint:

$$\sum_{k \in K_d} SI10N^2_{k,h,d} \le 10 \cdot ORRHIG_d .$$

5.11 Bid/Offer Inter-Hour/Multi-Hour Constraints

5.11.1 Status Variables

5.11.1.1 For the same reasons as discussed for Pass 1, for *generation facilities* that are scheduled to start up, and for hour, *h* > 1:

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

For *h* = 1:

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

5.11.2 Ramping

5.11.2.1 Constraints limiting hour-to-hour changes in *energy* schedules are congruous to those used in Pass 1.

Start Up Scenario ($OPRG^2_{h,b}$ = 1, and $OPRG^2_{h-1,b}$ = 0)

$$0 \le \sum_{k \in K_b} SPRG^2_{k,h,b} \le \sum_{k \in K_b} 30 \times URRPRG_b$$

Continued On Scenario ($OPRG^2_{h-1,b}$ = $OPRG^2_{h,b}$ = 1)

$$\sum_{k \in K_b} \left(SPRG^2_{k,h-1,b}\right) - 60 \times DRRPRG_b \le \sum_{k \in K_b} SPRG^2_{k,h,b} \le \sum_{k \in K_b} \left(SPRG^2_{k,h-1,b}\right) + 60 \times URRPRG_b$$

Shut Down Scenario ($OPRG^2_{h,b}$ = 1, and $OPRG^2_{h+1,b}$ = 0)

$$0 \le \sum_{k \in K_b} SPRG^2_{k,h,b} \le \sum_{k \in K_b} 30 \times DRRPRG_b$$

5.11.2.2 Similarly, the ramping constraint for the *dispatchable load* will be as follows:

$$\sum_{j \in J_b} \left(QPRL_{j,h-1,b} - SPRL^2_{j,h-1,b} \right) - 60 \cdot URRPRL_b$$
$$\leq \sum_{j \in J_b} \left(QPRL_{j,h,b} - SPRL^2_{j,h,b} \right)$$
$$\leq \sum_{j \in J_b} \left(QPRL_{j,h-1,b} - SPRL^2_{j,h-1,b} \right) + 60 \cdot DRRPRL_b .$$

5.11.2.3 The above two constraints apply for all hours from 1 to 24. In the above two constraints the variables related to hour zero belong to the last hour of the previous day and are obtained from the initializing assumptions.

5.11.2.4 The ramping rates in the ramping constraints must be adjusted to allow the resource to:

a) Ramp down from its lower limit in hour (*h-1*) to its upper limit in hour *h*.

b) Ramp up from its upper limit in hour (*h-1*) to its lower limit in hour *h*.

5.11.2.5 This will allow a solution to be obtained when changes to the upper and lower limits between hours are beyond the ramping capability of the resources.

5.11.2.6 In the above ramping constraints, a single ramp up and a single ramp down, $URRPRG_b$ and $DRRPRG_b$ for *generation facilities* and $URRPRL_b$ and $DRRPRL_b$ for *dispatchable loads* are used. The ramp rate is assumed constant over the full operating range of the *dispatchable load and generation facility*. However, this is not the case. *Dispatchable load bids and generator offers* will include multi-*energy* ramp rates. The multiple ramp rates are described in sections 4.10.2.8 and 4.10.2.9.

5.11.3 Minimum Generation Block Run-Time and Minimum Generation Block Down Time

5.11.3.1 Constraints pertaining to *minimum generation block run-times* and *minimum generation block down times* precisely mirror those used in Pass 1. Therefore,

if $0 < InitOperHrs_b < MRTPRG_b$, then

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

if $OPRG^2_{h,b} = 1$, $OPRG^2_{h+1,b} = 0$, and $MDTPRG_b > 1$, then

$$OPRG^2_{h+2,b}, OPRG^2_{h+3,b}, \ldots, OPRG^2_{\min(24, h+MDTPRG_b), b} = 0;$$ and

and if $OPRG^2_{h,b} = 0$, $OPRG^2_{h+1,b} = 1$, and $MRTPRG_b > 1$, then

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

for all hours *h* and buses *b* and

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

5.11.4 Energy Limited Resources

5.11.4.1 A constraint must be added in order to ensure that *energy*-limited units are not scheduled to provide more *energy* than they have indicated they are capable of providing. In addition to limiting *energy* schedules over the course of the day to the *energy* limit specified for a unit, this constraint must also ensure that units are not scheduled to provide *energy* in amounts that would preclude them from providing reserve when activated. Given those factors:

Therefore:

$$\begin{aligned}
&\sum_{h=1}^{1}\left(OPRG_{h,b}^{2}\cdot MinQPRG_{h,b}+\sum_{k\in K_b}(SPRG_{k,h,b}^{2})\right)\\
&\quad+10ORConv\left(\sum_{k\in K_b}10SSPRG_{k,1,b}^{2}+\sum_{k\in K_b}10NSPRG_{k,1,b}^{2}\right)\\
&\quad+30ORConv\sum_{k\in K_b}30RSPRG_{k,1,b}^{2}\le EL_b;\\
&\sum_{h=1}^{2}\left(OPRG_{h,b}^{2}\cdot MinQPRG_{h,b}+\sum_{k\in K_b}(SPRG_{k,h,b}^{2})\right)\\
&\quad+10ORConv\left(\sum_{k\in K_b}10SSPRG_{k,2,b}^{2}+\sum_{k\in K_b}10NSPRG_{k,2,b}^{2}\right)\\
&\quad+30ORConv\sum_{k\in K_b}30RSPRG_{k,2,b}^{2}\le EL_b;\\
&\qquad\qquad\vdots\\
&\sum_{h=1}^{24}\left(OPRG_{h,b}^{2}\cdot MinQPRG_{h,b}+\sum_{k\in K_b}(SPRG_{k,h,b}^{2})\right)\\
&\quad+10ORConv\left(\sum_{k\in K_b}10SSPRG_{k,24,b}^{2}+\sum_{k\in K_b}10NSPRG_{k,24,b}^{2}\right)\\
&\quad+30ORConv\sum_{k\in K_b}30RSPRG_{k,24,b}^{2}\le EL_b
\end{aligned}$$

for all buses *b* at which *energy*-limited resources are located. The factors *10ORConv* and *30ORConv* are applied to scheduled *ten-minute* and *thirty-minute operating reserves* for *energy*-limited resources to convert MW into MWh. This factor is set to unity.

5.11.5 Maximum Number of Starts

5.11.5.1 To ensure that *generation facilities* are not scheduled to cycle on and off more than their specified maximum number in a day, the following constraints are defined:

$$\sum_{h=1}^{24} IPRG_{h,b}^2 \le MaxStartsPRG_b.$$

5.12 Constraints to Ensure Schedules Do Not Violate Reliability Requirements

5.12.1 Load

5.12.1.1 Load constraints are structured in the same manner as described in section 4.11.1 for Pass 1.

5.12.1.2 The total amount of withdrawals scheduled in Pass 2 at each bus *b* in each hour *h*, $With^2_{h,b}$, is the sum of:

- The portion of the load forecast for that hour that has been allocated to that bus; and
- All *dispatchable load bid*, net of the amount of load reduction scheduled (since the *dispatchable load* is excluded from the *demand* forecast by the DACP calculation engine), yielding:

$$With_{h,b}^2 = LDF_{h,b} \cdot PFL_h + \left[\sum_{j \in J_b} \left(QPRL_{j,h,b} - SPRL_{j,h,b}^2 \right) \right]; \text{ and}$$

the total amount of withdrawals scheduled in Pass 2 at each *intertie zone* sink bus *d* in each hour *h*, $With^2_{h,d}$, is the sum of:

- Exports from Ontario to each *intertie zone* sink bus; and
- Outflows from Ontario associated with loop flows between Ontario and each *intertie zone*, allocated among the buses in the *intertie zones* using the distribution factors developed for that purpose, yielding:

$$With_{h,d}^2 = \sum_{j \in J_d} (SHXL_{j,h,d}^2) - \sum_{a \in A} ProxyUPOWt_{d,a} \cdot \min(0, PF_{h,a}).$$

5.12.1.3 The total amount of injections scheduled in Pass 2 at each bus *b* in each hour *h*, $Inj^2_{h,b}$, is the sum of:

- *Generation facilities* scheduled at that bus, yielding:

$$Inj_{h,b}^2 = OPRG_{h,b}^2 \cdot MinQPRG_{h,b} + \sum_{k \in K_b} \left(SPRG_{k,h,b}^2 \right); \text{ and}$$

the total amount of injections scheduled in Pass 2 at each *intertie zone* source bus *d* in each hour *h*, $Inj^2_{h,d}$, is the sum of:

- Imports into Ontario from each *intertie zone* source bus; and

- Inflows from Ontario associated with loop flows between Ontario and each *intertie zone*, allocated among the buses in the *intertie zones* using the distribution factors developed for that purpose, yielding:

$$Inj_{h,d}^{2} = \sum_{k \in K_d} (SHIG_{k,h,d}^{2}) + \sum_{a \in A} ProxyUPIWt_{d,a} \cdot \max(0, PF_{h,a}).$$

5.12.1.4 Injections and withdrawals at each bus must 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 actual and marginal losses. Load reduction associated with the *demand* constraint violation will be subtracted from the total load and generation reduction associated with the *demand* constraint violation will be subtracted from total generation to ensure that the calculation engine will always produce a solution. These violation variables are assigned a very high cost to limit their use to infeasible cases.

$$\begin{aligned}
&\sum_{b \in B} (1 + MglLoss_{h,b}) With_{h,b}^{2} + \sum_{d \in D} (1 + MglLoss_{h,b}) With_{h,d}^{2} - SLdViol_{h}^{2} \\
&\quad = \sum_{b \in B} (1 + MglLoss_{h,b}) Inj_{h,b}^{2} \\
&\quad\quad + \sum_{d \in D} (1 + MglLoss_{h,d}) Inj_{h,d}^{2} - SGenViol_{h}^{2} + LossAdj_{h}.
\end{aligned}$$

5.12.2 Operating Reserve

5.12.2.1 Sufficient *operating reserve* must be provided on the system to meet system wide requirements for 10-minute synchronized reserve, *ten-minute operating reserve* and *thirty-minute operating reserve*, as well as all applicable regional minimum and maximum requirements for *operating reserve*.

5.12.2.2 Therefore, taking into consideration the potential not to meet these minimum and maximum requirements if the cost of meeting those requirements becomes too high:

$$\begin{aligned}
&\sum_{b \in B} \left(\sum_{j \in J_b} 10SSPRL_{j,h,b}^{2} \right) + \sum_{b \in B} \left(\sum_{k \in K_b} 10SSPRG_{k,h,b}^{2} \right) + S10SViol_{h}^{2} \\
&\quad \geq TOT10S_{h};
\end{aligned}$$

$$\begin{aligned}
&\sum_{b \in B} \left(\sum_{j \in J_b} 10SSPRL_{j,h,b}^{2} \right) + \sum_{b \in B} \left(\sum_{k \in K_b} 10SSPRG_{k,h,b}^{2} \right) + S10RViol_{h}^{2} \\
&\quad + \sum_{b \in B} \left(\sum_{k \in K_b} 10NSPRG_{k,h,b}^{2} \right) + \sum_{b \in B} \left(\sum_{j \in J_b} 10NSPRL_{j,h,b}^{2} \right) \\
&\quad + \sum_{d \in D} \left(\sum_{k \in K_d} SI10N_{k,h,d}^{2} \right) + \sum_{d \in D} \left(\sum_{j \in J_d} SX10N_{j,h,d}^{2} \right) \geq TOT10R_{h}; \text{ and}
\end{aligned}$$

$$\sum_{b\in B}\left(\sum_{j\in J_b} 10SSPRL^2_{j,h,b}\right)+\sum_{b\in B}\left(\sum_{k\in K_b} 10SSPRG^2_{k,h,b}\right)+S30RViol^2_h$$
$$+\sum_{b\in B}\left(\sum_{k\in K_b}(10NSPRG^2_{k,h,b}+30RSPRG^2_{k,h,b})\right)$$
$$+\sum_{b\in B}\left(\sum_{j\in J_b}(10NSPRL^2_{j,h,b}+30RSPRL^2_{j,h,b})\right)$$
$$+\sum_{d\in D}\left(\sum_{k\in K_d}(SI10N^2_{k,h,d}+SI30R^2_{k,h,d})\right)$$
$$+\sum_{d\in D}\left(\sum_{j\in J_d}(SX10N^2_{j,h,d}+SX30R^2_{j,h,d})\right)\geq TOT30R_h$$

for all hours *h*, and

$$\sum_{b\in r}\left(\sum_{j\in J_b} 10SSPRL^2_{j,h,b}\right)+\sum_{b\in r}\left(\sum_{k\in K_b} 10SSPRG^2_{k,h,b}\right)+SREG10RViol^2_{r,h}$$
$$+\sum_{b\in r}\left(\sum_{k\in K_b} 10NSPRG^2_{k,h,b}\right)+\sum_{b\in r}\left(\sum_{j\in J_b} 10NSPRL^2_{j,h,b}\right)$$
$$\geq REGMin10R_{r,h};$$

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

$$\sum_{b\in r}\left(\sum_{j\in J_b} 10SSPRL^2_{j,h,b}\right)+\sum_{b\in r}\left(\sum_{k\in K_b} 10SSPRG^2_{k,h,b}\right)+SREG30RViol^2_{r,h}$$
$$+\sum_{b\in r}\left(\sum_{k\in K_b}(10NSPRG^2_{k,h,b}+30RSPRG^2_{k,h,b})\right)$$
$$+\sum_{b\in r}\left(\sum_{j\in J_b}(10NSPRL^2_{j,h,b}+30RSPRL^2_{j,h,b})\right)$$
$$\geq REGMin30_{r,h};\text{ and}$$

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

for all hours *h*, and for all regions *r* in the set *ORREG.*

5.12.3 Internal Transmission Limits

5.12.3.1 The *IESO* must ensure that the set of DACP schedules produced by Pass 2 of the calculation engine would not violate any *security limits* in either the pre-contingency state or in any contingency. To develop the constraints to ensure that this occurs, the total amount of *energy* scheduled to be injected at each bus and the total amount of *energy* scheduled to be withdrawn at each bus will be used.

5.12.3.2 Then the pre-contingency limits on transmission within Ontario will not be violated if:

$$\sum_{b\in B} PreConSF_{b,f,h}(Inj^2_{h,b}-With^2_{h,b})+\sum_{d\in D} PreConSF_{d,f,h}(Inj^2_{h,d}-With^2_{h,d})$$
$$-SPreConITLViol^2_{f,h}\leq AdjNormMaxFlow_{f,h}$$

for all *facilities f* and hours *h*.

5.12.3.3 Post-contingency limits on transmission *facilities* within Ontario will not be violated if:

$$\sum_{b\in B} SF_{b,f,c,h}(Inj^2_{h,b}-With^2_{h,b})+\sum_{d\in D} SF_{d,f,c,h}(Inj^2_{h,d}-With^2_{h,d})$$
$$-SITLViol^2_{f,c,h}\leq AdjEmMaxFlow_{f,c,h}$$

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

5.12.4 Intertie Limits and Constraints on Net Imports

5.12.4.1 The calculation engine would not violate any *security limits* associated with *interties* between Ontario and *intertie zones*. To ensure this, we must calculate the net amount of *energy* scheduled to flow over each *intertie* in each hour and the amount of *operating reserve* scheduled to be provided by resources in that *control area*. This will be summed over all affected *interties*. The result will be compared to the limit associated with that constraint. Consequently:

$$\sum_{a \in A}\left[\begin{array}{l} EnCoeff_{a,z}\left(\sum_{d \in DI_a, k \in K_d}(SHIG^2_{k,h,d}) + PF_{h,a} - \sum_{d \in DX_a, j \in J_d}\left(SHXL^2_{j,h,d}\right)\right) + \\ 0.5(EnCoeff_{a,z}+1)\left[\begin{array}{l} \sum_{d \in DI_a, k \in K_d}\left(SI10N^2_{k,h,d} + SI30R^2_{k,h,d}\right) \\ + \sum_{d \in DX_a, j \in J_d}\left(SX10N^2_{j,h,d} + SX30R^2_{j,h,d}\right) \end{array}\right] \end{array}\right]$$
$$\leq MaxExtSch_{z,h}$$

for all hours *h*, for all *intertie zones a* relevant to the constraint *z*

($EnCoeff_{a,z} \neq 0$), and for all constraints *z* in the set Z_{sch}.

5.12.4.2 In addition, changes in the net *energy* schedule over all *interties* cannot exceed the limits set forth by the *IESO* for hour-to-hour changes in those schedules. The net import schedule is summed over all *interties* for a given hour. It cannot exceed the sum of net import schedule for all *interties* for the previous hour plus the maximum permitted hourly increase. It cannot be less than the sum of the net import schedule for all *interties* for the previous hour minus the maximum permitted hourly decrease. Violation variables are provided for both the up and down ramp limits to ensure that the calculation engine will always find a solution.

Therefore:

$$\sum_{d \in D}\left(\sum_{k \in K_d}(SHIG^2_{k,h-1,d}) - \sum_{j \in J_d}(SHXL^2_{j,h-1,d})\right) - ExtDSC_h - SDRmpXTLViol^2_h$$
$$\leq \sum_{d \in D}\left(\sum_{k \in K_d}(SHIG^2_{k,h,d}) - \sum_{j \in J_d}(SHXL^2_{j,h,d})\right)$$
$$\leq \sum_{d \in D}\left(\sum_{k \in K_d}(SHIG^2_{k,h-1,d}) - \sum_{j \in J_d}(SHXL^2_{j,h-1,d})\right) + ExtUSC_h + SURmpXTLViol^2_h$$

for all hours *h* (schedules for hour, *h*=0 are obtained from the initializing inputs listed in section 3.8).

5.12.5 Intertie Schedule Limits Based on Pass 1 Output

5.12.5.1 Pass 2 will not reduce the amount of imported *energy* scheduled from each *intertie zone* in any hour. Additional imports of *energy* may be scheduled in Pass 2. Therefore, for imports that are not part of a linked wheeling transaction:

$$SHIG^2_{k,h,d} \geq SHIG^1_{k,h,d}$$

for all *offers k*, hours *h* and *intertie zones* source bus *d*.

5.12.5.2 Pass 2 will not increase the amount of exported *energy* scheduled from each *intertie zone* sink bus in any hour over the amount scheduled in Pass 1.

5.12.5.3 Therefore, for exports that are not part of a linked wheeling transaction:

$$SHXL^{2}_{j,h,d} \leq SHXL^{1}_{j,h,d}$$

for all *bids j*, hours *h* and *intertie zones* sink bus *d*.

5.12.5.4 Finally, the purpose of Pass 2 is to determine whether additional *generation facilities* need to be committed to ensure that the *IESO* can meet peak forecast load, given the resources committed in Pass 1 (and if so, which resources are committed). Consequently, it will be necessary to ensure that resources committed in Pass 1 are not de-committed in this pass. Therefore:

$$OPRG^{2}_{h,b} \geq OPRG^{1}_{h,b}$$

for all hours *h* and buses.

6. Pass 3: Constrained Scheduling to Meet Average Demand

6.1 Overview

6.1.1 Pass 3 performs a least cost, *security* constrained scheduling to meet the forecast average *demand* and *IESO*-specified *operating reserve* requirements.

6.1.2 The *commitment* for generation and schedules for imports *and* exports, resulting from Pass 2 are used to schedule the least cost set of resources (*dispatchable loads, generation facilities,* imports and exports) to meet average forecast *demand* and *IESO*-specified *operating reserve* requirements, taking account of all transmission limitations including *intertie* transfer limits.

6.1.3 *Generation facilities* committed in Passes 1 and 2 will be scheduled. There will be no additional exports scheduled beyond what was scheduled in Pass 2. Imports will not be scheduled below what was scheduled in Pass 2. The import and export components of linked wheel transactions are allowed to go higher or lower than schedules produced in Pass 2.

6.2 Inputs into Pass 3

6.2.1 Inputs for Pass 3 include those described in section 3.

6.2.2 In addition, commitments from Passes 1 and 2 and schedules from Pass 2 are used as inputs.

6.3 Optimization Objective for Pass 3

6.3.1 As for Passes 1 and 2, the gains from trade shall be maximized for Pass 3. This is accomplished by maximizing an objective function similar to that described in 4.3. The Pass 3 objective function is different in that it does not include the variables for commitment. This is so because no more commitment is required for Pass 3.

6.4 Security Assessment

6.4.1 The same *security* assessment is performed as described in section 4.4.

6.5 Outputs from Pass 3

6.5.1 The primary outputs of Pass 3 include the following:

4.5.1.1 Constrained schedules for *energy* for the *schedule of record*; and

4.5.1.2 Shadow prices.

6.6 Glossary of Sets, Indices, Variables and Parameters for Pass 3

6.6.1 Fundamental Sets and Indices

6.6.1.1 Same as those described in section 4.6.1.

6.6.2 Variables and Parameters

6.6.2.1 Bid and Offer Inputs

Same as those described in 4.6.2.1.

6.6.2.2 Transmission and Security Inputs and Intermediate Variables

Same as those described in 4.6.2.2.

6.6.2.3 Other Inputs

Same as those described in 4.6.2.3.

6.6.2.4 Constraint Violation Price Inputs

Same as those described in 4.6.2.4.

6.6.2.5 Variables determined in Pass 2 and Used in Pass 3

$SHXL^2_{j,h,d}$	The amount of exports scheduled in hour *h* in Pass 2 from *intertie zone* sink bus *d* in association with *bid j*.
$SHIG^2_{k,h,d}$	The amount of imports scheduled in hour *h* in Pass 2 from *intertie zone* source bus *d* in association with *offer k*.
$OPRG^2_{h,b}$	Indication of whether a *generation facility* at bus *b* was scheduled to operate in hour *h* in Pass 2.
$IPRG^2_{h,b}$	Indication of whether a *generation facility* at bus *b* was scheduled to start in hour *h* in Pass 2.

6.6.2.6 Output Schedule and Commitment Variables

$SHXL^3_{j,h,d}$	The amount of exports scheduled in hour *h* in Pass 3 from *intertie zone* sink bus *d* in association with *bid j.*

$SX10N^3_{j,h,d}$	The amount of non-synchronized *ten-minute operating reserve* scheduled from the export in hour *h* in Pass 3 from *intertie zone* sink bus *d* in association with *bid j.*
$SX30R^3_{j,h,d}$	The amount of *thirty-minute operating reserve* scheduled from the export in hour *h* in Pass 3 from *intertie zone* sink bus *d* in association with *bid j.*
$SPRL^3_{j,h,b}$	The amount of *dispatchable load* reduction scheduled at bus *b* in hour *h* in Pass 3 in association with *bid j*.
$10SSPRL^3_{j,h,b}$	The amount of synchronized *ten-minute operating reserve* that a qualified *dispatchable load* is scheduled to provide at bus *b* in hour *h* in Pass 3 in association with *bid j*.
$10NSPRL^3_{j,h,b}$	The amount of non-synchronized *ten-minute operating reserve* that a qualified *dispatchable load* is scheduled to provide at bus *b* in hour *h* in Pass 3 in association with *bid j*.
$30RSPRL^3_{j,h,b}$	The amount of *thirty-minute operating reserve* that a qualified *dispatchable load* is scheduled to provide at bus *b* in hour *h* in Pass 3 in association with *bid j*.
$SHIG^3_{k,h,d}$	The amount of hourly imports scheduled in hour *h* from *intertie zone* source bus *d* in Pass 3 in association with *offer k.*
$SI10N^3_{k,h,d}$	The amount of imported *ten-minute operating reserve* scheduled in hour *h* from *intertie zone* source bus *d* in Pass 3 in association with *offer k.*
$SI30R^3_{k,h,d}$	The amount of imported *thirty-minute operating reserve* scheduled in hour *h* from *intertie zone* source bus *d* in Pass 3 in association with *offer k.*
$SPRG^3_{k,h,b}$	The amount of *energy* scheduled for the *generation facility* at bus *b* in hour *h* in Pass 3 in association with *offer k*. This is in addition to any $MinQPRG_{h,b}$, the *minimum loading point*, which must also be committed.
$OPRG^3_{h,b}$	Represents whether the *generation facility* at bus *b* has been scheduled in hour *h* in Pass 3.
$IPRG^3_{h,b}$	Represents whether *generation facility* at bus *b* has been scheduled to start in hour *h* in Pass 3.
RAMPUP_ENRG	The coefficient used to calculate the estimated fraction of a *generation facility*'s *minimum loading point* in the hour prior to the first hour it is scheduled. This value is used by the DACP calculation engine to determine constrained schedules in Pass 3 so that the *energy* produced by the *generation facility* during ramping to their *minimum loading point* is accounted for.
$10SSPRG^3_{k,h,b}$	The amount of synchronized *ten-minute operating reserve* that a qualified *generation facility* at bus *b* is scheduled to provide in hour *h* in Pass 3 in association with *offer k*.

$10NSPRG^{3}_{k,h,b}$	The amount of non-synchronized *ten-minute operating reserve* that a qualified *generation facility* at bus *b* is scheduled to provide in hour *h* in Pass 3 in association with *offer k*.
$30RSPRG^{3}_{k,h,b}$	The amount of *thirty-minute operating reserve* that a qualified *generation facility* at bus *b* is scheduled to provide in hour *h* in Pass 3 in association with *offer k*.

6.6.2.7 Output Violation Variables

$ViolCost^{3}_{h}$	The cost incurred in order to avoid having the Pass 3 schedules for hour *h* violate specified constraints.
$SLdViol^{3}_{h}$	Projected load curtailment, that is, the amount of load that cannot be met using *offers* scheduled or committed in hour *h* in Pass 3.
$SGenViol^{3}_{h}$	The amount of additional load that must be scheduled in hour *h* in Pass 3 to ensure that there is enough load on the system to offset the must-run requirements of *generation facilities*.
$S10SViol^{3}_{h}$	The amount by which the overall synchronized *ten-minute operating reserve* requirement is not met in hour *h* of Pass 3 because the cost of meeting that portion of the requirement was greater than or equal to *P10SViol.*
$S10RViol^{3}_{h}$	The amount by which the overall *ten-minute operating reserve* requirement is not met in hour *h* of Pass 3 (above and beyond any failure to meet the synchronized *ten-minute operating reserve* requirement) because the cost of meeting that portion of the requirement was greater than or equal to *P10RViol.*
$S30RViol^{3}_{h}$	The amount by which the overall *thirty-minute operating reserve* requirement is not met in hour *h* of Pass 3 (above and beyond any failure to meet the *ten-minute operating reserve* requirement) because the cost of meeting that portion of the requirement was greater than or equal to *P30RViol.*
$SREG10RViol^{3}_{r,h}$	The amount by which the minimum *ten-minute operating reserve* requirement for region *r* is not met in hour *h* of Pass 3 because the cost of meeting that portion of the requirement was greater than or equal to *PREG10RViol.*
$SREG30RViol^{3}_{r,h}$	The amount by which the minimum *thirty-minute operating reserve* requirement for region *r* is not met in hour *h* of Pass 3 because the cost of meeting that portion of the requirement was greater than or equal to *PREG30RViol.*
$SXREG10RViol^{3}_{r,h}$	The amount by which the *ten-minute operating reserve* scheduled for region *r* exceeds the maximum required in hour *h* of Pass 3 because the cost of meeting that the maximum requirement limit was greater than or equal to *PXREG10RViol.*

$SXREG30RViol^3_{r,h}$	The amount by which the *thirty-minute operating reserve* scheduled for region *r* exceeds the maximum required in hour *h* of Pass 3 because the cost of meeting the maximum requirement limit was greater than or equal to *PXREG30RViol.*
$SPreConITLViol^3_{f,h}$	The amount by which pre-contingency flows over *facility f* in hour *h* of Pass 3 exceed the normal limit for flows over that *facility*, because the cost of alternative solutions that would not result in such an overload was greater than or equal to *PPreConITLViol.*
$SITLViol^3_{f,c,h}$	The amount by which flows over *facility f* that would follow the occurrence of contingency *c* in hour *h* of Pass 3 exceed the emergency limit for flows over that *facility*, because the cost of alternative solutions that would not result in such an overload was greater than or equal to *PITLViol.*
$SPreConXTLViol^3_{z,h}$	The amount by which *intertie* flows over *facility z* in hour *h* of Pass 3 exceed the normal limit for flows over that *facility*, because the cost of alternative solutions that would not result in such an overload was greater than or equal to *PPreConXTLViol.*
$SURmpXTLViol^3_{h}$	The amount by which the total net scheduled import increase for hour *h* in Pass 3 exceeds the up ramp limits, because the cost of alternative solutions that would not result in violation was greater than or equal to *PRmpXTLViol.*
$SDRmpXTLViol^3_{h}$	The amount by which the total net scheduled import decrease in hour *h* of Pass 2 exceed the down ramp limits, because the cost of alternative solutions that would not result in violation was greater than or equal to *PRmpXTLViol.*

6.6.2.8 Output Shadow Prices

Shadow Prices of Constraints:

SPL^3_{h}	The Pass 3 shadow price measuring the rate of change of the objective function for a change in load at the *reference bus* in hour *h*.
$SPNormT^3_{f,h}$	The Pass 3 shadow price measuring the rate of change of the objective function for a change in the limit, $AdjNormMaxFlow_{f,h}$, on flows over transmission *facilities* in normal conditions for *facility f* in hour *h*.
$SPEmT^3_{f,c,h}$	The Pass 3 shadow price measuring the rate of change of the objective function for a change in the limit, $AdjEmMaxFlow_{f,c,h}$, on flows over transmission *facilities* in emergency conditions for *facility f* in monitored contingency *c* in hour *h*.
$SPExtT^3_{z,h}$	The Pass 3 shadow price measuring the rate of change of the objective function for a change in the limit, $MaxExtSch_{z,h}$, on flows over transmission *facilities* on the boundary between Ontario and other *control areas* for each constraint z in hour *h*.

$SPRUExtT^3_h$	The Pass 3 shadow price measuring the rate of change of the objective function for a change in the limit, $ExtUSC_h$, on the upward change of the sum of net imports over all *interties* from the previous hour to hour *h*.
$SPRDExtT^3_h$	The Pass 3 shadow price measuring the rate of change of the objective function for a change in the limit, $ExtDSC_h$, on the downward change of the sum of net imports over all *interties* from the previous hour to hour *h*.
$SP10S^3_h$	The Pass 3 shadow price measuring the rate of change of the objective function for a change in the total synchronized *ten-minute operating reserve* requirement, $TOT10S_h$, in hour *h*.
$SP10R^3_h$	The Pass 3 shadow price measuring the rate of change of the objective function for a change in the total *ten-minute operating reserve* requirement, $TOT10R_h$, in hour *h*.
$SP30R^3_h$	The Pass 3 shadow price measuring the rate of change of the objective function for a change in the total *thirty-minute operating reserve* requirement, $TOT30R_h$, in hour *h*.
$SPREGMin10R^3_{r,h}$	The Pass 3 shadow price measuring the rate of change of the objective function for a change in the minimum *ten-minute operating reserve* requirement, $REGMin10R_{r,h}$, for region *r* in hour *h*.
$SPREGMin30R^3_{r,h}$	The Pass 3 shadow price measuring the rate of change of the objective function for a change in the minimum *thirty-minute operating reserve* requirement, $REGMin30R_{r,h}$, for region *r* in hour *h*.
$SPREGMax10R^3_{r,h}$	The Pass 3 shadow price measuring the rate of change of the objective function for a change in the maximum *ten-minute operating reserve* limit, $REGMax10R_{r,h}$, for region *r* in hour *h*.
$SPREGMax30R^3_{r,h}$	The Pass 3 shadow price measuring the rate of change of the objective function for a change in the maximum *thirty-minute operating reserve* limit, $REGMax30R_{r,h}$, for region *r* in hour *h*.

Shadow Price for Energy:

$LMP^3_{h,b}$	The Pass 3 locational marginal price for *energy* at each bus *b* in each hour *h.* It measures the *offered* price of meeting an infinitesimal change in the amount of load at that bus in that hour, or equivalently, measures the value of an incremental amount of supply at that bus in that hour in Pass 3.

$ExtLMP^3_{h,d}$	The Pass 3 locational marginal price for *energy* at each *intertie zone* sink and source bus *d* in each hour *h.* It measures the *offered* price of meeting an infinitesimal change in the amount of load at that bus in that hour, or equivalently, measures the value of an incremental amount of supply at that bus in that hour in Pass 3.

6.6.2.9 Energy Ramp Rates

Same as those in section 4.6.2.8.

6.7 Objective Function

6.7.1 The optimization of the objective function in Pass 3 is to maximize the expression:

$$\sum_{h=1,\ldots,24}\left\{\begin{array}{l}\sum_{d\in DX,j\in J_d}(SHXL^3_{j,h,d}\cdot PHXL_{j,h,d}-SX10N^3_{j,h,d}\cdot PX10N_{j,h,d}-SX30R^3_{j,h,d}\cdot PX30R_{j,h,d})\\ -\sum_{b\in B}\left[\begin{array}{l}\sum_{j\in J_b}SPRL^3_{j,h,b}\cdot PPRL_{j,h,b}\\ +\sum_{j\in J_b}\begin{array}{l}10NSPRL^3_{j,h,b}\cdot 10NPPRL_{j,h,b}+10SSPRL^3_{j,h,b}\cdot 10SPPRL_{j,h,b}+\\ 30RSPRL^3_{j,h,b}\cdot 30RPPRL_{j,h,b}\end{array}\end{array}\right]\\ -\sum_{d\in DI,k\in K_d}\left(SHIG^3_{k,h,d}\cdot PHIG_{k,h,d}+SI10N^3_{k,h,d}\cdot PI10N_{k,h,d}+SI30R^3_{k,h,d}\cdot PI30R_{k,h,d}\right)\\ -\sum_{b\in B}\left[\begin{array}{l}\sum_{k\in K_b}\left(SPRG^3_{k,h,b}\cdot PPRG_{k,h,b}\right)\\ +\sum_{k\in K_b}\begin{array}{l}10SSPRG^3_{k,h,b}\cdot 10SPPRG_{k,h,b}+10NSPRG^3_{k,h,b}\cdot 10NPPRG_{k,h,b}\\ +30RSPRG^3_{k,h,b}\cdot 30RPPRG_{k,h,b}\end{array}\end{array}\right]\\ -ViolCost^3_h\end{array}\right\};$$

where $ViolCost^3_h$ is calculated as follows:

$$
\begin{aligned}
ViolCost_h^3 &= SLdViol_h^3 \cdot PLdViol - SGenViol_h^3 \cdot PGenViol \\
&+ S10SViol_h^3 \cdot P10SViol + S10RViol_h^3 \cdot P10RViol \\
&+ S30RViol_h^3 \cdot P30RViol \\
&+ \sum_{r \in ORREG} \begin{pmatrix} SREG10RViol_{r,h}^3 \cdot PREG10RViol \\ + SREG30RViol_{r,h}^3 \cdot PREG30RViol \\ + SXREG10RViol_{r,h}^3 \cdot PXREG10RViol \\ + SXREG30RViol_{r,h}^3 \cdot PXREG30RViol \end{pmatrix} \\
&+ \sum_{z \in Z} \left(SPreConXTLViol_{z,h}^3 \cdot PPreConXTLViol \right) \\
&+ SURmpXTLViol^3 \cdot PRmpXTLViol + SDRmpXTLViol^3 \cdot PRmpXTLViol \\
&+ \sum_{f \in F} SPreConITLViol_{f,h}^3 \cdot PPreConITLViol \\
&+ \sum_{f \in F, c \in C} SITLViol_{f,c,h}^3 \cdot PITLViol .
\end{aligned}
$$

6.8 Constraints Overview

6.8.1 Resources not already committed in Pass 2 will not be scheduled and the constraints that require their inputs will be eliminated.

6.9 Bid/Offer Constraints Applying to Single Hours

6.9.1 Status Variables and Capacity Constraints

6.9.1.1 No schedule can be negative, nor can any schedule exceed the amount of capacity *offered* for that service. Therefore:

$$0 \le SPRL_{j,h,b}^3 \le QPRL_{j,h,b};$$

$$0 \le 10SSPRL_{j,h,b}^3 \le 10SQPRL_{j,h,b};$$

$$0 \le 10NSPRL_{j,h,b}^3 \le 10NQPRL_{j,h,b};$$

$$0 \le 30RSPRL_{j,h,b}^3 \le 30RQPRL_{j,h,b};$$

$$0 \le SHXL_{j,h,d}^3 \le QHXL_{j,h,d};$$

$$0 \le SX10N_{j,h,d}^3 \le QX10N_{j,h,d};$$

$$0 \leq SX30R^3_{j,h,d} \leq QX30R_{j,h,d};$$

$$0 \leq SHIG^3_{k,h,d} \leq QHIG_{k,h,d};$$

$$0 \leq SI10N^3_{k,h,d} \leq QI10N_{k,h,d};$$ and

$$0 \leq SI30R^3_{k,h,d} \leq QI30R_{k,h,d};$$

for all *bids j*, *offers k*, hours *h*, buses *b* and *intertie zones* source/sink buses *d*.

6.9.1.2 In the case of *generation facilities*, in addition to restrictions on their schedules similar to those above, their schedules must be consistent with their operating status determined at the conclusion of Pass 2. To simplify the writing of subsequent constraints, we will define the following variable for buses where *generation facilities* are located:

$$OPRG^3_{h,b} = OPRG^2_{h,b};$$ and

$$IPRG^3_{h,b} = IPRG^2_{h,b}$$

which will indicate whether a resource at bus *b* may be scheduled to operate or start in Pass 3 in hour *h*. Then:

$$0 \leq SPRG^3_{k,h,b} \leq OPRG^3_{h,b} \cdot QPRG_{k,h,b};$$

$$0 \leq 10SSPRG^3_{k,h,b} \leq OPRG^3_{h,b} \cdot 10SQPRG_{k,h,b};$$

$$0 \leq 10NSPRG^3_{k,h,b} \leq OPRG^3_{h,b} \cdot 10NQPRG_{k,h,b};$$ and

$$0 \leq 30RSPRG^3_{k,h,b} \leq OPRG^3_{h,b} \cdot 30RQPRG_{k,h,b}$$

for all *offers k*, hours *h*, and buses *b.*

6.9.1.3 In the case of linked wheeling transactions (the export *bid* and the import *offer* have the same *NERC* tag identifier), the amount of scheduled export *energy* must be equal to the amount of scheduled import *energy*. Therefore:

$$\sum_{j \in J_d} SHXL^3_{j,h,dx} = \sum_{k \in k_d} SHIG^3_{k,h,di}$$

where *dx* and *di* are the respective buses of the export and import schedules associated with the wheeling transactions.

6.9.1.4 The minimum and/or maximum output of the *generation facilities* may be limited because of *outages* and/or de-ratings or in order for the units to provide *regulation* or voltage support. These constraints will take the form:

$$MinPRG_{h,b} \le MinQPRG_{h,b}(OPRG^3_{h,b}) + \sum_{k \in K_b} SPRG^3_{k,h,b} \le MaxPRG_{h,b}.$$

6.9.1.5 Similarly, the maximum level of load reduction is the mechanism by which a *dispatchable load* indicates any de-rating to its registered maximum load reduction level due to mechanical or operational adjustments to their *facility*. The constraint will take the form:

$$\sum_{j \in J_b} SPRL^3_{j,h,b} \le MaxPRL_{h,b}.$$

6.9.2 Operating Reserve Constraints

6.9.2.1 The total reserve (10-minute synchronized, 10-minute non-synchronized and 30-minute) from committed *dispatchable load* cannot exceed its ramp capability over 30 minutes. It cannot exceed the total scheduled load (maximum load *bid* minus the load reductions). These conditions can be enforced by the following two constraints:

$$\sum_{j \in J_b} (10SSPRL^3_{j,h,b} + 10NSPRL^3_{j,h,b} + 30RSPRL^3_{j,h,b}) \le 30 \cdot ORRPRL_b; \text{and}$$

$$\sum_{j \in J_b} (10SSPRL^3_{j,h,b} + 10NSPRL^3_{j,h,b} + 30RSPRL^3_{j,h,b}) \le \sum_{j \in J_b} (QPRL_{j,h,b} - SPRL^3_{j,h,b}).$$

6.9.2.2 In addition, this next constraint ensures that the total(10-minute synchronized, 10-minute non-synchronized and 30-minute) from committed *dispatchable load* cannot exceed the *dispatchable load's* ramp capability to increase load reduction (schedules for hour, *h*=0 are obtained from the initializing inputs listed in section 3.8):

$$\sum_{j \in J_b} (10SSPRL^3_{j,h,b} + 10NSPRL^3_{j,h,b} + 30RSPRL^3_{j,h,b}) \le -\sum_{j \in J_b} \left[\left(QPRL_{j,h-1,b} - SPRL^3_{j,h-1,b}\right) - \left(QPRL_{j,h,b} - SPRL^3_{j,h,b}\right)\right] + 60 \cdot URRPRL_b.$$

6.9.2.3 Finally, the total (10-minute synchronized, 10-minute non-synchronized; and 30-minute) from committed *dispatchable load* cannot exceed the *dispatchable load's* Pass 3 scheduled consumption:

$$\sum_{j\in J_b}(10SSPRL^3_{j,h,b} + 10NSPRL^3_{j,h,b} + 30RSPRL^3_{j,h,b})$$
$$\leq MaxPRL_{h,b} - \sum_{j\in J_b} SPRL^3_{j,h,b}.$$

6.9.2.4 The amount of 10-minute synchronized and 10-minute non-synchronized reserve that a *dispatchable load* is scheduled to provide cannot exceed the amount by which it can decrease its load over 10 minutes, as limited by its *operating reserve* ramp rate. This condition can be enforced by the following constraint:

$$\sum_{j\in J_b} 10SSPRL^3_{j,h,b} + 10NSPRL^3_{j,h,b} \leq 10 \cdot ORRPRL_b.$$

6.9.2.5 The total reserve (10-minute synchronized, 10-minute non-synchronized and 30-minute) from a committed *generation facility* cannot exceed its ramp capability over 30 minutes. It cannot exceed the remaining capacity (maximum *offered* generation minus the *energy* schedule). These conditions can be enforced by the following two constraints:

$$\sum_{k\in K_b}(10SSPRG^3_{k,h,b} + 10NSPRG^3_{k,h,b} + 30RSPRG^3_{k,h,b})$$
$$\leq 30 \cdot ORRPRG_b \text{; and}$$

$$\sum_{k\in K_b}(10SSPRG^3_{k,h,b} + 10NSPRG^3_{k,h,b} + 30RSPRG^3_{k,h,b})$$
$$\leq \sum_{k\in K_b}(QPRG_{k,h,b} - SPRG^3_{k,h,b}).$$

6.9.2.6 In addition, this next constraint ensures that the total (10-minute synchronized, 10-minute non-synchronized and 30-minute) from a committed *generation facility* cannot exceed its ramp capability (schedules for hour, *h*=0 are obtained from the initializing inputs listed in section 3.8). Ramping considerations from start ups or shut downs are not carried forward from one day to the next:

$$\sum_{k\in K_b}(10SSPRG^3_{k,h,b} + 10NSPRG^3_{k,h,b} + 10RSPRG^3_{k,h,b}) \leq \sum_{k\in K_b}\left(SPRG^3_{k,h-1,b} - SPRG^3_{k,h,b}\right) + 60 \times URRPRG_b$$

and

$$\sum_{k\in K_b}\left(10SSPRG^3_{k,h,b} + 10NSPRG^3_{k,h,b} + 30RSPRG^3_{k,h,b}\right) + \sum_{k\in K_b}\left(SPRG^3_{k,h,b}\right) \leq [(h - n) * 60 + 30] \times URRPRG_b \times OPRG^3_{h,b}$$

where *n* is the hour of the last start before or in hour *h*

and

$$\sum_{k\in K_b}\left(10SSPRG^3_{k,h,b} + 10NSPRG^3_{k,h,b} + 30RSPRG^3_{k,h,b}\right) + \sum_{k\in K_b}\left(SPRG^3_{k,h,b}\right) \leq [(m - h) * 60 + 30] \times DRRPRG_b \times OPRG^3_{h,b}$$

where *m* is the hour of the last shut down in or after hour *h*

6.9.2.7 Finally, the total (10-minute synchronized, 10-minute non-synchronized and 30-minute) from a committed *generation facility* cannot exceed the *it*s Pass 3 unscheduled capacity:

$$\sum_{k \in K_b} (10SSPRG^3_{k,h,b} + 10NSPRG^3_{k,h,b} + 30RSPRG^3_{k,h,b}) \le MaxPRG_{h,b} - \sum_{k \in K_b} SPRG^3_{k,h,b} - MinQPRG_{h,b}.$$

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

$$\sum_{k \in K_b} (10SSPRG^3_{k,h,b} + 10NSPRG^3_{k,h,b}) \le 10 \cdot ORRPRG_b.$$

6.9.2.9 The total reserve (10-minute non-synchronized and 30-minute) from hourly exports cannot exceed its ramp capability over 30 minutes. It cannot exceed the total scheduled export. These conditions can be enforced by the following two constraints:

$$\sum_{j \in J_d} (SX10N^3_{j,h,d} + SX30R^3_{j,h,d}) \le 30 \cdot ORRHXL_d;$$

and

$$\sum_{j \in J_d} (SX10N^3_{j,h,d} + SX30R^3_{j,h,d}) \le \sum_{j \in J_d} SHXL^3_{j,h,d}.$$

6.9.2.10 The amount of 10-minute non-synchronized reserve that hourly export is scheduled to provide cannot exceed the amount by which it can decrease its load over 10 minutes, as limited by its *operating reserve* ramp rate. This condition can be enforced by the following constraint:

$$\sum_{j \in J_d} SX10N^3_{j,h,d} \le 10 \cdot ORRHXL_d.$$

6.9.2.11 The total reserve (10-minute non-synchronized and 30-minute) from hourly imports cannot exceed its ramp capability over 30 minutes. It cannot exceed the remaining capacity (maximum import *offer* minus scheduled *energy* import). These conditions can be enforced by the following two constraints:

$$\sum_{k \in K_d} (SI10N^3_{k,h,d} + SI30R^3_{k,h,d}) \le 30 \cdot ORRHIG_d;$$

and

$$\sum_{k \in K_d} (SI10N^3_{k,h,d} + SI30R^3_{k,h,d}) \le \sum_{k \in K_d} (QHIG_{k,h,d} - SHIG^3_{k,h,d}).$$

6.9.2.12 The amount of 10-minute non-synchronized reserve that hourly import is scheduled to provide cannot exceed the amount by which it can increase the output over 10 minutes, as limited by its *operating reserve* ramp rate. This condition can be enforced by the following constraint:

$$\sum_{k \in K_d} SI10N^3_{k,h,d} \leq 10 \cdot ORRHIG_d .$$

6.10 Bid/Offer Inter-Hour/Multi-Hour Constraints

6.10.1 Ramping

6.10.1.1 *Energy* schedules for each resource cannot vary by more than an hour's ramping capacity for that resource. The *energy* schedule change in the hour in which the unit is scheduled to start or shut down depends on the unit ramp rate below its *minimum loading point*. Almost all non-quick start *generation facilities* will need one or more hours to reach their *minimum loading point* and to go down from *minimum loading point* to zero. Since non-committed *generation facilities* must be assigned zero output and committed units must operate at or above their *minimum loading point*, it is assumed that these units will be at their *minimum loading point* at the beginning of the first commitment hour and at the end of the hour before shut down.

6.10.1.2 The following three part constraint ensures that the *energy* schedules do not exceed the *generation facility's* ramp capability in the hours where the unit starts, stays on and shuts down.

Start Up Scenario ($OPRG^3_{h,b} = 1$, and $OPRG^3_{h-1,b} = 0$)

$$0 \leq \sum_{k \in K_b} SPRG^3_{k,h,b} \leq \sum_{k \in K_b} 30 \times URRPRG_b$$

Continued On Scenario ($OPRG^3_{h-1,b} = OPRG^3_{h,b} = 1$)

$$\sum_{k \in K_b} \left(SPRG^3_{k,h-1,b}\right) - 60 \times DRRPRG_b \leq \sum_{k \in K_b} SPRG^3_{k,h,b} \leq \sum_{k \in K_b} \left(SPRG^3_{k,h-1,b}\right) + 60 \times URRPRG_b$$

Shut Down Scenario ($OPRG^3_{h,b} = 1$, and $OPRG^3_{h+1,b} = 0$)

$$0 \leq \sum_{k \in K_b} SPRG^3_{k,h,b} \leq \sum_{k \in K_b} 30 \times DRRPRG_b$$

6.10.1.3 It should be noted that these ramp up/down rates apply to the operating range above the *minimum loading point* of the *generation facility*.

6.10.1.4 Similar logic is applied to *dispatchable loads* to arrive at the following constraint:

$$\sum_{j\in J_b}\left(QPRL_{j,h-1,b}-SPRL^3_{j,h-1,b}\right)-60\cdot URRPRL_{h,b}$$
$$\leq \sum_{j\in J_b}\left(QPRL_{j,h,b}-SPRL^3_{j,h,b}\right)$$
$$\leq \sum_{j\in J_b}\left(QPRL_{j,h-1,b}-SPRL^3_{j,h-1,b}\right)+60\cdot DRRPRL_{h,b}.$$

6.10.1.5 The above two constraints apply for all hours from 1 to 24. In the above two constraints the variables related to hour zero belong to the last hour of the previous day and are obtained from the initializing assumptions.

6.10.1.6 The ramping rates in the ramping constraints must be adjusted to allow the resource to:

a) Ramp down from its lower limit in hour (*h-1*) to its upper limit in hour *h*.

b) Ramp up from its upper limit in hour (*h-1*) to its lower limit in hour *h*.

6.10.1.7 This will allow a solution to be obtained when changes to the upper and lower limits between hours are beyond the ramping capability of the resources.

6.10.1.8 In the above ramping constraints, a single ramp up and a single ramp down, $URRPRG_b$ and $DRRPRG_b$ for *generation facilities* and $URRPRL_b$ and $DRRPRL_b$ for *dispatchable loads* are used. The ramp rate is assumed constant over the full operating range of the *dispatchable load and generation facility*. However, this is not the case. *Dispatchable load bids and generator offers* will include multi-*energy* ramp rates. The multiple ramp rates are described in sections 4.10.2.8 and 4.10.2.9.

6.10.2 Energy Limited Resources

6.10.2.1 Constraints applying to *energy*-limited resources are very similar to the constraints used in Pass 1. Therefore:

$$\sum_{h=1}^{1}\left(OPRG_{h,b}^{3}\cdot MinQPRG_{h,b}+\sum_{k\in K_b}SPRG_{k,h,b}^{3}\right)$$
$$+10ORConv\left(\sum_{k\in K_b}10SSPRG_{k,1,b}^{3}+\sum_{k\in K_b}10NSPRG_{k,1,b}^{3}\right)$$
$$+30ORConv\sum_{k\in K_b}30RSPRG_{k,1,b}^{3}\leq EL_b;$$

$$\sum_{h=1}^{2}\left(OPRG_{h,b}^{3}\cdot MinQPRG_{h,b}+\sum_{k\in K_b}SPRG_{k,h,b}^{3}\right)$$
$$+10ORConv\left(\sum_{k\in K_b}10SSPRG_{k,2,b}^{3}+\sum_{k\in K_b}10NSPRG_{k,2,b}^{3}\right)$$
$$+30ORConv\sum_{k\in K_b}30RSPRG_{k,2,b}^{3}\leq EL_b;$$

$$\vdots$$

$$\sum_{h=1}^{24}\left(OPRG_{h,b}^{3}\cdot MinQPRG_{h,b}+\sum_{k\in K_b}SPRG_{k,h,b}^{3}\right)$$
$$+10ORConv\left(\sum_{k\in K_b}10SSPRG_{k,24,b}^{3}+\sum_{k\in K_b}10NSPRG_{k,24,b}^{3}\right)$$
$$+30ORConv\sum_{k\in K_b}30RSPRG_{k,24,b}^{3}\leq EL_b$$

for all hours *h* and for all buses *b* at which *energy*-limited resources are located. The factors *10ORConv* and *30ORConv* are applied to scheduled *ten-minute operating reserve* and *thirty-minute operating reserves* for *energy*-limited resources to convert MW into MWh. This factor is set to unity.

6.11 Constraints to Ensure Schedules Do Not Violate Reliability Requirements

6.11.1 Load

6.11.1.1 The total amount of withdrawals scheduled in Pass 3 at each bus *b* in each hour *h*, $With^{3}_{h,b}$, is the sum of:

- The portion of the load forecast for that hour that has been allocated to that bus; and
- All *dispatchable load bid*, net of the amount of load reduction scheduled (since the *dispatchable load* is excluded from the *demand* forecast by the DACP calculation engine), yielding:

$$With_{h,b}^{3}=LDF_{h,b}\cdot AFL_{h}+\left[\sum_{j\in J_b}\left(QPRL_{j,h,b}-SPRL_{j,h,b}^{3}\right)\right];\text{and}$$

the total amount of withdrawals scheduled in Pass 3 at each *intertie zone* sink bus *d* in each hour *h*, $With^3_{h,b}$, is the sum of:

- Exports from Ontario to each *intertie zone* sink bus; and
- Outflows from Ontario associated with loop flows between Ontario and each *intertie zone*, allocated among the buses in the *intertie zones* using the distribution factors developed for that purpose, yielding:

$$With^3_{h,d} = \sum_{j \in J_d} (SHXL^3_{j,h,d}) - \sum_{a \in A} ProxyUPOWt_{d,a} \cdot \min(0, PF_{h,a}).$$

6.11.1.2 The total amount of injections scheduled in Pass 3 at each bus *b* in each hour *h*, $Inj^3_{h,b}$, is the sum of:

- Generation scheduled at that bus, yielding:

$$Inj^3_{h,b} = (OPRG^3_{h,b} + RAMPUP\_ENRG \cdot IPRG^3_{h+1,b}) MinQPRG_{h,b} + \sum_{k \in K_b} \left(SPRG^3_{k,h,b} \right); \text{ and}$$

the total amount of injections scheduled in Pass 3 at each *intertie zone* source bus *d* in each hour *h*, $Inj^3_{h,d}$, is the sum of:

- Imports into Ontario from each *intertie zone* source bus; and
- Inflows from Ontario associated with loop flows between Ontario and each *intertie zone*, allocated among the buses in the *intertie zones* using the distribution factors developed for that purpose:

$$Inj^3_{h,d} = \sum_{k \in K_d} (SHIG^3_{k,h,d}) + \sum_{a \in A} ProxyUPIWt_{d,a} \cdot \max(0, PF_{h,a}).$$

6.11.1.3 Injections and withdrawals at each bus must 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 actual and marginal losses. Load reduction associated with the *demand* constraint violation will be subtracted from the total load and generation reduction associated with the *demand* constraint violation will be subtracted from total generation to ensure that the calculation engine will always produce a solution. These violation variables are assigned a very high cost to limit their use to infeasible cases.

$$\sum_{b \in B} (1 + MglLoss_{h,b}) With^3_{h,b} + \sum_{d \in D} (1 + MglLoss_{h,b}) With^3_{h,d} - SLDViol^3_h$$
$$= \sum_{b \in B} (1 + MglLoss_{h,b}) Inj^3_{h,b} + \sum_{d \in D} (1 + MglLoss_{h,d}) Inj^3_{h,d} - SGenViol^3_h + LossAdj_h.$$

6.11.2 Operating Reserve

6.11.2.1 Sufficient *operating reserve* must be provided on the system to meet system wide requirements for 10-minute synchronized reserve, *ten-minute operating reserve* and *thirty-minute operating reserve*, as well as all applicable regional minimum and maximum requirements for *operating reserve*.

6.11.2.2 Therefore, taking into consideration the potential not to meet these minimum and maximum requirements if the cost of meeting those requirements becomes too high:

$$\sum_{b\in B}\left(\sum_{j\in J_b} 10SSPRL^3_{j,h,b}\right)+\sum_{b\in B}\left(\sum_{k\in K_b} 10SSPRG^3_{k,h,b}\right)+S10SViol^3_h \geq TOT10S_h;$$

$$\sum_{b\in B}\left(\sum_{j\in J_b} 10SSPRL^3_{j,h,b}\right)+\sum_{b\in B}\left(\sum_{k\in K_b} 10SSPRG^3_{k,h,b}\right)+S10RViol^3_h + \sum_{b\in B}\left(\sum_{k\in K_b} 10NSPRG^3_{k,h,b}\right)+\sum_{b\in B}\left(\sum_{j\in J_b} 10NSPRL^3_{j,h,b}\right) + \sum_{d\in D}\left(\sum_{k\in K_d} SI10N^3_{k,h,d}\right)+\sum_{d\in D}\left(\sum_{j\in J_d} SX10N^3_{j,h,d}\right) \geq TOT10R_h; \text{ and}$$

$$\sum_{b\in B}\left(\sum_{j\in J_b} 10SSPRL^3_{j,h,b}\right)+\sum_{b\in B}\left(\sum_{k\in K_b} 10SSPRG^3_{k,h,b}\right)+S30RViol^3_h + \sum_{b\in B}\left(\sum_{k\in K_b} (10NSPRG^3_{k,h,b}+30RSPRG^3_{k,h,b})\right) + \sum_{b\in B}\left(\sum_{j\in J_b} (10NSPRL^3_{j,h,b}+30RSPRL^3_{j,h,b})\right) + \sum_{d\in D}\left(\sum_{k\in K_d} (SI10N^3_{k,h,d}+SI30R^3_{k,h,d})\right) + \sum_{d\in D}\left(\sum_{j\in J_d} (SX10N^3_{j,h,d}+SX30R^3_{j,h,d})\right) \geq TOT30R_h$$

for all hours *h*; and

$$\sum_{b\in r}\left(\sum_{j\in J_b} 10SSPRL^3_{j,h,b}\right)+\sum_{b\in r}\left(\sum_{k\in K_b} 10SSPRG^3_{k,h,b}\right)+SREG10RViol^3_{r,h}$$
$$+\sum_{b\in r}\left(\sum_{k\in K_b} 10NSPRG^3_{k,h,b}\right)+\sum_{b\in r}\left(\sum_{j\in J_b} 10NSPRL^3_{j,h,b}\right)$$
$$\geq REGMin10R_{r,h};$$

$$\sum_{b\in r}\left(\sum_{j\in J_b} 10SSPRL^3_{j,h,b}\right)+\sum_{b\in r}\left(\sum_{k\in K_b} 10SSPRG^3_{k,h,b}\right)-SXREG10RViol^3_{r,h}$$
$$+\sum_{b\in r}\left(\sum_{k\in K_b} 10NSPRG^3_{k,h,b}\right)+\sum_{b\in r}\left(\sum_{j\in J_b} 10NSPRL^3_{j,h,b}\right)$$
$$\leq REGMax10R_{r,h};$$

$$\sum_{b\in r}\left(\sum_{j\in J_b} 10SSPRL^3_{j,h,b}\right)+\sum_{b\in r}\left(\sum_{k\in K_b} 10SSPRG^3_{k,h,b}\right)+SREG30RViol^3_{r,h}$$
$$+\sum_{b\in r}\left(\sum_{k\in K_b}(10NSPRG^3_{k,h,b}+30RSPRG^3_{k,h,b})\right)$$
$$+\sum_{b\in r}\left(\sum_{j\in J_b}(10NSPRL^3_{j,h,b}+30RSPRL^3_{j,h,b})\right)$$
$$\geq REGMin30R_{r,h};\text{ and}$$

$$\sum_{b\in r}\left(\sum_{j\in J_b} 10SSPRL^3_{j,h,b}\right)+\sum_{b\in r}\left(\sum_{k\in K_b} 10SSPRG^3_{k,h,b}\right)-SXREG30RViol^3_{r,h}$$
$$+\sum_{b\in r}\left(\sum_{k\in K_b}(10NSPRG^3_{k,h,b}+30RSPRG^3_{k,h,b})\right)$$
$$+\sum_{b\in r}\left(\sum_{j\in J_b}(10NSPRL^3_{j,h,b}+30RSPRL^3_{j,h,b})\right)$$
$$\leq REGMax30R_{r,h}$$

for all hours *h*, and for all regions *r* in the set *ORREG.*

6.11.3 Internal Transmission Limits

6.11.3.1 The *IESO* must ensure that the set of DACP schedules produced by Pass 3 of the calculation engine would not violate any *security limits* in either the pre-contingency state or in any contingency. To develop the constraints to ensure that this occurs, the total amount of *energy* scheduled to be injected at each bus and the total amount of *energy* scheduled to be withdrawn at each bus will be used.

6.11.3.2 Then the pre-contingency limits on transmission within Ontario will not be violated if:

$$\sum_{b\in B} PreConSF_{b,f,h}(Inj^3_{h,b} - With^3_{h,b}) + \sum_{d\in D} PreConSF_{d,f,h}(Inj^3_{h,d} - With^3_{h,d}) - SPreConITLViol^3_{f,h} \le AdjNormMaxFlow_{f,h}$$

for all *facilities* f and hours h.

6.11.3.3 Post-contingency limits on transmission *facilities* within Ontario will not be violated if:

$$\sum_{b\in B} SF_{b,f,c,h}(Inj^3_{h,b} - With^3_{h,b}) + \sum_{d\in D} SF_{d,f,c,h}(Inj^3_{h,d} - With^3_{h,d}) - SITLViol^3_{f,c,h} \le AdjEmMaxFlow_{f,c,h}$$

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

6.11.4 Intertie Transmission Limits and Constraints on Net Imports

6.11.4.1 The calculation engine would not violate any *security limits* associated with *interties* between Ontario and *intertie zones*. To ensure this, we must calculate the net amount of *energy* scheduled to flow over each *intertie* in each hour and the amount of *operating reserve* scheduled to be provided by resources in that *control area*. This will be summed over all affected *interties*. The result will be compared to the limit associated with that constraint. Consequently:

$$\sum_{a\in A}\left[\begin{array}{l} EnCoeff_{a,z}\left(\sum_{d\in DI_a,k\in K_d}(SHIG^3_{k,h,d}) + PF_{h,a} - \sum_{d\in DX_a,j\in J_d}\left(SHXL^3_{j,h,d}\right)\right) + \\ 0.5(EnCoeff_{a,z}+1)\left[\begin{array}{l}\sum_{d\in DI_a,k\in K_d}\left(SI10N^3_{k,h,d} + SI30R^3_{k,h,d}\right) \\ + \sum_{d\in DX_a,j\in J_d}\left(SX10N^3_{j,h,d} + SX30R^3_{j,h,d}\right)\end{array}\right]\end{array}\right] \le MaxExtSch_{z,h}$$

for all hours h, for all *intertie zones* a relevant to the constraint z

($EnCoeff_{a,z} \neq 0$), and for all constraints z in the set Z_{sch}.

6.11.4.2 In addition, changes in the net *energy* schedule over all *interties* cannot exceed the limits set forth by the *IESO* for hour-to-hour changes in those schedules. The net import schedule is summed over all *interties* for a given hour. It cannot exceed the sum of net import schedule for all *interties* for the previous hour plus the maximum permitted hourly increase. It cannot be less than the sum of the net import schedule for all *interties* for the previous hour minus the maximum permitted hourly decrease. Violation variables are provided for both the up and down ramp limits to ensure that the calculation engine will always find a solution. Therefore:

$$\sum_{d\in D}\left(\sum_{k\in K_d}(SHIG^3_{k,h-1,d}) - \sum_{j\in J_d}(SHXL^3_{j,h-1,d})\right) - ExtDSC_h - SDRmpXTLViol^3_h$$
$$\leq \sum_{d\in D}\left(\sum_{k\in K_d}(SHIG^3_{k,h,d}) - \sum_{j\in J_d}(SHXL^3_{j,h,d})\right)$$
$$\leq \sum_{d\in D}\left(\sum_{k\in K_d}(SHIG^3_{k,h-1,d}) - \sum_{j\in J_d}(SHXL^3_{j,h-1,d})\right) + ExtUSC_h + SURmpXTLViol^3_h$$

for all hours *h* (schedules for hour, *h*=0 are obtained from the initializing inputs listed in section 3.8).

6.11.5 Intertie Schedule Limits Based on Pass 2 Outputs

6.11.5.1 Pass 3 will not reduce the amount of imported *energy* scheduled from each *intertie zone* in any hour. Additional imports of *energy* may be scheduled in Pass 3, Therefore, for imports that are not part of a linked wheeling transaction:

$$SHIG^3_{k,h,d} \geq SHIG^2_{k,h,d}$$

for all *offers k*, hours *h* and *intertie zones* source bus *d*, and:

6.11.5.2 Pass 3 will not increase the amount of exported *energy* scheduled from each *intertie zone* in any hour to the amount scheduled in Pass 2.

6.11.5.3 Therefore, for exports that are not part of a linked wheeling transaction:

$$SHXL^3_{j,h,d} \leq SHXL^2_{j,h,d}.$$

6.12 Shadow Prices

6.12.1 The *IESO* shall also determine *energy* and *operating reserve* prices in Pass 3 that will be *published* for informational purposes.

6.12.2 Shadow Energy Prices

6.12.2.1 The Pass 3 shadow price at each bus *b* in each hour *h* shall be calculated at buses in Ontario as:

$$LMP^3_{h,b} = \left(1 + MglLoss_{h,b}\right)\cdot SPL^3_h + \sum_{f\in F}\left(\begin{array}{l} PreConSF_{b,f,h}\cdot SPNormT^3_{f,h} \\ +\sum_{c\in C} SF_{b,f,c,h}\cdot SPEmT^3_{f,c,h}\end{array}\right)$$

6.12.3 Shadow Energy Prices at *Intertie Zones*

6.12.3.1 The Pass 3 shadow price at each *intertie zone* source/sink bus *d* in each hour *h* is calculated as:

$$ExtLMP_{h,d}^{3} = \left(1 + MglLoss_{h,d}\right) \cdot SPL_{h}^{3} + \sum_{f \in F} \left(\begin{array}{l} PreConSF_{d,f,h} \cdot SPNormT_{f,h}^{3} \\ + \sum_{c \in C} (SF_{d,f,c,h} \cdot SPEmT_{f,c,h}^{3}) \end{array} \right) + \sum_{z \in Z_{sch}} (EnCoeff_{a,z} \cdot SPExtT_{z,h}^{3}) + SPRUExtT_{h}^{3} - SPRDExtT_{h}^{3}$$

6.12.3.2 The first component of this calculation, the cost of meeting load at each *intertie zone* reflecting marginal losses incurred in transmitting *energy* from the *reference bus* to that *intertie zone*, is the same as the first component of the previous equation. The second component of this calculation determines the effect of congestion on internal transmission *facilities* on the price at each bus.

6.12.3.3 The last three components reflect the impact of limits on imports or exports, which are relevant for the calculation of prices at *intertie zones*. The first of the three components provides the effect of congestion resulting from *security limits* associated with *interties* between Ontario and *intertie zones*, for all constraints *z* in the set Z_{sch}. The last two components reflect the congestion cost resulting from the upward/downward limits of hour-to-hour net *energy* changes across all *interties*.

6.12.4 Shadow 30-Minute Reserve Prices

6.12.4.1 Shadow prices can also be calculated for each bus, reflecting the marginal contribution that each category of *operating reserve* would have if provided at that bus to increasing the value of the objective function. For each bus *b,* define $ORREG_b$ as the subset of *ORREG* consisting of regions that include bus *b.* The Pass 3 price of *thirty-minute operating reserve* at a given bus *b,* $L30RP^{3}_{h,b}$, is the shadow price of the total *thirty-minute operating reserve* constraint, plus the shadow prices of all of the constraints requiring a minimum amount of *thirty-minute operating reserve* to be provided by resources in regions that include that bus, minus the shadow prices of all the constraints limiting the amount of *thirty-minute operating reserve* that can be provided by resources in regions that include that bus; given these definitions:

$$L30RP_{h,b}^{3} = SP30R_{h}^{3} + \sum_{r \in ORREG_b} SPREGMin30R_{r,h}^{3} - \sum_{r \in ORREG_b} SPREGMax30R_{r,h}^{3}.$$

6.12.5 Shadow 10-Minute Non-synchronized Reserve Prices

6.12.5.1 The Pass 3 price of 10-minute non-synchronized reserve at a given bus *b,* $L10NP^{3}_{h,b}$, is the shadow price of the total *ten-* and *thirty-minute operating reserve* constraints, plus the shadow prices of all of the constraints requiring a minimum amount of *ten-* or *thirty-minute operating reserve* to be provided by resources in regions that include that bus, minus the shadow prices of all the constraints limiting the amount of *ten-* or *thirty-minute operating reserve* that can be provided by resources in regions that include that bus:

$$
\begin{aligned}
&L10NP^{3}_{h,b} \\
&\quad = SP10R^{3}_{h} + SP30R^{3}_{h} \\
&\qquad + \sum_{r \in ORREG_{b}} \left(SPREGMin10R^{3}_{r,h} + SPREGMin30R^{3}_{r,h} \right) \\
&\qquad - \sum_{r \in ORREG_{b}} \left(SPREGMax10R^{3}_{r,h} + SPREGMax30R^{3}_{r,h} \right).
\end{aligned}
$$

6.12.6 Shadow 10-Minute Synchronized Reserve Prices

6.12.6.1 Finally, the Pass 3 price of 10-minute synchronized reserve at a given bus *b,* $L10SP^{3}_{h,b}$, is the shadow price of the total *ten-* and *thirty-minute operating reserve* constraints and the total 10-minute synchronized reserve constraint, plus the shadow prices of all of the constraints requiring a minimum amount of *ten-* or *thirty-minute operating reserve* or 10-minute synchronized reserve to be provided by resources in regions that include that bus, minus the shadow prices of all the constraints limiting the amount of *ten-* or *thirty-minute operating reserve* or 10-minute synchronized reserve that can be provided by resources in regions that include that bus:

$$
\begin{aligned}
&L10SP^{3}_{h,b} \\
&\quad = SP10S^{3}_{h} + SP10R^{3}_{h} + SP30R^{3}_{h} \\
&\qquad + \sum_{r \in ORREG_{b}} \left(SPREGMin10R^{3}_{r,h} + SPREGMin30R^{3}_{r,h} \right) \\
&\qquad - \sum_{r \in ORREG_{b}} \left(SPREGMax10R^{3}_{r,h} + SPREGMax30R^{3}_{r,h} \right).
\end{aligned}
$$

6.12.7 Shadow Operating Reserve Prices at *Intertie* Zones

6.12.7.1 Shadow *operating reserve* prices can also be calculated for *intertie zones*. These prices need to take into account the shadow prices of constraints in the set Z_{sch}, as some of these constraints will limit the amount of *operating reserve* that can be imported into Ontario. They do not need to take into account the shadow prices of constraints associated with lower limits on the amount of *operating reserve* that must be supplied within regions of Ontario or upper limits on the amount of *operating reserve* that may be supplied within regions of Ontario, since imported *operating reserve* will not affect either of these types of constraints. Nor do they need to take into account the shadow price for the hour-to-hour change in net *energy* flow over all *interties*, as these constraints will only affect the amount of *energy* that can be scheduled to flow into or out of Ontario.

6.12.7.2 The Pass 3 price of *thirty-minute operating reserve* at a given *intertie zone a,* $Ext30RP^{3}_{h,a}$, is the shadow price of the total *thirty-minute operating reserve* constraint, minus the product of:

- The impact that imports of *operating reserve* from that *intertie zone* have on each constraint limiting the import of *operating reserve* from that *intertie zone*, and

- The shadow price of that constraint, summed over all constraints:

$$
Ext30RP^{3}_{h,a} = SP30R^{3}_{h} - \sum_{z \in Z_{sch}} 0.5(ENCoeff_{a,z} + 1)SPExtT^{3}_{z,h}.
$$

6.12.7.3 The Pass 3 price of *ten-minute operating reserve* at a given *intertie zone a,* $Ext10RP^{3}_{h,a}$, is the shadow price of the total *ten-* and *thirty-minute operating reserve* constraints, minus the product of:

- The impact that imports of *operating reserve* from that *intertie zone* have on each constraint limiting the import of *operating reserve* from that *intertie zone*, and
- The shadow price of that constraint, summed over all constraints:

$$Ext10RP^{3}_{h,a} = SP10R^{3}_{h} + SP30R^{3}_{h} - \sum_{z \in Z_{sch}} 0.5(ENCoeff_{a,z} + 1)SPExtT^{3}_{z,h}.$$

6.12.7.4 There is no need to calculate a price for 10-minute synchronized reserve at *intertie zones*, since 10-minute synchronized reserve cannot be imported.

7. Combined-Cycle Modeling

7.1 Overview

7.1.1 *Registered market participants* with combined-cycle plants of one or more combustion turbines and one steam turbine may choose to have the associated *generation facilities* modeled as one or more *pseudo-units*. Each *pseudo-unit* comprises of a single combustion turbine and a share of the steam turbine capacity. Inputs for *pseudo-units* used by the DACP calculation engine are described in Chapter 7, section 2.2.6G.

7.2 Modeling by DACP Calculation Engine

7.2.1 The *pseudo-units* are independently scheduled in each Pass subject to the optimization objective function described in sections 4.3, 5.3 and 6.3 respectively. However, the security assessment described in section 4.4 is performed for each *generation facility* of the combined-cycle plant.

7.2.2 As the security assessment function iterates with the scheduling function of the DACP calculation engine, the output relationship of each combustion turbine and its share of output from the steam turbine is respected. This output relationship is described as follows:

7.2.2.1 For a combined-cycle plant with *i* combustion turbines and one steam turbine, it is represented by *i pseudo-units*.

7.2.2.2 For each *pseudo-unit i*, let $pst_{i,k}$ represent the percentage of the *pseudo-unit*'s schedule that relates to the steam turbine in association with *offer k*.

7.2.2.3 Then for each *pseudo-unit i*, the percentage of the *pseudo-unit's* schedule that relates to the combustion turbine *i* is (100% - $pst_{i,k}$).

7.2.2.4 For a given *pseudo-unit* schedule $SPSU_{k,h}$ for hour *h* and *k* offers its associated combustion turbine schedule is: $\sum_{k} SPSU_{k,h} \times (100\% - pst_{i,k})$.

7.2.2.5 And the steam turbine schedule of the *pseudo-unit* plant for hour *h* is: $\sum_{i}\sum_{k} SPSU_{k,h} \times pst_{i,k}$.