SECTION C: LINEAR PROGRAM

D.14 OBJECTIVE FUNCTION

D.14.1 The NetBenefit is maximised, where:

\[
\text{NetBenefit} = \sum_{(j,p) \in \text{PURCHASEBIDBLOCKS}, \text{where } p \in \text{ENERGYBIDS}} \text{PurchaseBidPrice}_{p,j} \times \text{PurchaseBlock}_{p,j}
- \sum_{(j,g) \in \text{GENERATIONOFFERBLOCKS}, \text{where } g \in \text{ENERGYOFFERS}} \text{Generation OfferPrice}_{g,j} \times \text{Generation Block}_{g,j}
- \sum_{(j,r) \in \text{RAWRESERVESBLOCKS}, \text{where } r \in \text{RAWRESERVESOFFERS}} \text{ReserveOfferPrice}_{r,j} \times \text{RawReserve Block}_{r,j}
- \sum_{(j,l) \in \text{REGULATIONOFFERBLOCKS}, \text{where } l \in \text{REGULATIONOFFERS}} \text{Regulation OfferPrice}_{l,j} \times \text{Regulation Block}_{l,j}
- \sum_{(j,n) \in \text{EXCESSGENERATIONBLOCKS}, \text{where } n \in \text{NODES}} \text{ExcessGenerationPenalty}_{n,j} \times \text{ExcessGenerationBlock}_{k,n,j}
- \sum_{(j,n) \in \text{DEFICITGENERATIONBLOCKS}, \text{where } n \in \text{NODES}} \text{DeficitGenerationPenalty}_{n,j} \times \text{DeficitGenerationBlock}_{n,j}
- \text{ViolationPenalties}
- \text{TieBreakingPenalties}
\]

Explanatory Note: NetBenefit is the sum of producer surplus and consumer surplus. The objective of the MCE’s optimization process is to maximize the value of economic welfare, as measured by the sum of producer surplus and consumer surplus, which is equivalent to minimizing the cost.
D.15 CONSTRAINTS ON ENERGY GENERATION AND PURCHASES

D.15.1 Generation Constraints

D.15.1.1 Generation Block Constraint:

\[ \text{Generation Block}_{g,j} \leq \text{Generation Block Max}_{g,j} \]

\[ \{ j, g | j \in \text{GENERATION OFFER BLOCKS}_{g}, \text{where } g \in \text{ENERGY OFFERS} \} \]

D.15.1.2 Generation Summation Constraint:

\[ \text{Generation}_g = \sum_{j \in \text{GENERATION OFFER BLOCKS}_g} \text{Generation Block}_{g,j} \]

\[ \{ g \in \text{ENERGY OFFERS} \} \]

D.15.1.3 Mixed Integer Program Based Minimum Stable Load constraints:

D.15.1.3.1 Minimum Stable Load Decommitment Constraint:

\[ \text{Generation}_g - \text{Infinite Positive Value} \times \text{MSL Selector}_g - \text{Excess MSL}_g \leq 0 \]

\[ \{ g \in \text{ENERGY OFFERS}, \text{for which } \text{Minimum Stable Load}_g > 0 \} \]

D.15.1.3.2 Minimum Stable Load Commitment Constraint:

\[ \text{Generation}_g - \text{MSL Selector}_g \times \text{Minimum Stable Load}_g + \text{Deficit MSL}_g \geq 0 \]

\[ \{ g \in \text{ENERGY OFFERS}, \text{for which } \text{Minimum Stable Load}_g > 0 \} \]

D.15.2 Purchase Constraints

D.15.2.1 Purchase Block Constraint:

\[ \text{Purchase Block}_{p,j} \leq \text{Purchase Block Max}_{p,j} \]

\[ \{ j, p | j \in \text{PURCHASE BID BLOCKS}_p, \text{where } p \in \text{ENERGY BIDS} \} \]

D.15.2.2 Purchase Summation Constraint:

\[ \text{Purchase}_p = \sum_{j \in \text{PURCHASE BID BLOCKS}_p} \text{Purchase Block}_{p,j} \]

\[ \{ p \in \text{ENERGY BIDS} \} \]
D.15.2.3 Total Purchase Calculation:

\[
\text{Total Purchase} = \sum_{p \in \text{ENERGYBIDS}} \sum_{p \in \text{INTERTEEENERGYBIDS}} \text{Purchase}_p
\]

D.15.3 LRF with REB Constraints

D.15.3.1 LRF Nodal Purchase Limit Constraint:

\[
\text{Purchase}_{p,n} \leq \text{Proportion}_{p,n} \times \sum_{j \in \text{PURCHASEDBLOCK}_{p,j}} \text{PurchaseBlockMax}_{p,j}
\]

\{p \in \text{RESTRICTEDENERGYBIDS}, n \in \text{NODES}_p\}

D.15.3.2 LRF Nodal Purchase Aggregation Constraint:

\[
\text{Purchase}_p = \sum_{n \in \text{NODES}_p} \text{Purchase}_{p,n}
\]

\{p \in \text{RESTRICTEDENERGYBIDS}\}

D.15.3.3 Load Curtailment Calculation:

\[
\text{Curtailed Load}_p = \min \left( \frac{\text{PurchaseEndMax}_p}{\sum_{j \in \text{PURCHASEDBLOCK}_{p,j}} \text{PurchaseBlockMax}_{p,j}} \right) - \text{Purchase}_p
\]

\{p \in \text{RESTRICTEDENERGYBIDS}\}
D.16 TRANSMISSION

D.16.1 Node Balance

D.16.1.1 Node Balance Flow Constraint:

\[
\text{NodeNetInj}_{n} = \sum_{k \in \text{LINES} \cup \text{ARTIFICIAL LINES}1} \text{LineFlow}_{k} - \sum_{k \in \text{LINES} \cup \text{ARTIFICIAL LINES}3} \text{LineFlow}_{k} + \frac{1}{2} \sum_{k \in \text{ARTIFICIAL LINES}1, \text{ARTIFICIAL LINES}3} \text{LineLoss}_{k}
\]

\[
\{n \in \text{NODES}\}
\]

D.16.1.2 Node Balance Generation Constraint:

\[
\text{NodeNetInj}_{n} = \sum_{g \in \text{ENERGYOFFERS}_{n}} \text{Generation}_{g} - \sum_{p \in \text{RESTRICTEDENERGYBIDS}_{n}} \text{Purchase}_{p,n}
\]

\[
- \sum_{p \in \text{RESTRICTEDENERGYBIDS}_{n}} \text{Purchase}_{p,n}
\]

\[
+ \sum_{j \in \text{DEFICITGENERATIONBLOCKS}_{n}} \text{DeficitGenerationBlock}_{n,j}
\]

\[
- \sum_{j \in \text{EXCESSGENERATIONBLOCKS}_{n}} \text{ExcessGenerationBlock}_{n,j}
\]

\[
\{n \in \text{NODES}\}
\]

D.16.1.3 Deficit Generation Block Constraint:

\[
\text{DeficitGenerationBlock}_{n,j} \leq \text{DeficitGenerationBlockMax}_{n,j}
\]

\[
\{j,n \mid j \in \text{DEFICITGENERATIONBLOCKS}_{n}, \text{ where } n \in \text{NODES}\}
\]

D.16.1.4 Excess Generation Block Constraint:

\[
\text{ExcessGenerationBlock}_{n,j} \leq \text{ExcessGenerationBlockMax}_{n,j}
\]

\[
\{j,n \mid j \in \text{EXCESSGENERATIONBLOCKS}_{n}, \text{ where } n \in \text{NODES}\}
\]

D.16.2 Line Flow

D.16.2.1 Flow Reverse Constraint:

\[
\text{LineMaxReverse}_{k} \leq \text{LineFlow}_{k} + \text{ExcessLineFlowReverse}_{k}
\]

\[
\{k \in \text{LINES}, k \notin \text{ARTIFICIAL LINES}1 \cup \text{ARTIFICIAL LINES}3\}
D.16.2.2 Flow Forward Constraint:
\[
\text{LineMaxForward}_k \geq \text{LineFlow}_k - \text{ExcessLineFlowForward}_k
\]
\(\{ k \in \text{LINES}, k \notin \text{ARTIFICIALLINES3}\}\)

D.16.2.3 Node Angle Constraint:
\[
\text{LineFlow}_k = \text{LineAdmittance}_k \times (\text{NodeAngle}_{\text{NodeAtStartOf}(k)} - \text{NodeAngle}_{\text{NodeAtEndOf}(k)} + \text{PhaseAngleShift}_k)
\]
\(\{ k \in \text{LINES}, k \notin \text{ARTIFICIALLINES1} \cup \text{ARTIFICIALLINES3}\}\)

However, in the case where the constraint in this section D.16.2.3 corresponds to a notional line connecting two electrically equivalent buses introduced to the dispatch network in accordance with section D.6.3.4, then the following constraint shall be substituted:
\[
0 = (\text{NodeAngle}_{\text{NodeAtStartOf}(k)} - \text{NodeAngle}_{\text{NodeAtEndOf}(k)})
\]
\(\{ k \in \text{ARTIFICIALLINES3}\}\)

D.16.2.4 Reference Node Angle Constraint:
\[
\text{NodeAngle}_{\text{REFERENCENODE}} = 0
\]

D.16.3 Line Losses

D.16.3.1 Line Flow Constraint:
\[
\text{LineFlow}_k = \sum_{j \in \text{DISCRSUB}_k} \text{LineFlowConstant}_{kj} \times \text{Weight}_{kj} + \text{DeficitWLLineFlow}_k - \text{ExcessWLLineFlow}_k
\]
\(\{ k \in \text{LINES}, k \notin \text{ARTIFICIALLINES1} \cup \text{ARTIFICIALLINES3}\}\)

D.16.3.2 Line Loss Constraint:
\[
\text{LineLoss}_k = \sum_{j \in \text{DISCRSUB}_k} \text{LineLossConstant}_{kj} \times \text{Weight}_{kj}
\]
\(\{ k \in \text{LINES}, k \notin \text{ARTIFICIALLINES1} \cup \text{ARTIFICIALLINES3}\}\)
D.16.3.3 Weight Summation Constraint:

\[ \sum_{j \in \text{DISCRSUB}_k} \text{Weight}_{k,j} = 1 \]

\{ k \in \text{LINES}, k \notin \text{ARTIFICIAL LINES}_1 \cup \text{ARTIFICIAL LINES}_3 \} 

D.16.4 Relaxation of Line Constraints

The provisions of this section shall only apply to a re-run of the market clearing engine under Section 10.2.3A.2 and section 10.2.5B of Chapter 6.

D.16.4.1 Revised Flow Reverse Constraint

\[ \text{LineMaxReverse}_k \leq \text{LineFlow}_k + \text{ExcessLineFlowReverse}_k \]

\{ k \in \text{ARTIFICIAL LINES}_2 \} 

This constraint will replace constraint in D.16.2.1

D.16.4.2 Revised Flow Forward Constraint

\[ \text{LineMaxForward}_k \geq \text{LineFlow}_k - \text{ExcessLineFlowForward}_k \]

\{ k \in \text{ARTIFICIAL LINES}_1 \cup \text{ARTIFICIAL LINES}_2 \} 

This constraint will replace constraint in D.16.2.2

D.16.4.3 The constraint in section D.21.2 shall apply in place of the constraint in section D.21.1.

D.16.4.4 Revised MaxLineRating

\[ \text{MaxLineRating}_k = \text{maximum} (\text{LineRating Forward}_k, \text{LineRating Reverse}_k) \]

\[ \text{RevisedMaxLineRating}_k = \frac{\text{Additional NumPoints}_k}{2} \times \frac{\text{MaxLineRating}_k}{(\text{NumPoints}_k - 1)/2} \]

\[ + \text{MaxLineRating}_k \]

\[ \text{LineFlowCost}_{k,j} = -\text{RevisedMaxLineRating}_k \]

\[ + \frac{j - 1}{\text{NumPoints}_k - 1} \times \text{RevisedMaxLineRating}_k \times 2 \]

\{ k, j \mid j \in \{1, ..., \text{NumPoints}_k \}, \text{where } k \in \text{LINES}, k \notin \text{ARTIFICIAL LINES} \}
This section will replace section D.9.3 for the purposes of constraint relaxation.

Explanatory Note: Additional line flow/line loss points are required in order to accommodate the increased flow that may occur when line flow constraints are relaxed.
D.17 **RISK AND OPERATING RESERVE**

D.17.1 Risk

D.17.1.1 Generator Risk Constraint:

\[
\text{Risk}_c \geq \text{Risk Adjustment Factor}_c \times \text{Raw Calculated Risk}_c
\]

where:

\[
\text{Raw Calculated Risk}_c = \text{Generation}_{g,c} - \text{Power System Response}_{g,c} + \text{Est Reserve Effective Demand}_{g,c} \times \text{Raw Reserve}_{r(g,c)} + \sum_{h \in \text{SECONDARY RESERVE GENERATORS}} \left( \text{Generation}_{h,c} + \text{Est Reserve Effective Demand}_{h,c} \times \text{Raw Reserve}_{r(h,c)} \right)
\]

and

\[
\text{Power System Response}_{g,c} = \text{Est Intertie Contribution}_c \times \text{Acceptable Frequency Deviation}_c \\
\times \text{Est Load Damping}_c \times \text{Total Purchase}
\]

\[
- \text{Est G Output Damping}_c \times \sum_{i \in \text{DAMPING GENERATORS}} \text{Generation}_i
\]

\[
\{ g, c \mid g \in \text{RISK GENERATORS}, c \in \text{RESERVE CLASSES} \}
\]

D.17.1.2 Minimum Risk Constraint:

\[
\text{Risk}_c \geq \text{Minimum Risk}_c
\]

\[
\{ c \mid c \in \text{RESERVE CLASSES} \}
\]

D.17.2 Supply of Contingency Reserve

D.17.2.1 Raw Reserve Block Constraint:

\[
\text{Raw Reserve Block}_{r,j} \leq \text{Raw Reserve Block Max}_{r,j}
\]

\[
\{ j, r \mid j \in \text{RAW RESERVE BLOCKS}, r \in \text{RAW RESERVE OFFERS} \}
\]

D.17.2.2 Raw Reserve Summation Constraint:

\[
\text{Raw Reserve}_r = \sum_{j \in \text{RAW RESERVE BLOCKS}} \text{Raw Reserve Block}_{r,j}
\]

\[
\{ r \in \text{RAW RESERVE OFFERS} \}
\]

D.17.2.3 Reserve Proportion Constraint:

\[
\text{Raw Reserve}_r - \text{Excess Raw Reserve}_r \leq \text{Reserve Proportion}_r \times \text{Generation}_{g(r)}
\]

\[
\{ r \in \text{GEN RESERVE OFFERS} \}
\]
D.17.2.4 Reserve Generation Max Constraint:
\[
\text{Generation}_{g(r)} + \text{RawReserve}_{r} + \text{Regulation}_{g(r)} - \text{ExcessResGen}_{r} \leq \text{ReserveGenerationMax}_{r},
\]
\[
\{ r \in \text{GENRESERVEOFFERS} \}
\]

D.17.2.5 Reserve Generation Segment 1
\[
\text{RawReserve}_{r} - \text{ExcessResGenSegment1}_{r} \leq \text{HighLoadReserve}_{r} + \text{Slope} \times (\text{Generation}_{g(r)} - \text{HighLoad}_{g(r)})
\]
\[
\{ r \in \text{GENRESERVEOFFERS} \}
\]
where:
\[
\text{Slope} = -\frac{\text{HighLoadReserve}_{r}}{(\text{StandingReserveGenerationMax}_{g(r)} - \text{HighLoad}_{g(r)})}
\]

D.17.2.6 Reserve Generation Segment 2
\[
\text{RawReserve}_{r} - \text{ExcessResGenSegment2}_{r} \leq \text{MediumLoadReserve}_{r} + \text{Slope} \times (\text{Generation}_{g(r)} - \text{MediumLoad}_{g(r)})
\]
\[
\{ r \in \text{GENRESERVEOFFERS} \}
\]
where:
\[
\text{Slope} = \frac{(\text{HighLoadReserve}_{r} - \text{MediumLoadReserve}_{r})}{(\text{HighLoad}_{g(r)} - \text{MediumLoad}_{g(r)})}
\]

D.17.2.7 Reserve Generation Segment 3
\[
\text{RawReserve}_{r} - \text{ExcessResGenSegment3}_{r} \leq \text{LowLoadReserve}_{r} + \text{Slope} \times (\text{Generation}_{g(r)} - \text{LowLoad}_{g(r)})
\]
\[
\{ r \in \text{GENRESERVEOFFERS} \}
\]
where:
\[
\text{Slope} = \frac{(\text{MediumLoadReserve}_{r} - \text{LowLoadReserve}_{r})}{(\text{MediumLoad}_{g(r)} - \text{LowLoad}_{g(r)})}
\]
D.17.2.8 Mixed Integer Program Based Reserve Constraints
The provisions of this section D.17.2.8 shall apply only to primary reserve in solving the linear program.

D.17.2.8.1 Mixed Integer Program Based Zero Raw Reserve Constraint
RawReserve\textsubscript{r} – InfinitePositiveValue \times ReserveEligibilitySwitch\textsubscript{g(r)} \leq 0
\{r | r \in GENPRIRESERVEOFFERS\}

D.17.2.8.2 Mixed Integer Program Based Reserve Low Load Constraint
Generation\textsubscript{g(r)} + InfinitePositiveValue \times (1 – ReserveEligibilitySwitch\textsubscript{g(r)}) \geq LowLoad\textsubscript{g(r)}
\{r | r \in GENPRIRESERVEOFFERS\}

D.17.3 Matching of requirements and availability

D.17.3.1 Group Response Constraint:
\sum_{j \in RESERVEGROUPS} \sum_{x,j} GroupResponse\textsubscript{nse} x,j \leq \sum_{r \in RAWRESERVEDOFFERS} RawReserve\textsubscript{r}
\{x \in RESERVEGROUPS\}

D.17.3.2 Group Response Block Constraint:
GroupResponse\textsubscript{nse} x,j \leq GroupResponse\textsubscript{nseMax} x,j
\{j \in RESERVEGRO UPBLOCKS\textsubscript{x}, where \ x \in RESERVEGRO UPS\}

D.17.3.3 Effective Reserve Constraint:
EffectiveReserve\textsubscript{x} = \sum_{j \in RESERVEGROUPS} \sum_{x,j} Effectiveness\textsubscript{e} x,j \times GroupResponse\textsubscript{x,j}
\{x \in RESERVEGROUPS\}

D.17.3.4 Reserve Balance Constraint:
\sum_{x \in RESERVEGROUPS} EffectiveReserve\textsubscript{x} + DeficitReserve\textsubscript{c} \geq Risk\textsubscript{c}
\{c \in RESERVECLASSES\}
D.17.3.5 Zone Summation Constraint:
\[ \text{ZoneResponse}_{z,c} = \sum_{r \in \text{RAWRESERVE}^z} \text{Raw Reserve}_r \]
\[ \{ z, c \mid z \in \text{LOADZONES}, c \in \text{RESERVECLASSES} \} \]

D.17.3.6 Zone Response Constraint:
\[ \text{ZoneResponse}_{z,c} + \sum_{p \in \text{RESTRICTEDENERGYBIDS}} \text{CurtailedLoad}_p \leq \text{ZoneResponseMax}_z \]
\[ \{ z, c \mid z \in \text{LOADZONES}, c \in \text{RESERVECLASSES} \} \]

D.17.3.7 Interruptible Load Max Constraint
\[ \sum_{z \in \text{LOADZONES}} \text{ZoneResponse}_{z,c} \leq \text{ILProportionMax}_c \times \text{Risk}_c \]
\[ \{ c \in \text{RESERVECLASSES} \} \]

Note that Constraints D.17.3.6 and D.17.3.7 will limit the raw reserve.
D.17.4 Load Curtailment Restriction Constraints

D.17.4.1 Load Response System Wide Limit:

\[ \sum_{z \in \text{LOADZONES}} \text{ZoneResponse}_z + \sum_{p \in \text{RESTRICTEDENERGYBIDS}} \text{CurtailedLoad}_p \leq \text{SystemLoad ResponseMax} \]

\[ \{c \in \text{RESERVECLASSES}\} \]

D.17.4.2 Mixed Integer Program Based Load Curtailment and Reserve Constraints

D.17.4.2.1 Load Curtailment Constraint:

\[ \text{CurtailedLoad}_{p(r)} - \text{InfinitePositiveValue} \times \text{LoadEnergyReserveSelector}_{p(r)} \leq 0 \]

\[ \{r \in \text{DISPLOADRESERVEOFFERS}\} \]

D.17.4.2.2 Load Reserve Constraint:

\[ \text{RawReserve}_r - (1 - \text{LoadEnergyReserveSelector}_{p(r)}) \times \text{InfinitePositiveValue} \leq 0 \]

\[ \{r \in \text{DISPLOADRESERVEOFFERS}\} \]
D.18 REGULATION

D.18.1 Supply of Regulation

D.18.1.1 Regulation Block Constraint:

\[ \text{BlockMax}_{i,j} \leq \text{Regulation Block}_{i,j} \]

\{ j, l \mid j \in \text{REGULATION OFFERBLOCK} S_l, \text{where } l \in \text{REGULATION OFFERS} \}

D.18.1.2 Regulation Summation Constraint:

\[ \text{Regulation}_i = \sum_{j \in \text{REGULATION OFFERBLOCKS}, l} \text{Regulation Block}_{i,j} \]

\{ l \in \text{REGULATION OFFERS} \}

D.18.1.3 Mixed Integer Program Based Regulation Max Constraint:

\[ \text{Generation}_{g(t)} + \text{Regulation}_i - \text{ExcessRegGeneration}_i - \text{InfinitePriceSensitiveValue} e \times (1 - \text{Regulation Eligibility} ySwitch_i) \leq \text{Regulation Max}_{g(t)} \]

\{ l \in \text{REGULATION OFFERS} \}

D.18.1.4 Mixed Integer Program Based Regulation Min Constraint:

\[ \text{Generation}_{g(t)} - \text{Regulation}_i + \text{DeficitRegGeneration}_i + \text{InfinitePriceSensitiveValue} e \times (1 - \text{Regulation Eligibility} ySwitch_i) \geq \text{Regulation Min}_{g(t)} \]

\{ l \in \text{REGULATION OFFERS} \}

D.18.1.5 Mixed Integer Program Based Zero Regulation Constraint

\[ \text{Regulation}_i - \text{InfinitePriceSensitiveValue} e \times \text{Regulation Eligibility} ySwitch_i \leq 0 \]

\{ l \in \text{REGULATION OFFERS} \}

D.18.2 Matching of requirements and availability

D.18.2.1 Regulation Balance Constraint:

\[ \sum_{j \in \text{REGULATION OFFERS}} \text{Regulation}_j + \text{DeficitRegulation} \geq \text{Regulation Requirement} \]
D.19 **RAMPING**

D.19.1 Energy Ramping Constraints

D.19.1.1 Up Ramp Constraint:

\[
\text{Generation}_g - \text{ExcessUpRamp}_g \leq \text{GenerationEndMax}_g
\]

\[
\{ g \in \text{ENERGYOFFERS}, g \notin \text{INTERTIEENERGYOFFERS} \}
\]

D.19.1.2 Down Ramp Constraint:

\[
\text{Generation}_g + \text{ExcessDownRamp}_g \geq \text{GenerationEndMin}_g
\]

\[
\{ g \in \text{ENERGYOFFERS}, g \notin \text{INTERTIEENERGYOFFERS} \}
\]

D.19.2 Combined ramping, reserve and regulation constraints

D.19.2.1 Reserve Ramp Constraint:

\[
\text{RawReserve}_r + \text{ReserveResponseRatio}_r \times (\text{Generation}_{g(r)} - \text{ExpectedStartGeneration}_{g(r)}) - \text{ExcessResRamp}_r \leq \text{MaxResponse}_r
\]

\[
\{ r \in \text{GENRESERVEOFFERS}, \text{where ReserveResponsePeriod}_{c(r)} > \text{CombinedRampThreshold} \}
\]

D.19.2.2 Reserve Proportion Ramp Constraint:

\[
\text{RawReserve}_r + \text{ReserveResponseRatio}_r \times (\text{Generation}_{g(r)} - \text{ExpectedStartGeneration}_{g(r)}) - \text{ExcessResPropRamp}_r \leq \text{ReserveProportionCombined}_r \times \text{Generation}_{g(r)}
\]

\[
\{ r \in \text{GENRESERVEOFFERS}, \text{where ReserveResponsePeriod}_{c(r)} > \text{CombinedRampThreshold} \}
\]

D.19.2.3 Regulation Ramp Constraint:

\[
\text{Regulation}_l + \text{RegulationResponseRatio}_l \times (\text{Generation}_{g(l)} - \text{ExpectedStartGeneration}_{g(l)}) - \text{ExcessRegRamp}_l \leq \text{MaxResponse}_l
\]

\[
\{ l \in \text{REGULATIONOFFERS}, \text{where RegulationResponsePeriod} > \text{CombinedRampThreshold} \}
\]

D.19.3 Load Ramping Constraints

D.19.3.1 Up Ramp Constraint:

\[
\text{Purchase}_p - \text{ExcessUpRamp}_p \leq \text{PurchaseEndMax}_p
\]
D.19.3.2 Down Ramp Constraint:

\[ \text{Purchase}_p + \text{ExcessDownRamp}_p \geq \text{PurchaseEndMin}_p \]

\{p \in \text{RESTRICTEDENERGYBIDS}\}
D.20 **GENERIC AND MULTI-UNIT CONSTRAINTS**

D.20.1 Generic constraint

D.20.1.1 Generic Security Constraint:

\[
\sum_{k \in \text{SECURITYLINEGROUP}} \text{SecurityGroupLineWeight}_{s,k} \times \text{LineFlow}_k + \sum_{n \in \text{SECURITYNODEGROUP}} \text{SecurityGroupNodeWeight}_{s,n} \times \text{NodeNetInjection}_n + \sum_{g \in \text{SECURITYGENERATIONGROUP}} \text{SecurityGroupGenerationWeight}_{s,g} \times \text{Generation}_g + \text{DeficitSecurity}_s \geq \text{GenericSecurityLimit}_s \quad \{s \in \text{SECURITYCONSTRAINTS}\}
\]

D.20.2 Multi-unit Constraint

D.20.2.1 Multi-unit Constraint:

\[
\sum_{k \in \text{MULTIUNITCONSTRAINTSLINEGROUP}} \text{MultiGroupLineWeight}_{s,k} \times \text{LineFlow}_k + \text{DeficitMulti}_s - \text{ExcessMulti}_s = 0 \quad \{s \in \text{MULTIUNITCONSTRAINTS}\}
\]
D.20A TIE-BREAKING CONSTRAINTS

D.20A.1 Energy Tie-Breaking Constraint:

\[
\frac{\text{GenerationBlock}_{(x(o),j(o))}}{\text{GenerationBlockMax}_{(x(o),j(o))}} - \frac{\text{GenerationBlock}_{(x(o'),j(o'))}}{\text{GenerationBlockMax}_{(x(o'),j(o'))}} = \text{EnergyTieBreakSlack1}_o - \text{EnergyTieBreakSlack2}_o
\]

\(\{o \in \text{TIEDENERGYOFFERBLOCKPAIRS}\}\)

D.20A.2 Reserve Tie-Breaking Constraint:

\[
\frac{\text{RawReserveBlock}_{(r(o),j(o))}}{\text{RawReserveBlockMax}_{(r(o),j(o))}} - \frac{\text{RawReserveBlock}_{(r(o'),j(o'))}}{\text{RawReserveBlockMax}_{(r(o'),j(o'))}} = \text{ReserveTieBreakSlack1}_o - \text{ReserveTieBreakSlack2}_o
\]

\(\{o \in \text{TIEDRESERVEOFFERBLOCKPAIRS}\}\)

D.20A.3 Regulation Tie-Breaking Constraint:

\[
\frac{\text{RegulationBlock}_{(l(o),j(o))}}{\text{RegulationBlockMax}_{(l(o),j(o))}} - \frac{\text{RegulationBlock}_{(l(o'),j(o'))}}{\text{RegulationBlockMax}_{(l(o'),j(o'))}} = \text{RegulationTieBreakSlack1}_o - \text{RegulationTieBreakSlack2}_o
\]

\(\{o \in \text{TIEDREGULATIONOFFERBLOCKPAIRS}\}\)

D.20A.4 Tie-Breaking Penalty Constraint:

\[
\text{TieBreakingPenalties} = \text{TieBreakingPenaltyFactor} \times \sum_{o \in \text{TIEDENERGYOFFERBLOCKPAIRS}} (\text{EnergyTieBreakSlack1}_o + \text{EnergyTieBreakSlack2}_o) + \sum_{o \in \text{TIEDRESERVEOFFERBLOCKPAIRS}} (\text{ReserveTieBreakSlack1}_o + \text{ReserveTieBreakSlack2}_o) + \sum_{o \in \text{TIEDREGULATIONOFFERBLOCKPAIRS}} (\text{RegulationTieBreakSlack1}_o + \text{RegulationTieBreakSlack2}_o)
\]
D.21 Violation Group Constraints

D.21.1 Line Flow Constraint:
\[ \sum_{j \in \text{VIOLATION GROUP BLOCK} \cap \text{LINES}} \text{Violation Group Block}_{y(k),j} \geq \text{Excess Line Flow Forward}_k + \text{Excess Line Flow Reverse}_k + \text{Deficit W Line Flow}_k + \text{Excess W Line Flow}_k \]
\[ \forall k \in \text{LINES, } k \not\in \text{ARTIFICIAL LINES} \]

D.21.2 Line Flow Constraint (applies only to a re-run of the market clearing engine under section 10.2.3A.2 and section 10.2.5B of Chapter 6):
\[ \sum_{j \in \text{VIOLATION GROUP BLOCK} \cap \text{LINES}} \text{Violation Group Block}_{y(k),j} \geq \text{Deficit W Line Flow}_k + \text{Excess W Line Flow}_k \]
\[ \forall k \in \text{LINES, } k \not\in \text{ARTIFICIAL LINES} \]

D.21.3 Deficit Reserve Constraint:
\[ \sum_{j \in \text{VIOLATION GROUP BLOCK} \cap \text{RESERVES}} \text{Violation Group Block}_{y(c),j} \geq \text{Deficit Reserve}_c \]
\[ \forall c \in \text{RESERVE CLASSES} \]

D.21.3.1 Reserve Violation Group Block Constraint 1:
\[ \text{Violation Group Block}_{y(c),1} \leq \text{Violation Group Proportion}_c \times \text{Risk}_c \]
\[ \forall c \in \text{RESERVE CLASSES} \]

D.21.3.2 Reserve Violation Group Block Constraint 2:
\[ \text{Violation Group Block}_{y(c),1} + \text{Violation Group Block}_{y(c),2} \leq \text{Risk}_c - \text{Minimum Risk}_c \]
\[ \forall c \in \text{RESERVE CLASSES} \]

D.21.4 Deficit Regulation Constraint:
\[ \sum_{j \in \text{VIOLATION GROUP BLOCK} \cap \text{REGULATIONS}} \text{Violation Group Block}_{y(\text{regulation}),j} \geq \text{Deficit Regulation} \]

D.21.4.1 Regulation Violation Group Block Constraint 1:
\[ \text{Violation Group Block}_{y(\text{regulation}),1} \leq \text{Regulation Requirement} - \text{Minimum Regulation} \]
Explanatory Note: There are three tranches of ViolationGroupBlock for deficit reserve and two tranches of ViolationGroupBlock for deficit regulation. The quantities within each ViolationGroupBlock are determined by constraints described in sections D.21.3.1 and D.21.3.2 (for reserve) and in section D.21.4.1 (for regulation). The ViolationGroupBlockPenalty corresponding to each ViolationGroupBlock is specified in section J.3 of Appendix 6J.

D.21.5 Facility Constraint:

\[
\sum_{j \in \text{VIOLATIONGROUPBLOCK} \cap \text{FAC}_{og}} \text{ViolationGroupBlock}_{r(g)/j} \geq \text{FacilityReserveViolation}_g
\]

+ FacilityRegulationViolation$_g$ + FacilityRampViolation$_g$

+ FacilityMultiUnitViolation$_g$ + FacilityLineFlowViolation$_g$

+ FacilityMSLViolation$_g$

\[
\left\{g \in \text{ENERGYOFFERS}\right\}
\]

D.21.5.1 Facility Reserve Constraint:

FacilityReserveViolation$_g$ = \[
\sum_{c \in \text{RESERVECLASSES}} \text{ExcessRawReserve}_{r(g,c)}
\]

+ \[
\sum_{c \in \text{RESERVECLASSES}} \text{ExcessResGen}_{r(g,c)}
\]

+ \[
\sum_{c \in \text{RESERVECLASSES}} \text{ExcessResGenSegment1}_{r(g,c)}
\]

+ \[
\sum_{c \in \text{RESERVECLASSES}} \text{ExcessResGenSegment2}_{r(g,c)}
\]

+ \[
\sum_{c \in \text{RESERVECLASSES}} \text{ExcessResGenSegment3}_{r(g,c)}
\]

+ \[
\sum_{c \in \text{RESERVECLASSES}} \text{ExcessResRamp}_{r(g,c)} + \sum_{c \in \text{RESERVECLASSES}} \text{ExcessResPropRamp}_{r(g,c)}
\]

\[
\left\{g \in \text{ENERGYOFFERS}\right\}
\]

D.21.5.2 Facility Regulation Constraint:

FacilityRegulationViolation$_g$ = \[
\text{ExcessRegGen}_{l(g)}
\]

+ DeficitRegGen$_l(g)$ + ExcessRegRamp$_l(g)$

\[
\left\{g \in \text{ENERGYOFFERS}\right\}
\]
D.21.5.3 Facility Ramp Rate Constraint:
FacilityRampViolation_g = ExcessUpRamp_g + ExcessDownRamp_g
\[ \{ g \in ENERGYOFFERS, g \notin INTERTIENERGYOFFERS \} \]

D.21.5.4 Facility Multi-unit Constraint:
FacilityMultiUnitViolation_g = \sum_{s \in MULTIUNITCONSTRAINTS} DeficitMulti_s(g) + \sum_{s \in MULTIUNITCONSTRAINTS} ExcessMulti_s(g)
\[ \{ g \in ENERGYOFFERS \} \]

D.21.5.5 Facility Connection Line Flow Constraint:
FacilityLineFlowViolation_g = \sum_{k_1 \in ARTIFICIALLINES1} ExcessLineFlowForward_{k_1(g)} + \sum_{k_2 \in ARTIFICIALLINES2} ExcessLineFlowReverse_{k_2(g)}
+ \sum_{k_2 \in ARTIFICIALLINES2} DeficitWLineFlow_{k_2(g)} + \sum_{k_2 \in ARTIFICIALLINES2} ExcessWLineFlow_{k_2(g)}
\[ \{ g \in ENERGYOFFERS \} \]

D.21.5.6 Facility Minimum Stable Load Constraint:
FacilityMinimumStableLoadViolation_g = DeficitMinimumStableLoad_g + ExcessMinimumStableLoad_g
\[ \{ g \in ENERGYOFFERS, for which MinimumStableLoad_g > 0 \} \]

D.21.5A LRF with REB Facility Constraint:
\[ \sum_{j \in VIOLATIONGROUPBLOCKS} \text{ViolationGroupBlock}_{j(p)} \geq FacilityRampViolation_{(p)} \]
\[ \{ p \in RESTRICTEDENERGYBIDS \} \]

D.21.5A.1 LRF with REB Facility Ramp Constraint:
FacilityRampViolation_p = ExcessUpRamp_p + ExcessDownRamp_p
\[ \{ p \in RESTRICTEDENERGYBIDS \} \]
D.21.6 Deficit Security Constraint:
\[
\sum_{j \in \text{VIOLATIONGROUPBLOCKS}} \text{ViolationGroupBlock}_{y,s}^{j} \geq \text{DeficitSecurity}_{s}, \quad \{s \in \text{SECURITYCONSTRAINTS}\}
\]

D.21.7 Violation Group Block Constraint:
\[
\text{ViolationGroupBlock}_{y,j} \leq \text{ViolationGroupBlockM}_{y,j} \times x_{y,j}
\]
\[
\{j,y| j \in \text{VIOLATIONGROUPBLOCKS} , y \in \text{VIOLATIONGROUPs}\}
\]

D.21.8 Violation Penalties Constraint:
\[
\text{ViolationPenalties} \geq \sum_{y \in \text{VIOLATIONGROUPS}} \left( \sum_{j \in \text{VIOLATIONGROUPBLOCKS}} (\text{ViolationGroupBlockPenalty}_{y,j} \times \text{ViolationGroupBlock}_{y,j}) \right)
\]
SECTION D: POST-PROCESSING

D.22 LOSS CALCULATION CORRECTION

D.22.1 The EMC shall set and publish the following values:

D.22.1.1 the system loss error tolerance; and

D.22.1.2 the maximum number of times the equations in section C (“the linear program”) may be solved for the purpose of loss calculation correction under section D.22 for any given dispatch period in any given run of the market clearing engine.

The EMC may update and re-publish these values as required.

D.22.2 After each solution of the linear program, the EMC shall carry out the procedures in sections D.22.3 to D.22.7 to the extent provided in those sections. However, the EMC shall not do so if any of the line violation variables, ExcessLineFlowForward\(_k\), ExcessLineFlowReverse\(_k\), DeficitWLineFlow\(_k\) or ExcessWLineFlow\(_k\), for any dispatch network line \(k\) is greater than zero.

D.22.3 Subject to section D.22.2, if the following condition:

\[
\text{Weight}_{k,j} = 0 \text{ or } \text{Weight}_{k,i} = 0
\]

\[\{k, j, i | j, i \in \text{DISCRSUB}_k, \text{where } k \in \text{LINES}, i > j + 1\} ,\]

is false for any pair of non-adjacent line flow/line loss points \(i\) and \(j\) on any dispatch network line \(k\), section D.22.4 shall apply. Otherwise, the EMC may accept the current solution of the linear program.
D.22.4 Subject to section D.22.3, the total erroneous losses in the solution of the linear program, SysError, shall be calculated and checked as follows:

\[ \text{SysError} = \sum_k \text{CircuitErr}_k \]

where:

\[ \text{CircuitErr}_k = \text{LineLoss}_k - \text{ActualLoss}_k \]

\[ \text{ActualLoss}_k = \text{LineLossConst}_{k,i} \]

\[ \frac{\text{LineFlow}_k - \text{LineFlowConst}_{k,i}}{\text{LineFlowConst}_{k,i+1} - \text{LineFlowConst}_{k,i}} \times (\text{LineLossConst}_{k,i+1} - \text{LineLossConst}_{k,i}) \]

\[ \left\{ \begin{array}{l} i,k | i \in \text{DISCRSUB}_k, \text{where } k \in \text{LINES}, \\ i = \text{Max} \left\{ j \right| j < N(\text{DISCRSUB}_k), \text{LineFlowCo}_{nst,k,i} \leq \text{LineFlow}_k \} \end{array} \right\} \]

If SysError is less than the system loss error tolerance established by the EMC under section D.22.1.1, the EMC may accept the current solution of the linear program. Otherwise, section D.22.5 shall apply.

D.22.5 Subject to section D.22.4, if the number of times the linear program has been solved for the purpose of loss calculation correction for a given dispatch period in a given run of the market clearing engine:

D.22.5.1 is equal to the maximum number established by the EMC under section D.22.1.2, and that run of the market clearing engine is to produce:

a. a real-time dispatch schedule, the EMC may halt the process of loss calculation correction and the provisions of section 9.1.2.2 of Chapter 5 and section 9.3.2B of Chapter 6 shall apply; or

b. a short-term schedule, pre-dispatch schedule or market outlook scenario, the EMC may accept the current solution of the linear program; or

D.22.5.2 is less than the maximum number established by the EMC under section D.22.1.2, sections D.22.6 and D.22.7 shall apply.
D.22.6 Subject to section D22.5, for each dispatch network line \( k \), the ordered set of line flow/line loss points in set \( \text{DISCRSUB}_k \) shall be adjusted according to sections D.22.6.1 and D.22.6.2.

D.22.6.1 Line flow/line loss point \( i \) shall be identified such that:
\[
\{ i \mid i \in \text{DISCRSUB}_k, \text{where } k \in \text{LINES}, i = \max (j \mid \text{LineFlowCo}_{nst,k,j} < \text{LineFlow}_{nst,k} + \text{SysError}) \}
\]

If there is no line flow/line loss point \( j \in \text{DISCRSUB}_k \) where \( j > i \), no adjustment shall be made. Otherwise, all line flow/line loss points \( j \in \text{DISCRSUB}_k \) where \( j > i \) shall be discarded and a new line flow/line loss point with line loss and line flow given by \( \text{LineLossConst}'_{k,i+1} \) and \( \text{LineFlowConst}'_{k,i+1} \) shall be defined:

\[
\text{LineFlowCo}_{nst,k,j+1} = \text{LineFlow}_{nst,k} + \text{SysError}
\]
\[
\text{LineLossCo}_{nst,k,j+1} = \text{LineLossCo}_{nst,k,j} + \frac{(\text{LineFlow}_{nst,k} + \text{SysError}) - \text{LineFlowCo}_{nst,k,i}}{\text{LineFlowCo}_{nst,k,i+1} - \text{LineFlowCo}_{nst,k,i}} \\
\times (\text{LineLossCo}_{nst,k,j+1} - \text{LineLossCo}_{nst,k,j})
\]

D.22.6.2 Line flow/line loss point \( i \) shall be identified such that:
\[
\{ i \mid i \in \text{DISCRSUB}_k, \text{where } k \in \text{LINES}, i = \min (j \mid \text{LineFlowCo}_{nst,k,j} > \text{LineFlow}_{nst,k} - \text{SysError}) \}
\]

If there is no line flow/line loss point \( j \in \text{DISCRSUB}_k \) where \( j < i \), no adjustment shall be made. Otherwise, all line flow/line loss points \( j \in \text{DISCRSUB}_k \) where \( j < i \) shall be discarded and a new line flow/line loss point with line loss and line flow given by \( \text{LineLossConst}'_{k,i-1} \) and \( \text{LineFlowConst}'_{k,i-1} \) shall be defined:

\[
\text{LineFlowCo}_{nst,k,i-1} = \text{LineFlow}_{nst,k} - \text{SysError}
\]
\[
\text{LineLossCo}_{nst,k,i-1} = \text{LineLossCo}_{nst,k,i} + \frac{(\text{LineFlow}_{nst,k} - \text{SysError}) - \text{LineFlowCo}_{nst,k,i}}{\text{LineFlowCo}_{nst,k,i-1} - \text{LineFlowCo}_{nst,k,i}} \\
\times (\text{LineLossCo}_{nst,k,i-1} - \text{LineLossCo}_{nst,k,i})
\]

D.22.7 The re-defined set of line flow/line loss points determined in section D.22.6 for each dispatch network line shall be used to re-solve the linear program for the given dispatch period in the given run of the market clearing engine.
D.22A COUNTERFACTUAL SOLVE WITH EXCLUSION OF RESTRICTED ENERGY BIDS SUBMITTED FOR LRFs WITH REB

D.22A.1 After each solution of the linear program for a dispatch period that involves at least one restricted energy bid, the EMC shall carry out the procedures in D.22A.2 to determine the counterfactual solution for that dispatch period.

D.22A.2 If the following condition:

$$\sum_{p \in \text{RESTRICTEDENERGYBIDS}} \text{CurtailedLoad}_p > 0$$

is true, then the linear program shall be re-solved with a revised bid price for the restricted energy bids of all LRFs with REB held by the EMC for the dispatch period as referred to in section 9.2.2.1 of Chapter 6. Such revised bid price shall be the value of $10 \times \text{VoLL}$, with the VoLL value as specified in section J.2 of Appendix 6J.

D.22A.3 The solution arising from the procedures described in this section shall only be used to derive the counterfactual uniform Singapore energy price referred to in sections D.24.8 and D.24.9.
D.23 **QUANTITY FORMATION**

D.23.1 *Energy* quantities scheduled from each *generation registered facility* are given by the values of the `Generation_g` variables.

D.23.2 *Reserve* quantities in each *reserve class* scheduled from each *reserve provider* are given by the values of the `RawReserve_r` variables.

D.23.3 *Regulation* quantities scheduled from each *regulation provider* are given by the values of the `Regulation_l` variables.

D.23.4 *Energy* quantities scheduled for *import to Singapore* across the *interties* are given by the values of the `Generation_g` for the *interie dispatch network nodes*. *Energy* quantities scheduled for *export from Singapore* across the *interties* are given by the values of the `Purchase_p` variables for the *interie dispatch network nodes*.

D.23.5 For the purposes of calculating the *load curtailment quantity* and *load curtailment price* as described in Appendix 6L, the reference energy withdrawal level for each *LRF with REB* associated with *restricted energy bid* `p` shall be calculated as follows:

\[
\text{ReferenceEnergyWithdrawal}_p = \text{Purchase}_p + \text{NonDispLoad}_p
\]

\[
\{p \in \text{RESTRICTEDENERGYBIDS}\}
\]

where:

\[
\text{NonDispLoad}_p = \text{TotalLoad}_p - \sum_{j \in \text{PURCHASEBIDBLOCKS}} \text{PurchaseBlockMax}_{p,j}
\]

`TotalLoad_p` is the total *load capacity* of a given *load registered facility* associated with *restricted energy bid* `p`, as stated in such *restricted energy bid* `p` and as referred to in section 5.2A.2.4 of Chapter 6.
D.24 **PRICE FORMATION**

D.24.1 The *market energy price* or MEP for each *market network node* shall be calculated as follows:

D.24.1.1 For *generation registered facilities* that are not *multi-unit facilities*, and for *generation settlement facilities* that are not *pseudo generation settlement facilities*, represented as *synchronised* in the *dispatch network data* or connected to the dispatch network in accordance with section D.6.5 in the *dispatch period*, the *market energy price* shall be calculated as follows:

\[
\text{MEP}^m(g) = \text{EnergyPrice}_{n(m)}
\]

where:

\[
\text{EnergyPrice}_{n(m)} \text{ is the dual variable corresponding to constraint D.16.1.2 for the dispatch network node } n \text{ corresponding to the market network node } m
\]

The price MEP\(^m\) shall then be further modified in accordance with section D.24.5.

D.24.1.2 For *generation registered facilities* that are *multi-unit facilities* represented as *synchronised* in the *dispatch network data* or connected to the dispatch network in accordance with section D.6.5 in the *dispatch period*, the *market energy prices* shall be calculated as follows:

\[
\text{MEP}^m(g) = \frac{\sum_{u \in \text{CONNECTEDINITS}} (\text{Proportion}_u \times \text{EnergyPrice}_{n(u)})}{\sum_{u \in \text{CONNECTEDINITS}} \text{Proportion}_u}
\]

where:

\[
\text{Proportion}_u \text{ is the relevant proportion of generation for generating unit } u \text{ of a multi-unit facility associated with energy offer } g \text{ specified by the EMC in accordance with section D.7.3;}
\]

\[
\text{EnergyPrice}_{n(u)} \text{ is the dual variable corresponding to constraint D.16.1.2 for the dispatch network node } n \text{ corresponding to the market network node } m; \text{ and}
\]

The price MEP\(^m\) shall then be further modified in accordance with section D.24.5.
D.24.1.3 For pseudo generation settlement facilities, the market energy price shall be calculated as follows:

\[ \text{MEP}^{m(g)} = \frac{\sum_{g \in \text{ENERGYOFFRES}} (\text{Generation}_g \times \text{MEP}^{m(g)})}{\sum_{g \in \text{ENERGYOFFRES}} \text{Generation}_g} \]

where:

\( \text{MEP}^{m(g)} \) is the market energy price for market network node \( m \) corresponding to the generation registered facility that energy offer \( g \) is for calculated in sections D.24.1.1 or D.24.1.2 after it has been modified in accordance with section D.24.5.

D.24.2 Nodal spot prices for dispatch network nodes or NSP \( n \) shall be calculated from the values of \( \text{EnergyPrice}_n \), the dual variables corresponding to constraint D.16.1.2 for the relevant dispatch network node, and then further modified in accordance with section D.24.5.

D.24.3 Reserve prices for each reserve class shall be calculated from the values of \( \text{ReservePrice}_c \), the dual variables corresponding to constraint D.17.3.4, and then further modified in accordance with section D.24.5.

D.24.4 The market regulation price or MFP shall be calculated from the values of \( \text{RegulationPrice} \), the dual variable corresponding to constraint D.18.2.1, and then further modified in accordance with section D.24.5.

D.24.5 The market clearing engine shall produce the following modified prices corresponding to the prices referred to in sections D.24.1 to D.24.4 for each dispatch period:

D.24.5.1 if the price referred to any of sections D.24.1 to D.24.4 is between the applicable upper and lower limits specified in Appendix 6J section J.1, then the modified price shall equal that price;

D.24.5.2 if the price referred to any of sections D.24.1 to D.24.4 exceeds the applicable upper limit specified in Appendix 6J section J.1, then the modified price shall be set to that upper limit; and

D.24.5.3 if the price referred to any of sections D.24.1 to D.24.4 is below the applicable lower limit specified in Appendix 6J section J.1, then the modified price shall be set to that lower limit.
D.24.6 The *market clearing engine* shall, for each *dispatch period*, determine the *uniform Singapore energy price* for the *settlement interval* corresponding to that *dispatch period* in accordance with the following formula:

\[
\text{USEP} = \frac{\sum_n (W^n \times \text{NSP}^n)}{\sum_n W^n}
\]

where:

\[
\{n|n \in \text{NODES}\}
\]

\[
W^n = \sum_{p\in\text{ENERGYBIDS}} \text{Purchase}_{p} - \sum_{j} \text{DeficitGenerationBlock}_{n,j}
\]

\[
\text{NSP}^n = \text{the nodal spot price for } DNN \ n \text{ referred to in section D.24.2 after it has been modified in accordance with section D.24.5.}
\]

D.24.7 The *market clearing engine* shall, for each *dispatch period*, determine the *market reserve price* or \( MR_P_x \) for each *reserve provider group* \( x \), in accordance with the following formula:

\[
MR_P_x = \text{ReservePrice}_c \times \text{Effectiveness}_{x,j}
\]

where:

\[
\{x|x \in \text{RESERVEGROUPS}_c\}
\]

\(\text{ReservePrice}_c = \text{the reserve class price referred to in section D.24.3 after it has been modified in accordance with section D.24.5.}\)

\(\text{Effectiveness}_{x,j} = \text{the effectiveness multiplier of raw reserve in block } j \text{ of reserve provider group } x, \text{ where:}\)

\(j \text{ is the last effectiveness block in }\)

\(\text{RESERVEGROUPBLOCKS}_x \text{ for which }\)

\(\text{GroupResponse}_{x,j} > 0\)

or \(j = 1 \text{ if } \text{GroupResponse}_{x,j} = 0 \text{ for all effectiveness blocks in }\)

\(\text{RESERVEGROUPBLOCKS}_x.\)
Explanatory Note: Reserve effectiveness describes the contribution that reserve scheduled for each reserve provider group makes to the reserve requirement for the relevant reserve class, and could include reliability of response as well as the profile of reserve response. There are several tranches of effectiveness specified by the PSO (see Section G.5.3 of Appendix 6G) with the effectiveness declining with increasing reserve supplied from a reserve provider group. The price for each reserve provider group is the reserve class price modified by the marginal effectiveness from the reserve provider group – i.e. the effectiveness corresponding to the last piece-wise linear tranche from which reserve has been scheduled from that reserve provider group, or by the effectiveness corresponding to the first piece-wise linear tranche for that reserve provider group if no reserve is scheduled from that reserve provider group.

D.24.8 The market clearing engine shall, for each dispatch period for which the linear program was re-solved pursuant to section D.22A, determine the counterfactual uniform Singapore energy price, or CUSEP, for the settlement interval corresponding to that dispatch period in accordance with the formula in section D.24.6, subject to section D.24.9.

D.24.9 If, for any settlement interval,

D.24.9.1 CUSEPₜₜ = USEPₜₜ = 0.9×VoLL; and
D.24.9.2 shortfalls in energy were scheduled in the counterfactual solution referred to in D.22A for the corresponding dispatch period,

then the value of CUSEPₜₜ shall be further modified and set to 1×VoLL.

Explanatory Note: The CUSEP is modified in an energy shortfall situation to better reflect the value of dispatchable load that was voluntarily curtailed by LRFs with REB.

D.24.10 The load curtailment price, or LCP, for each dispatch period shall be calculated in accordance with section L.4 of Appendix 6L.
D.25 ADDITIONAL OUTPUTS

D.25.1 The market clearing engine shall, at a minimum, produce the following information for each dispatch period:

D.25.1.1 the total load scheduled to be supplied at each dispatch network node:

\[ \text{Purchase}_p \quad \{p \in \text{ENERGYBIDS}\} \]

and in aggregate:

\[ \sum_{p \in \text{ENERGYBIDS}} \text{Purchase}_p \]

expressed in MW;

D.25.1.2 the total generation scheduled at each generation registered facility:

\[ \text{Generation}_g \quad \{g \in \text{ENERGYOFFERS}\} \]

and in aggregate,

\[ \sum_{g \in \text{ENERGYOFFERS}} \text{Generation}_g \]

expressed in MW;

D.25.1.2A the total energy scheduled to be withdrawn for each restricted energy bid associated with an LRF with REB:

\[ \text{Purchase}_p \quad \{p \in \text{RESTRICTEDENERGYBIDS}\} \]

expressed in MW;

D.25.1.2B the load curtailment in respect of each LRF with REB:

\[ \text{CurtailedLoad}_p \quad \{p \in \text{RESTRICTEDENERGYBIDS}\} \]

and the total load curtailment in respect of all LRFs with REB:

\[ \sum_{p \in \text{RESTRICTEDENERGYBIDS}} \text{CurtailedLoad}_p \]

each expressed in MW;
D.25.1.2C the total transmission losses in the system:

$$\sum_{k \in \text{LINES}} \text{LineLoss}_k$$

expressed in MW;

D.25.1.3 the extent of any shortfall in energy, by dispatch network node:

$$\sum_{(j \in \text{DEFICITGENERATIONBLOCKS}, n \in \text{NODES})} \text{DeficitGen} \text{eration Blo ck}_{n,j}$$

and in aggregate,

$$\sum_{(j \in \text{DEFICITGENERATIONBLOCKS}, n \in \text{NODES})} \text{DeficitGen} \text{eration Blo ck}_{n,j}$$

expressed in MW;

D.25.1.4 the extent of any surplus in energy, by dispatch network node:

$$\sum_{(j \in \text{EXCESSGENERATIONBLOCKS}, n \in \text{NODES})} \text{ExcessGen} \text{eration Bloc k}_{n,j}$$

and in aggregate,

$$\sum_{(j \in \text{EXCESSGENERATIONBLOCKS}, n \in \text{NODES})} \text{ExcessGen} \text{eration Bloc k}_{n,j}$$

expressed in MW;

D.25.1.4A total reserve requirement by reserve class:

$$\text{Risk}_c$$

expressed in MW;

D.25.1.5 total reserve scheduled to supply each reserve class, from each reserve provider group:

$$\text{EffectiveReserve}_x$$

and in aggregate,

$$\sum_{x \in \text{RESERVEGROUPS}, c \in \text{RESERVECLASSSES}} \text{EffectiveReserve}_x$$
expressed in MW;

D.25.1.6 the extent of any shortfall in reserve, by reserve class:
DeficitReserve
\[ \{c \in \text{RESERVECLASSES}\} \]
expressed in MW;

D.25.1.6A total regulation requirement:
RegulationRequirement expressed in MW;

D.25.1.7 total regulation scheduled:
\[ \sum_{l \in \text{REGULATIONOFFERS}} \text{Regulation}_l \]
expressed in MW;

D.25.1.8 the extent of any shortfall in regulation:
DeficitRegulation expressed in MW;

D.25.1.9 predicted power flows on dispatch network lines
LineFlow \[ \{k \in \text{LINES}\} \]
and energy losses on dispatch network lines
LineLoss \[ \{k \in \text{LINES}\} \]
expressed in MW;

D.25.1.10 a list of security constraints and generation fixing constraints applied, which is the set SECURITYCONSTRAINTS;

D.25.1.11 details of the extent of any constraint violations
\[ \sum_{j \in \text{VIOLATIONGROUPBLOCKS} \cap \text{SEC}_{ij}} \text{ViolationGroupBlock}_{y(s)j} \]
\[ \{y \in \text{VIOLATIONGROUPS}\} \]

D.25.1.12 the value, in dollars, of the objective function value NetBenefit specified in section D.14; and
D.25.1.13 the estimated hourly energy uplift rebate (HEUR) in accordance with the following formula:

Estimated HEUR =

\[
\frac{\sum_{p \in \text{ENERGYOFF}} \left( \text{MEP}^{\text{OFF}} \times \text{Generation}_p \times \frac{1}{2} \right) - \left( \sum_{p \in \text{ENERGYOFF}} \text{USEP} \times \sum_{p \in \text{INTERTIEENERGYBIDS}} \text{Purchase}_p \times \frac{1}{2} \right)}{\sum_{p \in \text{INTERIEENERGYBIDS}} \text{Purchase}_p \times \frac{1}{2}}
\]

Explanatory Note: The estimated hourly energy uplift rebate produced by the market clearing engine for each dispatch period is meant only to serve as an indicative figure of the hourly energy uplift rebate and will not be used for settlement.