SECTION C: LINEAR PROGRAM

D.14 OBJECTIVE FUNCTION

D.14.1 The NetBenefit is maximised, where:

$$
\begin{aligned}
\text{NetBenefit} = & \sum_{\substack{\{j,p|j\in \text{PURCHASEBIDBLOCKS}_p,\\ \text{where } p\in \text{ENERGYBIDS}\}}} \text{PurchaseBidPrice}_{p,j} \times \text{PurchaseBlock}_{p,j} \\
& - \sum_{\substack{\{j,g|j\in \text{GENERATIONOFFERBLOCKS}_g,\\ \text{where } g\in \text{OFFERS}\}}} \text{GenerationOfferPrice}_{g,j} \times \text{GenerationBlock}_{g,j} \\
& - \sum_{\substack{\{j,es|j\in \text{ENERGYSTORAGEOFFERBLOCKS}_{es},\\ \text{where } es\in \text{ENERGYSTORAGEOFFERS}\}}} \text{EnergyStorageOfferPrice}_{es,j} \times \text{EnergyStorageBlock}_{es,j} \\
& - \sum_{\substack{\{j,r|j\in \text{RAWRESERVEBLOCKS}_r,\\ \text{where } r\in \text{RAWRESERVEOFFERS}\}}} \text{ReserveOfferPrice}_{r,j} \times \text{RawReserveBlock}_{r,j} \\
& - \sum_{\substack{\{j,l|j\in \text{REGULATIONOFFERBLOCKS}_l,\\ \text{where } l\in \text{REGULATIONOFFERS}\}}} \text{RegulationOfferPrice}_{l,j} \times \text{RegulationBlock}_{l,j} \\
& - \sum_{\substack{\{j,n|j\in \text{EXCESSGENERATIONBLOCKS}_n,\\ \text{where } n\in \text{NODES}\}}} \text{ExcessGenerationPenalty}_{n,j} \times \text{ExcessGenerationBlock}_{n,j} \\
& - \sum_{\substack{\{j,n|j\in \text{DEFICITGENERATIONBLOCKS}_n,\\ \text{where } n\in \text{NODES}\}}} \text{DeficitGenerationPenalty}_{n,j} \times \text{DeficitGenerationBlock}_{n,j} \\
& - \text{ViolationPenalties} \\
& - \text{TieBreakingPenalties}
\end{aligned}
$$

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:

$$\text{GenerationBlock}_{g,j} \leq \text{GenerationBlockMax}_{g,j}$$

$\{j,g \mid j \in \text{GENERATIONOFFERBLOCKS}_g, \text{ where } g \in \text{ENERGYOFFERS}\}$

D.15.1.2 Generation Summation Constraint:

$$\text{Generation}_g = \sum_{j \in \text{GENERATIONOFFERBLOCKS}_g} \text{GenerationBlock}_{g,j}$$

$\{g \in \text{ENERGYOFFERS}\}$

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

D.15.1.3.1 Minimum Stable Load Decommitment Constraint:

$$\text{Generation}_g - \text{InfinitePositiveValue} \times \text{MSLSelector}_g - \text{ExcessMSL}_g \leq 0$$

$\{g \in \text{ENERGYOFFERS}, \text{ for which MinimumStableLoad}_g > 0\}$

D.15.1.3.2 Minimum Stable Load Commitment Constraint:

$$\text{Generation}_g - \text{MSLSelector}_g \times \text{MinimumStableLoad}_g + \text{DeficitMSL}_g \geq 0$$

$\{g \in \text{ENERGYOFFERS}, \text{ for which MinimumStableLoad}_g > 0\}$

D.15.2 Purchase Constraints

D.15.2.1 Purchase Block Constraint:

$$\text{PurchaseBlock}_{p,j} \leq \text{PurchaseBlockMax}_{p,j}$$

$\{j,p \mid j \in \text{PURCHASEBIDBLOCKS}_p, \text{ where } p \in \text{ENERGYBIDS}\}$

D.15.2.2 Purchase Summation Constraint:

$$\text{Purchase}_p = \sum_{j \in \text{PURCHASEBIDBLOCKS}_p} \text{PurchaseBlock}_{p,j}$$

$\{p \in \text{ENERGYBIDS}\}$

D.15.2.3 Total Purchase Calculation:

$$\text{TotalPurchase} = \sum_{\substack{p \in \text{ENERGYBIDS} \\ p \notin \text{INTERTIEENERGYBIDS}}} \text{Purchase}_p$$

D.15.3 LRF with REB Constraints

D.15.3.1 LRF Nodal Purchase Limit Constraint:

$$\text{Purchase}_{p,n} \leq \text{Proportion}_{p,n} \times \sum_{j \in \text{PURCHASEBIDBLOCKS}_p} \text{PurchaseBlockMax}_{p,j}$$

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

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:

$$\text{CurtailedLoad}_p = \text{Min}\left(\begin{array}{l}\text{PurchaseEndMax}_p, \\ \sum_{j \in \text{PURCHASEBIDBLOCKS}_p} \text{PurchaseBlockMax}_{p,j}\end{array}\right) - \text{Purchase}_p$$

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

D.15.4 Energy Storage Constraints

D.15.4.1 Energy Storage Block Constraint for Discharging:

$$0 \leq \text{EnergyStorageBlock}_{es,j} \leq \text{EnergyStorageBlockLimit}_{es,j}$$

$\{j, es \mid j \in \text{ENERGYSTORAGEOFFERBLOCKS}_{es}$ where $\text{EnergyStorageBlockLimit}_{es,j} \geq 0\}$

D.15.4.2 Energy Storage Block Constraint for Charging:

$$\text{EnergyStorageBlockLimit}_{es,j} \leq \text{EnergyStorageBlock}_{es,j} \leq 0$$

$\{j, es \mid j \in \text{ENERGYSTORAGEOFFERBLOCKS}_{es}$ where $\text{EnergyStorageBlockLimit}_{es,j} < 0\}$

D.15.4.3 Energy Storage Discharging Constraint:

$$\mathrm{EnergyStorageDischarging}_{es} = \sum_{\substack{j \in ENERGYSTORAGEOFFERBLOCKS_{es} | \\ EnergyStorageBlockLimit_{es,j} \geq 0}} \mathrm{EnergyStorageBlock}_{es,j}$$

$\{es \in \text{ENERGYSTORAGEOFFERS}\}$

D.15.4.4 Energy Storage Charging Constraint:

$$\mathrm{EnergyStorageCharging}_{es} = \sum_{\substack{j \in ENERGYSTORAGEOFFERBLOCKS_{es} | \\ EnergyStorageBlockLimit_{es,j} < 0}} \mathrm{EnergyStorageBlock}_{es,j}$$

$\{es \in \text{ENERGYSTORAGEOFFERS}\}$

D.15.4.5 Energy Storage Summation Constraint:

$$\mathrm{EnergyStorageTransfer}_{es} = \mathrm{EnergyStorageDischarging}_{es} - \mathrm{EnergyStorageCharging}_{es}$$

$\{es \in \text{ENERGYSTORAGEOFFERS}\}$

D.16 TRANSMISSION

D.16.1 Node Balance

D.16.1.1 Node Balance Flow Constraint:

$$\text{NodeNetInjection}_n = \sum_{\{k \in \text{LINES} \mid NodeAtStartOf(k)=n\}} \text{LineFlow}_k - \sum_{\{k \in \text{LINES} \mid NodeAtEndOf(k)=n\}} \text{LineFlow}_k + \tfrac{1}{2} \times \sum_{\substack{k \in \text{LINES}_n, \\ k \notin \text{ARTIFICIAL LINES1} \\ k \notin \text{ARTIFICIAL LINES3}}} \text{LineLoss}_k$$

$\{n \in \text{NODES}\}$

D.16.1.2 Node Balance Generation Constraint:

$$\begin{aligned} &\text{NodeNetInjection}_n \\ &= \sum_{g \in \text{ENERGYOFFERS}_n} \text{Generation}_g \\ &+ \sum_{es \in \text{ENERGYSTORAGEOFFERS}_n} \text{EnergyStorageTransfer}_{es} \\ &- \sum_{p \in \text{ENERGYBIDS}_n} \text{Purchase}_p \\ &- \sum_{p \in \text{RESTRICTEDENERGYBIDS}_n} \text{Purchase}_{p,n} \\ &+ \sum_{j \in \text{DEFICITGENERATIONBLOCKS}_n} \text{DeficitGenerationBlock}_{n,j} \\ &- \sum_{j \in \text{EXCESSGENERATIONBLOCKS}_n} \text{ExcessGenerationBlock}_{n,j} \end{aligned}$$

$\{n \in \text{NODES}\}$

~~D.16.1.4~~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.16.1.5~~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:

$$\text{LineMaxReverse}_k \leq \text{LineFlow}_k + \text{ExcessLineFlowReverse}_k$$

$$\{k \in \text{LINES}, k \notin \text{ARTIFICIALLINES1} \cup \text{ARTIFICIALLINES3}\}$$

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:

$$\text{LineFlow}_k = \text{LineAdmittance}_k \times (\text{NodeAngle}_{NodeAtStartOf(k)} - \text{NodeAngle}_{NodeAtEndOf(k)} + \text{PhaseAngleShift}_k)$$

$$\{k \in \text{LINES}, k \notin \text{ARTIFICIALLINES1} \cup \text{ARTIFICIALLINES3}\}$$

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:

$$0 = (\text{NodeAngle}_{NodeAtStartOf(k)} - \text{NodeAngle}_{NodeAtEndOf(k)})$$

$$\{k \in \text{ARTIFICIALLINES3}\}$$

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:

$$\text{LineFlow}_k = \sum_{j \in \text{DISCRSUB}_k} \text{LineFlowCoast}_{k,j} \times \text{Weight}_{k,j} + \text{DeficitWLineFlow}_k - \text{ExcessWLineFlow}_k$$

$$\{k \in \text{LINES}, k \notin \text{ARTIFICIALLINES1} \cup \text{ARTIFICIALLINES3}\}$$

D.16.3.2 Line Loss Constraint:

$$\text{LineLoss}_k = \sum_{j \in \text{DISCRSUB}_k} \text{LineLossConst}_{k,j} \times \text{Weight}_{k,j}$$

$\{k \in \text{LINES}, k \notin \text{ARTIFICIALLINES1} \cup \text{ARTIFICIALLINES3}\}$

D.16.3.3 Weight Summation Constraint:

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

$\{k \in \text{LINES}, k \notin \text{ARTIFICIALLINES1} \cup \text{ARTIFICIALLINES3}\}$

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

$$\text{LineMaxReverse}_k \leq \text{LineFlow}_k + \text{ExcessLineFlowReverse}_k$$

$\{k \in \text{ARTIFICIALLINES2}\}$

This constraint will replace constraint in D.16.2.1

D.16.4.2 Revised Flow Forward Constraint

$$\text{LineMaxForward}_k \geq \text{LineFlow}_k - \text{ExcessLineFlowForward}_k$$

$\{k \in \text{ARTIFICIALLINES1} \cup \text{ARTIFICIALLINES2}\}$

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

$$\text{MaxLineRating}_k = \text{maximum}(\text{LineRatingForward}_k, \text{LineRatingReverse}_k)$$

$$\text{RevisedMaxLineRating}_k = \frac{\text{AdditionalNumPoints}_k}{2} \times \frac{\text{MaxLineRating}_k}{(\text{NumPoints}_k - 1)/2} + \text{MaxLineRating}_k$$

$$\text{LineFlowConst}_{k,j} = -\text{RevisedMaxLineRating}_k + \frac{\text{j} - 1}{\text{NumPoints}_k - 1} \times \text{RevisedMaxLineRating}_k \times 2$$

$$\{k,j \mid j \in \{1,\ldots,\text{NumPoints}_k\}, \text{where } k \in \text{LINES},\ k \notin \text{ARTIFICIALLINES}\}$$

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:

$$\text{Risk}_c \geq \text{RiskAdjustmentFactor}_c \times \text{RawCalculatedRisk}_{g,c}$$

where:

$$\text{RawCalculatedRisk}_{g,c} = \text{Generation}_g - \text{PowerSystemResponse}_{g,c} + \text{EstReserveEffectiveness}_{r(g,c)} \times \text{RawReserve}_{r(g,c)} + \sum_{h \in \text{SECONDARYRISKGENERATORS}, h \neq g} (\text{Generation}_h + \text{EstReserveEffectiveness}_{r(h,c)} \times \text{RawReserve}_{r(h,c)})$$

and

$$\text{PowerSystemResponse}_{g,c} = \text{EstIntertieContribution} \times \text{AcceptableFreqDeviation}_c \times \text{EstLoadDamping}_c \times \text{TotalPurchase} - \text{EstGTOutputDamping}_c \times \sum_{i \in \text{DAMPINGGENERATORS}, i \neq g} \text{Generation}_i$$

$\{g,c | g \in \text{RISKGENERATORS}, c \in \text{RESERVECLASSES}\}$

D.17.1.1A Energy Storage Risk Constraint:

$$\text{Risk}_c \geq \text{RiskAdjustmentFactor}_c \times \text{RawCalculatedRisk}_{es,c}$$

where:

$$\text{RawCalculatedRisk}_{es,c} = \text{EnergyStorageTransfer}_{es} - \text{PowerSystemResponse}_c + \text{EstReserveEffectiveness}_{r(es,c)} \times \text{RawReserve}_{r(es,c)} + \sum_{h \in \text{SECONDARYRISKGENERATORS}} (\text{Generation}_h + \text{EstReserveEffectiveness}_{r(h,c)} \times \text{RawReserve}_{r(h,c)})$$

and

$$\text{PowerSystemResponse}_c = \text{EstIntertieContribution} \times \text{AcceptableFreqDeviation}_c \times \text{EstLoadDamping}_c \times \text{TotalPurchase} - \text{EstGTOutputDamping}_c \times \sum_{i \in \text{DAMPINGGENERATORS}} \text{Generation}_i$$

$\{es,c | es \in \text{ENERGYSTORAGEOFFERS}, c \in \text{RESERVECLASSES}\}$

D.17.1.2 Minimum Risk Constraint:

$$\text{Risk}_c \geq \text{MinimumRisk}_c$$

$$\{c \mid c \in \text{RESERVECLASSES}\}$$

D.17.2 Supply of Reserve

D.17.2.1 Raw Reserve Block Constraint:

$$\text{RawReserveBlock}_{r,j} \leq \text{RawReserveBlockMax}_{r,j}$$

$$\{j, r \mid j \in \text{RAWRESERVEBLOCKS}_r, \text{where } r \in \text{RAWRESERVEOFFERS}\}$$

D.17.2.2 Raw Reserve Summation Constraint:

$$\text{RawReserve}_r = \sum_{j \in \text{RAWRESERVEBLOCKS}_r} \text{RawReserveBlock}_{r,j}$$

$$\{r \in \text{RAWRESERVEOFFERS}\}$$

D.17.2.3 Reserve Proportion Constraint:

$$\text{RawReserve}_r - \text{ExcessRawReserve}_r \leq \text{ReserveProportion}_r \times \text{Generation}_{g(r)}$$

$$\{r \in \text{GENRESERVEOFFERS}\}$$

D.17.2.4 Reserve Generation Max Constraint:

$$\text{Generation}_{g(r)} + \text{RawReserve}_r + \text{Regulation}_{l(r)} - \text{ExcessResGen}_r$$
$$\leq \text{ReserveGenerationMax}_r$$

$$\{r \in \text{GENRESERVEOFFERS}\}$$

D.17.2.4A Energy Storage Reserve Max Constraint:

$$\text{EnergyStorageTransfer}_{es(r)} + \text{RawReserve}_r + \text{Regulation}_{l(r)} - \text{ExcessResGen}_r \leq \text{ReserveGenerationMax}_r$$

$$\{r \in \text{STORAGERESERVEOFFERS}\}$$

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:

$$\text{Slope} = -\text{HighLoadReserve}_r / (\text{StandingReserveGenerationMax}_{g(r)} - \text{HighLoad}_{g(r)})$$

D.17.2.6 Reserve Generation Segment 2

$$\text{RawReserve}_r - \text{ExcessResGenSegment2}_r \le \text{MediumLoadReserve}_r + \text{Slope} \times (\text{Generation}_{g(r)} - \text{MediumLoad}_{g(r)})$$

$$\{r \in \text{GENRESERVEOFFERS}\}$$

where:

$$\text{Slope} = (\text{HighLoadReserve}_r - \text{MediumLoadReserve}_r) / (\text{HighLoad}_{g(r)} - \text{MediumLoad}_{g(r)})$$

D.17.2.7 Reserve Generation Segment 3

$$\text{RawReserve}_r - \text{ExcessResGenSegment3}_r \le \text{LowLoadReserve}_r + \text{Slope} \times (\text{Generation}_{g(r)} - \text{LowLoad}_{g(r)})$$

$$\{r \in \text{GENRESERVEOFFERS}\}$$

where:

$$\text{Slope} = (\text{MediumLoadReserve}_r - \text{LowLoadReserve}_r) / (\text{MediumLoad}_{g(r)} - \text{LowLoad}_{g(r)})$$

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

$$\text{RawReserve}_r - \text{InfinitePositiveValue} \times \text{ReserveEligibilitySwitch}_{g(r)} \le 0$$

$$\{r | r \in \text{GENPRIRESERVEOFFERS}\}$$

D.17.2.8.2 Mixed Integer Program Based Reserve Low Load Constraint

$$\text{Generation}_{g(r)} + \text{InfinitePositiveValue} \times (1 - \text{ReserveEligibilitySwitch}_{g(r)}) \ge \text{LowLoad}_{g(r)}$$

$$\{r | r \in \text{GENPRIRESERVEOFFERS}\}$$

D.17.3 Matching of requirements and availability

D.17.3.1 Group Response Constraint:

$$\sum_{j \in \text{RESERVEGROUPBLOCKS}_x} \text{GroupResponse}_{x,j} \le \sum_{r \in \text{RAWRESERVEOFFERS}_x} \text{RawReserve}_r$$

$$\{x \in \text{RESERVEGROUPS}\}$$

D.17.3.2 Group Response Block Constraint:

$$\text{GroupResponse}_{x,j} \leq \text{GroupResponseMax}_{x,j}$$

$$\{j \in \text{RESERVEGROUPBLOCKS}_x \text{ where } x \in \text{RESERVEGROUPS}\}$$

D.17.3.3 Effective Reserve Constraint:

$$\text{EffectiveReserve}_x = \sum_{j \in \text{RESERVEGROUPBLOCKS}_x} \text{Effectiveness}_{x,j} \times \text{GroupResponse}_{x,j}$$

$$\{x \in \text{RESERVEGROUPS}\}$$

D.17.3.4 Reserve Balance Constraint:

$$\sum_{x \in \text{RESERVEGROUPS}_c} \text{EffectiveReserve}_x + \text{DeficitReserve}_c \geq \text{Risk}_c$$

$$\{c \in \text{RESERVECLASSES}\}$$

D.17.3.5 Zone Summation Constraint:

$$\text{ZoneResponse}_{z,c} = \sum_{r \in \text{RAWRESERVEOFFERS}_{z,c}} \text{RawReserve}_r$$

$$\{z,c \mid z \in \text{LOADZONES},\ c \in \text{RESERVECLASSES}\}$$

D.17.3.6 Zone Response Constraint:

$$\text{ZoneResponse}_{z,c} + \sum_{p \in \text{RESTRICTEDENERGYBIDS}_z} \text{CurtailedLoad}_p$$

$$\leq \text{ZoneResponseMax}_z$$

$$\{z,c \mid z \in \text{LOADZONES},\ c \in \text{RESERVECLASSES}\}$$

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:

$$\sum_{z \in LOADZONES} ZoneResponse_{z,c} + \sum_{p \in RESTRICTEDENERGYBIDS} CurtailedLoad_p \le SystemLoadResponseMax$$

$\{c \in RESERVECLASSES\}$

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

D.17.4.2.1 Load Curtailment Constraint:

$$CurtailedLoad_{p(r)} - InfinitePositiveValue \times LoadEnergyReserveSelector_{p(r)} \le 0$$

$\{r \in DISPLOADRESERVEOFFERS\}$

D.17.4.2.2 Load Reserve Constraint:

$$RawReserve_r - (1 - LoadEnergyReserveSelector_{p(r)}) \times InfinitePositiveValue \le 0$$

$\{r \in DISPLOADRESERVEOFFERS\}$

D.18 REGULATION

D.18.1 Supply of Regulation

D.18.1.1 Regulation Block Constraint:

$$\text{RegulationBlock}_{l,j} \leq \text{RegulationBlockMax}_{l,j}$$

$$\{j,l \mid j \in \text{REGULATIONOFFERBLOCKS}_l, \text{where } l \in \text{REGULATIONOFFERS}\}$$

D.18.1.2 Regulation Summation Constraint:

$$\text{Regulation}_l = \sum_{j \in \text{REGULATIONOFFERBLOCKS}_l} \text{RegulationBlock}_{l,j}$$

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

D.18.1.3 Mixed Integer Program Based Regulation Max Constraint:

$$\text{Generation}_{g(l)} + \text{Regulation}_l - \text{ExcessRegGen}_l - \text{InfinitePositiveValue} \times (1 - \text{RegulationEligibilitySwitch}_l) \leq \text{RegulationMax}_{g(l)}$$

$$\{l \in \text{GENREGULATIONOFFERS}\}$$

D.18.1.4 Mixed Integer Program Based Regulation Min Constraint:

$$\text{Generation}_{g(l)} - \text{Regulation}_l + \text{DeficitRegGen}_l + \text{InfinitePositiveValue} \times (1 - \text{RegulationEligibilitySwitch}_l) \geq \text{RegulationMin}_{g(l)}$$

$$\{l \in \text{GENREGULATIONOFFERS}\}$$

D.18.1.5 Mixed Integer Program Based Zero Regulation Constraint

$$\text{Regulation}_l - \text{InfinitePositiveValue} \times \text{RegulationEligibilitySwitch}_l \leq 0$$

$$\{l \in \text{GENREGULATIONOFFERS}\}$$

D.18.1.6 Energy Storage Regulation Max Constraint:

$$\text{EnergyStorageTransfer}_{es(l)} + \text{Regulation}_l - \text{ExcessRegGen}_l \leq \text{RegulationMax}_{es(l)}$$

$$\{l \in \text{STORAGEREGULATIONOFFERS}\}$$

D.18.1.7 Energy Storage Regulation Min Constraint:

$$\text{EnergyStorageTransfer}_{es(l)} - \text{Regulation}_l + \text{DeficitRegGen}_l \geq \text{RegulationMin}_{es(l)}$$
$$\{l \in \text{STORAGEREGULATIONOFFERS}\}$$

D.18.2 Matching of requirements and availability

D.18.2.1 Regulation Balance Constraint:

$$\sum_{l \in \text{REGULATIONOFFERS}} \text{Regulation}_l + \text{DeficitRegulation} \geq \text{RegulationRequirement}$$

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.19.1.1A Energy Storage Up Ramp Constraint:

$$\text{EnergyStorageTransfer}_{es} - \text{ExcessUpRamp}_{es} \leq \text{EnergyTransferEndMax}_{es}$$
$$\{es \in \text{ENERGYSTORAGEOFFERS}\}$$

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.19.1.2A Energy Storage Down Ramp Constraint:

$$\text{EnergyStorageTransfer}_{es} + \text{ExcessDownRamp}_{es} \geq \text{EnergyTransferEndMin}_{es}$$
$$\{es \in \text{ENERGYSTORAGEOFFERS}\}$$

D.19.2 Combined ramping, reserve and regulation constraints

D.19.2.1 Reserve Ramp Constraint:

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

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

D.19.2.2 Reserve Proportion Ramp Constraint:

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

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

D.19.2.3 Regulation Ramp Constraint:

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

$\{l \in \text{GENREGULATIONOFFERS, where RegulationResponsePeriod} > \text{CombinedRampThreshold}\}$

D.19.3 Load Ramping Constraints

D.19.3.1 Up Ramp Constraint:

$$\text{Purchase}_p - \text{ExcessUpRamp}_p \leq \text{PurchaseEndMax}_p$$

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

D.19.3.2 Down Ramp Constraint:

$$\text{Purchase}_p + \text{ExcessDownRamp}_p \geq \text{PurchaseEndMin}_p$$

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

D.19A STATE-OF-CHARGE

D.19A.1 Combined Reserves Energy Regulation Minimum SoC Constraint:

$$\frac{\begin{array}{c}(\text{EnergyStorageDischarging}_{es} + \text{Regulation}_{l(es)} \\ +\text{RawReserve}_{r(es,Primary)} \times \frac{\text{PriResSustainTime}}{\text{DispatchPeriod}} \\ +\text{RawReserve}_{r(es,Contingency)} \times \frac{\text{DispatchPeriod} - \text{PriResSustainTime}}{\text{DispatchPeriod}})\end{array}}{\text{DischargingEfficiency}_{es}}$$

$$-\text{EnergyStorageCharging}_{es} \times \text{ChargingEfficiency}_{es}$$

$$-\text{ExcessDischarging}_{es}$$

$$\leq \frac{\text{SoCDischargeLimitMWh}_{es}}{\text{DispatchPeriod}/3600}$$

$$\{es \in \text{ENERGYSTORAGEOFFERS}\}$$

D.19A.2 Combined Primary Reserve Energy Regulation Minimum SoC Constraint:

$$\frac{\text{EnergyStorageDischarging}_{es} + \text{Regulation}_{l(es)} + \text{RawReserve}_{r(es,Primary)}}{\text{DischargingEfficiency}_{es}}$$

$$-\text{EnergyStorageCharging}_{es} \times \text{ChargingEfficiency}_{es}$$

$$-\text{ExcessPrimaryDischarging}_{es}$$

$$\leq \frac{\text{SoCDischargeLimitMWh}_{es}}{\text{DispatchPeriod}/3600}$$

$$\{es \in \text{ENERGYSTORAGEOFFERS}\}$$

D.19A.3 Combined Contingency Reserve Energy Regulation Minimum SoC Constraint:

$$\frac{\text{EnergyStorageDischarging}_{es} + \text{Regulation}_{l(es)} + \text{RawReserve}_{r(es,Contingency)}}{\text{DischargingEfficiency}_{es}}$$

$$-\text{EnergyStorageCharging}_{es} \times \text{ChargingEfficiency}_{es}$$

$$-\text{ExcessContingencyDischarging}_{es}$$

$$\leq \frac{\text{SoCDischargeLimitMWh}_{es}}{\text{ConResSustainTime}/3600}$$

$$\{es \in \text{ENERGYSTORAGEOFFERS}\}$$

D.19A.4 Combined Energy Regulation Maximum SoC Constraint:

$$\left(\text{EnergyStorageCharging}_{es} + \text{Regulation}_{l(es)}\right) \times \text{ChargingEfficiency}_{es}$$
$$- \frac{\text{EnergyStorageDischarging}_{es}}{\text{DischargingEfficiency}_{es}}$$
$$- \text{ExcessCharging}_{es}$$
$$\leq \frac{\text{SoCChargeLimitMWh}_{es}}{\text{DispatchPeriod}/3600}$$

$$\{es \in \text{ENERGYSTORAGEOFFERS}\}$$

D.20 GENERIC AND MULTI-UNIT CONSTRAINTS

D.20.1 Generic constraint

D.20.1.1 Generic Security Constraint:

$$\sum_{k \in SECURITYLINESGROUP_s} SecurityGroupLineWeight_{s,k} \times LineFlow_k$$
$$+ \sum_{n \in SECURITYNODESGROUP_s} SecurityGroupNodeWeight_{s,n} \times NodeNetInjection_n$$
$$+ \sum_{g \in SECURITYGENERATIONGROUP_s} SecurityGroupGenerationWeight_{s,g} \times Generation_g$$
$$+ \sum_{es \in SECURITYSTORAGETRANSFERGROUP_s} SecurityGroupStorageTransferWeight_{s,es}$$
$$\times EnergyStorageTransfer_{es}$$
$$+ DeficitSecurity_s \geq GenericSecurityLimit_s$$
$$\{s \in SECURITYCONSTRAINTS\}$$

D.20.2 Multi-unit Constraint

D.20.2.1 Multi-unit Constraint:

$$\sum_{k \in MULTICONSTRAINTSLINESGROUP_s} MultiGroupLineWeight_{s,k} \times LineFlow_k$$
$$+ DeficitMulti_s - ExcessMulit_s = 0$$
$$\{s \in MULTIUNITCONSTRAINTS\}$$

D.20A TIE-BREAKING CONSTRAINTS

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

$$\frac{\text{GenerationBlock}_{(g(o),j(o))}}{\text{GenerationBlockMax}_{(g(o),j(o))}} - \frac{\text{GenerationBlock}_{(g'(o),j'(o))}}{\text{GenerationBlockMax}_{(g'(o),j'(o))}} = \text{EnergyTieBreakSlack1}_o - \text{EnergyTieBreakSlack2}_o$$

$\{o \in \text{TIEDENERGYOFFERBLOCKPAIRS}\}$

$$\frac{\text{GenerationBlock}_{g(o),j(o))}}{\text{GenerationBlockMax}_{(g(o),j(o))}} - \frac{\text{EnergyStorageBlock}_{(es(o),j'(o))}}{\text{EnergyStorageBlockLimit}_{(es^{(o)},j'(o))}} = \text{EnergyTieBreakSlack1}_o - \text{EnergyTieBreakSlack2}_o$$

{o∈TIEDENERGYOFFERBLOCKPAIRS, where
g(o)∈ENERGYOFFERS,
es(o)∈ENERGYSTORAGEOFFERS,
$\text{EnergyStorageBlockLimit}_{es'} > 0$}

$$\frac{\text{EnergyStorageBlock}_{es(o),j(o))}}{\text{EnergyStorageBlockLimit}_{(es(o),j(o))}} - \frac{\text{EnergyStorageBlock}_{(es'(o),j'(o))}}{\text{EnergyStorageBlockLimit}_{(es'^{(o)},j'(o))}} = \text{EnergyTieBreakSlack1}_o - \text{EnergyTieBreakSlack2}_o$$

{o∈TIEDENERGYOFFERBLOCKPAIRS, where
es(o), es'(o)∈ENERGYSTORAGEOFFERS,

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:

$$\sum_{j \in VIOLATIONGROUPBLOCKSLIN_{y(k)}} ViolationGroupBlock_{y(k),j} \geq ExcessLineFlowForward_k + ExcessLineFlowReverse_k + DeficitWLineFlow_k + ExcessWLineFlow_k$$

$\{k \in LINES, k \notin ARTIFICIAL\ LINES\}$

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):

$$\sum_{j \in VIOLATIONGROUPBLOCKSLIN_{y(k)}} ViolationGroupBlock_{y(k),j} \geq DeficitWLineFlow_k + ExcessWLineFlow_k$$

$\{k \in LINES, k \notin ARTIFICIAL\ LINES\}$

D.21.3 Deficit Reserve Constraint:

$$\sum_{j \in VIOLATIONGROUPBLOCKSRES_{y(c)}} ViolationGroupBlock_{y(c),j} \geq DeficitReserve_c$$

$\{c \in RESERVECLASSES\}$

D.21.3.1 Reserve Violation Group Block Constraint 1:

$ViolationGroupBlock_{y(c),1} \leq ViolationGroupProportion_c \times Risk_c$

$\{c \in RESERVECLASSES\}$

D.21.3.2 Reserve Violation Group Block Constraint 2:

$ViolationGroupBlock_{y(c),1} + ViolationGroupBlock_{y(c),2} \leq Risk_c - MinimumRisk_c$

$\{c \in RESERVECLASSES\}$

D.21.4 Deficit Regulation Constraint:

$$\sum_{j \in VIOLATIONGROUPBLOCKSREG_{y(regulation)}} ViolationGroupBlock_{y(regulation),j} \geq DeficitRegulation$$

D.21.4.1 Regulation Violation Group Block Constraint 1:

$ViolationGroupBlock_{y(regulation),1} \leq RegulationRequirement - MinimumRegulation$

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:

$$\sum_{j \in \text{VIOLATIONGROUPBLOCKSFAC}_{y(g)}} \text{ViolationGroupBlock}_{y(g),j} \geq \text{FacilityReserveViolation}_g + \text{FacilityRegulationViolation}_g + \text{FacilityRampViolation}_g + \text{FacilityMultiUnitViolation}_g + \text{FacilityLineFlowViolation}_g + \text{FacilityMSLViolation}_g$$

$$\{g \in \text{ENERGYOFFERS}\}$$

D.21.5.1 Facility Reserve Constraint:

$$\text{FacilityReserveViolation}_g = \sum_{c \in \text{RESERVECLASSES}} \text{ExcessRawReserve}_{r(g,c)} + \sum_{c \in \text{RESERVECLASSES}} \text{ExcessResGen}_{r(g,c)} + \sum_{c \in \text{RESERVECLASSES}} \text{ExcessResGenSegment1}_{r(g,c)} + \sum_{c \in \text{RESERVECLASSES}} \text{ExcessResGenSegment2}_{r(g,c)} + \sum_{c \in \text{RESERVECLASSES}} \text{ExcessResGenSegment3}_{r(g,c)} + \sum_{c \in \text{RESERVECLASSES}} \text{ExcessResRamp}_{r(g,c)} + \sum_{c \in \text{RESERVECLASSES}} \text{ExcessResPropRamp}_{r(g,c)}$$

$$\{g \in \text{ENERGYOFFERS}\}$$

D.21.5.2 Facility Regulation Constraint:

$$\text{FacilityRegulationViolation}_g = \text{ExcessRegGen}_{l(g)} + \text{DeficitRegGen}_{l(g)} + \text{ExcessRegRamp}_{l(g)}$$

$$\{g \in \text{ENERGYOFFERS}\}$$

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:

$$FacilityLineFlowViolation_g = \sum_{k_1 \in ARTIFICIALLINES1} ExcessLineFlowForward_{k_1(g)} + \sum_{k_2 \in ARTIFICIALLINES2} ExcessLineFlowForward_{k_2(g)} + \sum_{k_2 \in ARTIFICIALLINES2} ExcessLineFlowReverse_{k_2(g)} + \sum_{k_2 \in ARTIFICIALLINES2} DeficitWLineFlow_{k_2(g)} + \sum_{k_2 \in ARTIFICIALLINES2} ExcessWLineFlow_{k_2(g)}$$

$$\{g \in ENERGYOFFERS\}$$

D.21.5.6 Facility Minimum Stable Load Constraint:

$$FacilityMSLViolation_g = DeficitMSL_g + ExcessMSL_g$$

$$\{g \in ENERGYOFFERS, \text{ for which } MinimumStableLoad_g > 0\}$$

D.21.5A LRF with REB Facility Constraint:

$$\sum_{j \in VIOLATIONGROUPBLOCKSFAC_{y(p)}} ViolationGroupBlock_{y(p),j} \geq FacilityRampViolation_p$$

$$\{p \in RESTRICTEDENERGYBIDS\}$$

D.21.5A.1 LRF with REB Facility Ramp Constraint:

$$FacilityRampViolation_p = ExcessUpRamp_p + ExcessDownRamp_p$$

$$\{p \in RESTRICTEDENERGYBIDS\}$$

D.21.5B Energy Storage Facility Constraint:

$$\sum_{j \in VIOLATIONGROUPBLOCKSFAC_{y(es)}} \text{ViolationGroupBlock}_{y(es),j} \geq \text{FacilityRampViolation}_{es} + \text{FacilityReserveViolation}_{es} + \text{FacilityRegulationViolation}_{es} + \text{FacilitySoCViolation}_{es} + \text{FacilityLineFlowViolation}_{es}$$

$$\{es \in ENERGYSTORAGEOFFERS\}$$

D.21.5B.1 Energy Storage Facility Ramp Constraint:

$$\text{FacilityRampViolation}_{es} = \text{ExcessUpRamp}_{es} + \text{ExcessDownRamp}_{es}$$

$$\{es \in ENERGYSTORAGEOFFERS\}$$

D.21.5B.2 Energy Storage Facility Reserve Constraint:

$$\text{FacilityReserveViolation}_{es} = \sum_{c \in RESERVECLASSES} \text{ExcessResGen}_{r(es,c)}$$

$$\{es \in ENERGYSTORAGEOFFERS\}$$

D.21.5B.3 Energy Storage Facility Regulation Constraint:

$$\text{FacilityRegulationViolation}_{es} = \text{ExcessRegGen}_{es} + \text{DeficitRegGen}_{es}$$

$$\{es \in ENERGYSTORAGEOFFERS\}$$

D.21.5B.4 Energy Storage Facility State-of-Charge Constraint:

$$\text{FacilitySoCViolation}_{es} = \text{ExcessDischarging}_{es} + \text{ExcessPrimaryDischarging}_{es} + \text{ExcessContingencyDischarging}_{es} + \text{ExcessCharging}_{es}$$

$$\{es \in ENERGYSTORAGEOFFERS\}$$

D.21.5B.5 Energy Storage Facility Line Flow Constraint:

$$\text{FacilityLineFlowViolation}_{es} = \sum_{k \in \text{ARTIFICIALLINE2}} \text{ExcessLineFlowForward}_{k(es)} + \sum_{k \in \text{ARTIFICIALLINE2}} \text{ExcessLineFlowReverse}_{k(es)} + \sum_{k \in \text{ARTIFICIALLINE2}} \text{DeficitWLineFlow}_{k(es)} + \sum_{k \in \text{ARTIFICIALLINE2}} \text{ExcessWLineFlow}_{k(es)}$$

$$\{es \in \text{ENERGYSTORAGEOFFERS}\}$$

D.21.6 Deficit Security Constraint:

$$\sum_{j \in \text{VIOLATIONGROUPBLOCKSSEC}_{y(s)}} \text{ViolationGroupBlock}_{y(s),j} \geq \text{DeficitSecurity}_{s}$$

$$\{s \in \text{SECURITYCONSTRAINTS}\}$$

D.21.7 Violation Group Block Constraint:

$$\text{ViolationGroupBlock}_{y,j} \leq \text{ViolationGroupBlockMax}_{y,j}$$

$$\{j,y \mid j \in \text{VIOLATIONGROUPBLOCKS}_{y}, \text{where } y \in \text{VIOLATIONGROUPS}\}$$

D.21.8 Violation Penalties Constraint:

$$\text{ViolationPenalties} \geq \sum_{y \in \text{VIOLATIONGROUPS}} \sum_{j \in \text{VIOLATIONGROUPBLOCKS}_y} \left(\text{ViolationGroupBlockPenalty}_{y,j} \times \text{ViolationGroupBlock}_{y,j} \right)$$

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, $\text{ExcessLineFlowForward}_k$, $\text{ExcessLineFlowReverse}_k$, $\text{DeficitWLineFlow}_k$ 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:

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

$$\{k, j, i \mid j, i \in \text{DISCRSUB}_k, \text{where } k \in \text{LINES}, i > j+1\}\ ,$$

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:

$$\text{SysError} = \sum_k \text{CircuitError}_k$$

where:

$$\text{CircuitError}_k = \text{LineLoss}_k - \text{ActualLoss}_k$$

$$\text{ActualLoss}_k = \text{LineLossConst}_{k,i} + \frac{\text{LineFlow}_k - \text{LineFlowConst}_{k,i}}{\text{LineFlowConst}_{k,i+1} - \text{LineFlowConst}_{k,i}} \times (\text{LineLossConst}_{k,i+1} - \text{LineLossConst}_{k,i})$$

$$\left\{ \begin{array}{l} i,k \mid i \in \text{DISCRSUB}_k, \text{where } k \in \text{LINES}, \\ i = \text{Max}\left(\begin{array}{l} j \mid j < N(DISCRSUB_k), \\ \text{LineFlowConst}_{k,j} \leq \text{LineFlow}_k \end{array} \right) \end{array} \right\}$$

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 $DISCRSUB_k$ 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:

$$\{i \mid i \in DISCRSUB_k, \text{ where } k \in LINES, i = Max(j \mid LineFlowConst_{k,j} < LineFlow_k + SysError)\}.$$

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

$$LineFlowConst'_{k,i+1} = LineFlow_k + SysError$$

$$LineLossConst'_{k,i+1} = LineLossConst_{k,i} + \frac{(LineFlow_k + SysError) - LineFlowConst_{k,i}}{(LineFlowConst_{k,i+1} - LineFlowConst_{k,i})} \times \left(LineLossConst_{k,i+1} - LineLossConst_{k,i}\right)$$

D.22.6.2 Line flow/line loss point i shall be identified such that:

$$\{i \mid i \in DISCRSUB_k, \text{ where } k \in LINES, i = Min(j \mid LineFlowConst_{k,j} > LineFlow_k - SysError)\}.$$

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

$$LineFlowConst'_{k,i-1} = LineFlow_k - SysError$$

$$LineLossConst'_{k,i-1} = LineLossConst_{k,i} + \frac{(LineFlow_k - SysError) - LineFlowConst_{k,i}}{(LineFlowConst_{k,i-1} - LineFlowConst_{k,i})} \times \left(LineLossConst_{k,i-1} - LineLossConst_{k,i}\right)$$

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:

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

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×*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 <u>QUANTITY FORMATION</u>

D.23.1 *Energy* quantities scheduled from each *generation registered facility* are given by the values of the Generation_g and $\text{EnergyStorageTransfer}_{es}$ 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 *intertie 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 *intertie 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:

$$\text{ReferenceEnergyWithdrawal}_p = \text{Purchase}_p + \text{NonDispLoad}_p \quad \{p \in \text{RESTRICTEDENERGYBIDS}\}$$

where:

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

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:

$$MEP^{m(g)} \text{ or } MEP^{m(es)} = EnergyPrice_{n(m)}$$

where:

$EnergyPrice_{n(m)}$ is the dual variable corresponding to constraint D.16.1.2 for the *dispatch network node n* corresponding to the *market network node m*

The price MEP^{m} shall then be further modified in accordance with section D.24.5 for *dispatch periods* where the *temporary price cap* is not in effect, or in accordance with section D.24.5A for *dispatch periods* where the *temporary price cap* is in effect.

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:

$$MEP^{m(g)} = \frac{\sum_{u \in CONNECTEDUNITS_g} \left(Proportion_u \times EnergyPrice_{n(u)} \right)}{\sum_{u \in CONNECTEDUNITS_g} Proportion_u}$$

where:

$Proportion_u$ is the relevant proportion of generation for *generating unit u* of a *multi-unit facility* associated with *energy offer g* specified by the *EMC* in accordance with section D.7.3;

$EnergyPrice_{n(u)}$ is the dual variable corresponding to constraint D.16.1.2 for the *dispatch network node n* corresponding to the *market network node m*; and

The price MEP^{m} shall then be further modified in accordance with section D.24.5 for *dispatch periods* where the *temporary price cap* is not in effect, or in accordance with section

D.24.5A for *dispatch periods* where the *temporary price cap* is in effect.

D.24.1.3 For *pseudo generation settlement facilities*, the *market energy price* shall be calculated as follows:

$$MEP = \frac{\sum_{g \in ENERGYOFFERS} (\mathsf{Generation}_g \times MEP^{m(g)}) + \sum_{es \in ENERGYSTORAGEOFFERS} (\mathsf{EnergyStorageTransfer}_{es} \times MEP^{m(es)})}{\sum_{g \in ENERGYOFFERS} \mathsf{Generation}_g + \sum_{es \in ENERGYSTORAGEOFFERS} \mathsf{EnergyStorageTransfer}_{es}}$$

where:

$MEP^{m(g)}$ or $MEP^{m(es)}$ is the *market energy price* for *market network node m* corresponding to the *generation registered facility* that *energy offer g* or *energy storage offer es* 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 for *dispatch periods* where the *temporary price cap* is not in effect, or in accordance with section D.24.5A for *dispatch periods* where the *temporary price cap* is in effect.

D.24.2 Nodal spot prices for *dispatch network nodes* or NSP_n shall be calculated from the values of $\mathsf{EnergyPrice}_n$, 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 for *dispatch periods* where the *temporary price cap* is not in effect, or in accordance with section D.24.5A for *dispatch periods* where the *temporary price cap* is in effect.

D.24.2A Reference nodal spot prices for *dispatch network nodes* or $RNSP_n$ shall be calculated from the values of $\mathsf{EnergyPrice}_n$, 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 $\mathsf{ReservePrice}_c$, the dual variables corresponding to constraint D.17.3.4, and then further modified in accordance with section D.24.5 for *dispatch periods* where the *temporary price cap* is not in effect, or in accordance with section D.24.5A for *dispatch periods* where the *temporary price cap* is in effect.

D.24.4 The *market regulation price* or *MFP* shall be calculated from the values of RegulationPrice, the dual variable corresponding to constraint D.18.2.1, and then further modified in accordance with section D.24.5 for *dispatch periods* where the *temporary price cap* is not in effect, or in accordance with section D.24.5A for *dispatch periods* where the *temporary price cap* is in effect.

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.1.7, 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.1.7, 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.1.7, then the modified price shall be set to that lower limit.

D.24.5A If the *temporary price cap* as referred to in section N.3.1 of Appendix 6N is activated, notwithstanding section D.24.5, the *market clearing engine* shall apply the upper and lower limits under Appendix 6J, section J.1.7A in its determination of modified prices as referred to in D.24.1 to D.24.4 for each *dispatch period* the *temporary price cap* is active for. For the avoidance of doubt, the upper limits under section J.1.7A of Appendix 6J shall not be applied in the determination of the $RNSP_n$ as referred to in D.24.2A.

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:

USEP = *uniform Singapore energy price*

= $\Sigma_n (W^n \times NSP^n) / \Sigma_n W^n$

where:

$\{n | n \in \text{NODES}\}$

$$W^n = \sum_{\substack{p \in \text{ENERGYBIDS}_n, \\ p \notin \text{INTERTIEENERGYBIDS}}} \text{Purchase}_p - \sum_{j \in \text{DEFICITGENERATIONBLOCKS}_n} \text{DeficitGenerationBlock}_{n,j}$$

NSP^n = the nodal spot price for *DNN* n referred to in section D.24.2 after it has been modified in accordance with section D.24.5 or section D.24.5A where applicable.

D.24.6A The *market clearing engine* shall, for each *dispatch period*, determine the *reference uniform Singapore energy price* or *RUSEP* corresponding to that *dispatch period* in accordance with the following formula:

RUSEP = *reference uniform Singapore energy price*

= $\Sigma_n (W^n \times RNSP^n) / \Sigma_n W^n$

where:

$\{n | n \in \text{NODES}\}$

$$W^n = \sum_{\substack{p \in \text{ENERGYBIDS}_n, \\ p \notin \text{INTERTIEENERGYBIDS}}} \text{Purchase}_p - \sum_{j \in \text{DEFICITGENERATIONBLOCKS}_n} \text{DeficitGenerationBlock}_{n,j}$$

$RNSP^n$ = the nodal spot price for *DNN* n referred to in section D.24.2A 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 MRP_x for each *reserve provider group x*, in accordance with the following formula:

$MRP_x = ReservePrice_c \times Effectiveness_{x,j}$

where:

$\{x | x \in RESERVEGROUPS_c\}$

$ReservePrice_c$ = the *reserve class* price referred to in section D.24.3 after it has been modified in accordance with section D.24.5 or section D.24.5A where applicable.

$Effectiveness_{x,j}$ = the effectiveness multiplier of raw *reserve* in block *j* of *reserve provider group x*, where:

j is the last effectiveness block in

$RESERVEGROUPBLOCKS_x$ for which

$GroupResponse_{x,j} > 0$

or $j = 1$ if $GroupResponse_{x,j} = 0$ for all effectiveness blocks in $RESERVEGROUPBLOCKS_x$.

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, for *dispatch periods* where the *temporary price cap* is not in effect, or in accordance with section D.24.6A for *dispatch periods* where the *temporary price cap* is in effect, subject to section D.24.9.

D.24.9 If, for any *settlement interval* where the *temporary price cap* is not in effect,

D.24.9.1 $CUSEP_h$= $USEP_h$ = 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 $CUSEP_h$ shall be further modified and set to 1×*VoLL*.

D.24.9A If, for any *settlement interval* where the *temporary price cap* is in effect,

D.24.9A.1 $CUSEP_h$= $RUSEP_h$ = 0.9×*VoLL*; and

D.24.9A.2 shortfalls in *energy* were scheduled in the counterfactual solution referred to in D.22A for the corresponding *dispatch period,*

then the value of $CUSEP_h$ 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 .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*:

$$\text{Purchase}_p$$

$$\{p \in \text{ENERGYBIDS}\}$$

and in aggregate:

$$\sum_{\substack{p \in \text{ENERGYBIDS} \\ p \notin \text{INTERTIENERGYBIDS}}} \text{Purchase}_p$$

expressed in MW;

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

$$\text{Generation}_g$$

$$\{g \in \text{ENERGYOFFERS}\}$$

$$\text{EnergyStorageTransfer}_{es}$$

$$\{es \in \text{ENERGYSTORAGEOFFERS}\}$$

and in aggregate,

$$\sum_{\substack{g \in \text{ENERGYOFFERS} \\ g \notin \text{INTERTIEENERGYBIDS}}} \text{Generation}_g + \sum_{es \in \text{ENERGYSTORAGEOFFERS}} \text{EnergyStorageTransfer}_{es}$$

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*:

$$\text{Purchase}_p$$

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

expressed in MW;

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

$$\text{CurtailedLoad}_p$$

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

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*:

$$\sum_{\{j | j \in \text{DEFICITGENERATIONBLOCKS}_n\}} \text{DeficitGenerationBlock}_{n,j} \quad \{n \in \text{NODES}\}$$

and in aggregate,

$$\sum_{\{j,n | j \in \text{DEFICITGENERATIONBLOCKS}_n, \text{where } n \in \text{NODES}\}} \text{DeficitGenerationBlock}_{n,j}$$

expressed in MW;

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

$$\sum_{\{j | j \in \text{EXCESSGENERATIONBLOCKS}_n\}} \text{ExcessGenerationBlock}_{n,j} \quad \{n \in \text{NODES}\}$$

and in aggregate,

$$\sum_{\{j | j \in \text{EXCESSGENERATIONBLOCKS}_n, \text{where } n \in \text{NODES}\}} \text{ExcessGenerationBlock}_{n,j}$$

expressed in MW;

D.25.1.4A total *reserve* requirement by *reserve class*:

$$\text{Risk}_c \quad \{c \in \text{RESERVECLASSES}\}$$

expressed in MW;

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

$$\text{EffectiveReserve}_x$$

$$\{x \in \text{RESERVEGROUPS}_c, \text{where } c \in \text{RESERVECLASSES}\}$$

and in aggregate,

$$\sum_{x \in \text{RESERVEGROUPS}_c} \text{EffectiveReserve}_x \quad \{c \in \text{RESERVECLASSES}\}$$

expressed in MW;

D.25.1.6 the extent of any shortfall in *reserve*, by *reserve class*:

$$\text{DeficitReserve}_c$$

$$\{c \in \text{RESERVECLASSES}\}$$

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*:

$$\text{DeficitRegulation}$$

expressed in MW;

D.25.1.9 predicted power flows on *dispatch network lines*

$$\text{LineFlow}_k$$

$$\{k \in \text{LINES}\}$$

and *energy* losses on *dispatch network lines*

$$\text{LineLoss}_k$$

$$\{k \in \text{LINES}\}$$

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

$$\sum_{j \in \text{VIOLATIONGROUPBLOCKSSEC}_{y(s)}} \text{ViolationGroupBlock}_{y(s),j}$$

$$\{y \in \text{VIOLATIONGROUPS}\}$$

;

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 =

$$\frac{\begin{bmatrix} \sum_{g \in ENERGYOFFERS}(\text{MEP}^{m(g)} \times \text{Generation}_g \times 1/2) \\ + \sum_{es \in ENERGYSTORAGEOFFERS}(\text{MEP}^{m(es)} \times \text{EnergyStorageTransfer}_{es} \times 1/2) \\ -(\text{USEP} \times \sum_{\substack{p \in ENERGYBIDS, \\ p \notin INTERTIEENERGYBIDS}} \text{Purchase}_p \times 1/2) \end{bmatrix}}{\sum_{\substack{p \in ENERGYBIDS, \\ p \notin INTERTIEENERGYBIDS}} \text{Purchase}_p \times 1/2}$$

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.

D.25.1.14 the estimated end-of-period *SoC* in accordance with the following formula:

$$\text{EndSoC}_{es} = \text{ExpectedStartSoC}_{es} - \frac{\text{EnergyStorageDischarging}_{es} \times \frac{\text{DispatchPeriod}}{3600}}{\text{DischargingEfficiency}_{es} \times \text{MaxCapacity}_{es}} + \frac{\text{EnergyStorageCharging}_{es} \times \text{ChargingEfficiency}_{es} \times \frac{\text{DispatchPeriod}}{3600}}{\text{MaxCapacity}_{es}}$$

{es ∈ ENERGYSTORAGEOFFERS}