APPENDIX D - MARKET CLEARING FORMULATION

SECTION A: DEFINITIONS

D.1 INTERPRETATION

D.1.1 In this appendix:

D.1.1.1 sets shall be identified by being expressed in CAPITAL letters;

D.1.1.2 variables in the linear program shall be identified by being expressed in Arial font text;

D.1.1.3 parameters set outside of the linear program shall be identified by being expressed in ordinary text;

D.1.1.4 indices or members of sets shall be identified by being expressed in lower case letters in *italicised* text;

D.1.1.4A a reference to *generation registered facility* shall include a reference to *import registered facility*;

D.1.1.5 a reference to "generation" shall be a reference to the output of a *generation registered facility*; and

D.1.1.6 unless a contrary intention appears, all sets, parameters, variables and functions are defined in relation to the single *dispatch period* for which the *market clearing engine* is being solved.

D.1.2 Wherever the following notation is found, it shall be interpreted as, for each x in the set GROUP, take each of the corresponding blocks from XBLOCKS:

$$\{j,x \mid j \in \text{XBLOCKS}_x \text{ where } x \in \text{GROUP}\}$$

D.2 SETS

D.2.1 Unless otherwise stated, a reference to a *generation registered facility* in this D.2 does not include a reference to a *generation registered facility* that is an *energy storage facility*.

ARTIFICIALLINES	The set of *dispatch network lines* that have been artificially added to the dispatch network to model the connection of *generation registered facilities,* including *energy storage facilities*. It comprises the union of the sets ARTIFICIALLINES1, ARTIFICIALLINES2 and ARTIFICIALLINES3. A subset of LINES.
ARTIFICIALLINES1	The set of *dispatch network lines* added to the dispatch network pursuant to section D.8.2. A subset of ARTIFICIALLINES and LINES.
ARTIFICIALLINES2	The set of *dispatch network lines* added to the dispatch network pursuant to section D.6.5. A subset of ARTIFICIALLINES and LINES.
ARTIFICIALLINES3	The set of *dispatch network lines* corresponding to notional loss-less lines connecting two electrically equivalent buses that have been introduced to the dispatch network in accordance with section D.6.3.4. A subset of ARTIFICIALLINES and LINES.
CONNECTEDUNITS$_g$	A subset of UNITS$_g$ that consists only of constituent *generating units*, of the *multi-unit facility* associated with *energy offer* g, that are either (i) represented as *synchronised* in the *dispatch network data* or (ii) connected to the dispatch network, in accordance with section D.6.5.
DAMPINGGENERATORS	The set of all *energy offers* which are associated with *generation registered facilities* that are considered likely to decrease their generation output as a result of the frequency drop during a

	primary contingency. A subset of ENERGY OFFERS. The set of *generation registered facilities* that this applies to is supplied by the *PSO* in accordance with Appendix 6G section G.5.12.
DEFICITGENERATIONBLOCKS$_n$	The set of generation penalty blocks for failure to meet demand at node *n*. Indexed by *j*.
DISCRSUB$_k$	The discretisation subset for line *k*. It defines the points on the line flow / loss curve that are used to define the linear approximation of the quadratic loss curve. These points may be revised where the circumstances described in section D.22 apply. An ordered set, starting with the point representing the maximum reverse flow.
DISPLOADRESERVEOFFERS	The set of *reserve offers* that have been submitted by the *dispatch coordinators* for *LRFs with REB*. A subset of RAWRESERVEOFFERS.
ENERGYBIDS	The set of all *energy bids*, referenced by *p*. This comprises all valid *restricted energy bids* associated with *LRFs with REB* received by the *EMC*, together with *bids* to purchase *energy* at the relevant *dispatch network nodes* created by the *EMC* in accordance with sections D.9A.3 and D.9A.4.
ENERGYBIDS$_n$	The set of *energy bids* associated with node *n*, but excluding the *energy bids* submitted for *LRFs with REB*. A subset of ENERGYBIDS.
ENERGYOFFERS	The set comprising all *energy offers* from *dispatch coordinators* for *generation registered facilities* together with data entered for the *intertie* nodes to represent any scheduled import flows across the *interties*.
ENERGYOFFERS$_n$	The set of all *energy offers* from the dispatch coordinators of *generation*

	registered facilities that will inject into node *n,* or the data entered for the *intertie* node *n* to represent any scheduled import flows across the *intertie*. A subset of ENERGYOFFERS.
ENERGYSTORAGEOFFERS	The set, indexed by *es*, comprising all *energy storage offers* from *dispatch coordinators* of *energy storage facilities*
$ENERGYSTORAGEOFFERS_n$	The set of all *energy storage offers* associated with node *n.* A subset of ENERGYSTORAGEOFFERS
$ENERGYSTORAGEOFFERBLOCKS_{es}$	The set of *price-quantity pairs* for the *energy storage offer* es. Indexed by *j*.
$EXCESSGENERATIONBLOCKS_n$	The set of penalty blocks for excess generation at node *n*. Indexed by *j*.
$GENERATIONOFFERBLOCKS_g$	The set of *price-quantity pairs* for the *energy offer g*. Indexed by *j*.
GENCONRESERVEOFFERS	The subset of GENRESERVEOFFERS that have been submitted by the *dispatch coordinators* for *generation registered facilities* for the purposes of offering contingency *reserve*, as set out in Section A.2.4 of Appendix 5A.
GENPRIRESERVEOFFERS	The subset of GENRESERVEOFFERS that have been submitted by the *dispatch coordinators* for *generation registered facilities* for the purposes of offering primary *reserve*, as set out in Section A.2.2 of Appendix 5A.
GENRESERVEOFFERS	The subset of RAWRESERVEOFFERS that have been submitted by the *dispatch coordinators* for *generation registered facilities*.
GENREGULATIONOFFERS	The subset of REGULATIONOFFERS that have been submitted by the *dispatch coordinators* for *generation registered facilities*
INTERTIEENERGYBIDS	The set of *energy bids* created by the *EMC* in accordance with section D.9A.4

	to represent scheduled export *energy* flows across the *interties*. A subset of ENERGYBIDS.
INTERTIEENERGYOFFERS	The set comprising *energy offers* created by the *EMC* in accordance with section D.9A.4 to represent scheduled import energy flows across the *interties*. A subset of ENERGYOFFERS.
LINES	The set of all *dispatch network lines* in the dispatch network representation of the *transmission system*, referenced by *k*.
$LINES_n$	The set of all *dispatch network lines* which are connected to node *n*. A subset of LINES.
$MULTICONSTRAINTSLINESGROUP_s$	A subset of LINES grouped together for the purpose of expressing multi-unit constraint $s \in$ MULTIUNITCONSTRAINTS. Indexed by *k*.
LOADZONES	The set of *load zones* associated with *load registered facilities*.
MULTIUNITCONSTRAINTS	The set of constraints on the ratios of injections at different connection points of a *multi-unit facility*. Indexed by *s*.
NODES	The set of all *dispatch network nodes* in the dispatch network representation of the *transmission system*, referenced by *n*.
$NODES_p$	The set of *dispatch network nodes* that are associated with *energy bid p*, where $p \in$ RESTRICTEDENERGYBIDS.
PSTLINES	The set of *pst lines*. A subset of LINES.
$PURCHASEBIDBLOCKS_p$	The set of *bid* blocks for the *energy bid p*. Indexed by *j*.
$RAWRESERVEBLOCKS_r$	The set of *price-quantity pairs* for the *reserve offer r*. Indexed by *j*.
RAWRESERVEOFFERS	The set of *reserve offers*, referenced by *r*.

RAWRESERVEOFFERS$_x$	The set of *reserve offers* that come from *reserve provider group x*. A subset of RAWRESERVEOFFERS.
REFERENCENODE	The singleton set whose element is the *dispatch network node* that is the reference node for the Singapore system.
REGULATIONOFFERBLOCKS$_l$	The set of *regulation offer price-quantity pairs* for the *regulation offer l*. Indexed by *j*.
REGULATIONOFFERS	The set of *regulation offers*, referenced by *l*.
RESERVECLASSES	The set of *reserve classes* referenced by *c*, comprising primary *reserve class* (indexed by primary) and contingency *reserve* class (indexed by contingency).
RESERVEGROUPBLOCKS$_x$	The set of blocks of the aggregate *reserve* response from *reserve providers* belonging to *reserve provider group x*.
RESERVEGROUPS	The set of *reserve provider groups*. Indexed by *x*.
RESERVEGROUPS$_c$	The set of *reserve provider groups* associated with *reserve class c*. A subset of RESERVEGROUPS.
RESTRICTEDENERGYBIDS	The set of *restricted energy bids* submitted by the *dispatch coordinators* for *LRFs with REB*. A subset of ENERGYBIDS.
RESTRICTEDENERGYBIDS$_n$	The set of *restricted energy bids* which are deemed to be associated with the *dispatch network node n*. A subset of RESTRICTEDENERGYBIDS.
RESTRICTEDENERGYBIDS$_z$	The set of *restricted energy bids* which are associated with the *load zone z*. A subset of RESTRICTEDENERGYBIDS.
RISKGENERATORS	The set of all *energy offers* which are associated with *generation registered facilities* that are considered a primary contingency risk. A subset of

	ENERGYOFFERS.
SECONDARYRISKGENERATORS	The set of all *energy offers* which are associated with *generation registered facilities* that are considered a secondary risk, that is *generation registered facilities* that may fail as a result of the frequency drop during a primary contingency. A subset of ENERGYOFFERS
SECURITYCONSTRAINTS	The set of all *security constraints*, referenced by *s*.
SECURITYGENERATIONGROUP$_s$	A subset of ENERGYOFFERS grouped together for the purpose of expressing *security constraint s*.
SECURITYLINESGROUP$_s$	A subset of LINES grouped together for the purpose of expressing *security constraint s*.
SECURITYNODESGROUP$_s$	A subset of NODES grouped together for the purpose of expressing *security constraint s*.
SECURITYSTORAGETRANSFERGROUP$_s$	A subset of ENERGYSTORAGEOFFERS grouped together for the purpose of expressing *security constraint* s.
STORAGEREGULATIONOFFERS	The subset of REGULATIONOFFERS that have been submitted by the *dispatch coordinators* for *energy storage facilities.*
STORAGERESERVEOFFERS	The subset of RAWRESERVEOFFERS that have been submitted by the *dispatch coordinators* for *energy storage facilities*.
TIEDENERGYOFFERBLOCKPAIR$_o$	The o^{th} pair of *price-quantity pairs* identified under section D.9C.2.
TIEDENERGYOFFERBLOCKPAIRS	The set of all pairs of *price-quantity pairs* identified under section D.9C.2. Indexed by *o*.
TIEDREGULATIONOFFERBLOCKPA	The o^{th} pair of *price-quantity pairs*

IR_o	identified under section D.9C.4.
TIEDREGULATIONOFFERBLOCKPAIRS	The set of all pairs of *price-quantity pairs* identified under section D.9C.4. Indexed by *o*.
$TIEDRESERVEOFFERBLOCKPAIR_o$	The o^{th} pair of *price-quantity pairs* identified under section D.9C.3.
TIEDRESERVEOFFERBLOCKPAIRS	The set of all pairs of *price-quantity pairs* identified under section D.9C.3. Indexed by *o*.
$UNITS_g$	The set of all constituent *generating units* that form part of the *multi-unit facility* associated with *energy offer g*.
$VIOLATIONGROUPBLOCKSFAC_{y(g)}$	The set of violation penalty blocks for violation of violation constraint group *y(g)* which consists of violations associated with *generation registered facilities*. Indexed by *j*.
$VIOLATIONGROUPBLOCKSFAC_{y(es)}$	The set of violation penalty blocks for violation of violation constraint group *y(es)* which consists of violations associated with *energy storage facilities*. Indexed by *j*.
$VIOLATIONGROUPBLOCKSFAC_{y(p)}$	The set of violation penalty blocks for violation of violation constraint group *y(p)* which consists of violations associated with the *LRF with REB* associated with *energy bid p*. Indexed by *j*.
$VIOLATIONGROUPBLOCKSLIN_{y(k)}$	The set of violation penalty blocks for violation of violation constraint group *y(k)* which consists of violations associated with lines. Indexed by *j*.
$VIOLATIONGROUPBLOCKSREG_{y(regulation)}$	The set of violation penalty blocks for violation of violation constraint group *y(regulation)* which consists of violations associated with *regulation* requirements. Indexed by *j*.
$VIOLATIONGROUPBLOCKSRES_{y(c)}$	The set of violation penalty blocks for violation of violation constraint group

	y(c) which consists of violations associated with *reserve* requirements for *reserve class c*. Indexed by *j*.
$VIOLATIONGROUPBLOCKSSEC_{y(s)}$	The set of violation penalty blocks for violation of violation constraint group *y(s)* which consists of violations associated with *security constraints*. Indexed by *j*.
$VIOLATIONGROUPBLOCKS_{y}$	The set of violation penalty blocks for violation of violation constraint group *y*. Indexed by *j*, in ascending order of violation group block penalty if multiple violation group blocks apply to a violation constraint group, as set out in section J.3 of Appendix 6J.
VIOLATIONGROUPS	The set of violation constraint groups, indexed by *y*. Violation constraint groups are used to group together violations of constraints. Each violation constraint group is associated with only one type of entity: lines, *reserve* requirement, *regulation* requirement, facility or *security constraint*.

D.3 PARAMETERS

D.3.1 Unless otherwise stated, a reference to a *generation registered facility* in this D.3 does not include a reference to a *generation registered facility* that is an *energy storage facility*.

AcceptableFreqDeviation$_c$	A scaling factor to represent the maximum frequency deviation that is acceptable in the event of a system event, for *reserve class c*. This factor is the ratio of the maximum acceptable frequency deviation to the nominal frequency. Determined based on *intertie* status, in accordance with section D.13B.2.
ActualLoss$_k$	The *dispatch network line* loss calculated for *dispatch network line k* after the linear program is solved, in the event that it is suspected that the linear program has not calculated the *dispatch network line* loss correctly. Calculated in accordance with section D.22.4.
AdditionalNumPoints$_k$	The additional number of line flow/line loss points used to represent *dispatch network line k* for the purpose of constraint relaxation. Set by the *EMC*.
ChargingEfficiency$_{es}$	The factor representing the expected increase in *energy* stored (in MWh) due to charging of the *energy storage facility* associated with *energy storage offer es* at 1MW for one hour, divided by 1MWh. Set from the *standing capability data* referred to in Appendix 6E section E.1A.1.15.
CircuitError$_k$	The difference between the *dispatch network line* loss calculated within the linear program and the *dispatch network line* loss calculated after the linear program has solved for *dispatch network line k*. Calculated in accordance with section D.22.4.
CombinedRampThreshold	The threshold in seconds that determines which instances of the combined ramping, *reserve* and *regulation* constraints, specified in section D.19.2, will be included in the linear program. Set by the *EMC*.
ConResSustainTime	The required sustain time for contingency *reserve class*, in seconds. Set in accordance with

	Appendix 5A section A.2.4
$DeficitGenerationBlockMax_{n,j}$	The maximum violation for block *j* of *energy* shortfall at *dispatch network node n*. Set by the *EMC* in accordance with Appendix 6J.
$DeficitGenerationPenalty_{n,j}$	The per MW constraint violation cost associated with block *j* of *energy* shortfall at *dispatch network node n*. Set from the *values* in Appendix 6J.
$DegreeShiftPerTap_{k}$	The degree of phase angle shift in radian units that will result from a change from one tap position to the next immediate tap position of the phase-shifting transformer of *pst line k* at no load condition. Received from the *PSO* in accordance with Appendix 6G section G.4.4A.
$DischargingEfficiency_{es}$	The factor representing 1MWh divided by the expected decrease in *energy* stored (in MWh) due to discharging of the *energy storage facility* associated with *energy storage offer es* at 1MW for one hour. Set from the *standing capability data* referred to in Appendix 6E section E.1A.1.14.
DispatchPeriod	The length in seconds of the dispatch period. This shall be 1800.
$DownRampRate_{g}$, $\underline{DownRampRate_{es}}$ or $DownRampRate_{p}$	The maximum ramp-down rate of the *generation registered facility* that the *energy offer g* is for, the *energy storage facility* that the *energy storage offer es* is for, or the *LRF with REB* that the *energy bid p* is for, in MW/minute. Set from the values stated in valid *energy offers* referred to in section 5.2.2.6 of Chapter 6, in valid *energy storage offers* referred to in section 5.2B.2.6 of Chapter 6, or in valid *restricted energy bids* referred to in section 5.2A.2.6 of Chapter 6.
$Effectiveness_{x,j}$	The effectiveness multiplier of raw *reserve* in block *j* of *reserve provider group x*. Received from the *PSO* in accordance with Appendix 6G section G.5.3.
$EndSoC_{es}$	The forecast *SoC* level at the end of a given *dispatch period* of an *energy storage facility* associated with *energy storage offer es* for that *dispatch period*, which shall be determined in

	accordance with section D.25.
$EnergyStorageBlockLimit_{es,j}$	The limit on the MW which can be scheduled from block *j* of $ENERGYSTORAGEOFFERBLOCKS_{es}$ for *energy storage offer es* in the set ENERGYSTORAGEOFFERS. Determined by the *price-quantity pairs* for valid *energy storage offers*. For the offers referred to in section 5.2B.2.4 of Chapter 6 for charging the *energy storage facility* this limit will be negative, and for the offers referred to in section 5.2B.2.4 of Chapter 6 for discharging the *energy storage facility* this limit will be positive.
$EnergyStorageOfferPrice_{es,j}$	The per MWh price assigned to *energy storage offer* es ∈ ENERGYSTORAGEOFFERS applicable to offer block *j* ∈ $ENERGYSTORAGEOFFERBLOCKS_{es}$. Set from the *price-quantity pairs* for valid *energy storage offers* referred to in section 5.2B.2.4 of Chapter 6.
$EnergyTransferEndMax_{es}$	The maximum end of *dispatch period* MW output for the *energy storage facility* associated with *energy storage offer* es, given its forecast status at the beginning of the *dispatch period*. Calculated in accordance with section D.12A.
$EnergyTransferEndMin_{es}$	The minimum end of *dispatch period* MW output for the *energy storage facility* associated with *energy storage offer* es, given its forecast status at the beginning of the *dispatch period*. Calculated in accordance with section D.12A.
$EstGTOutputDamping_{c}$	A scaling factor to represent the estimated contribution of GT output damping to the calculation of PowerSystemResponse, for *reserve class c*. This factor is the ratio of estimated GT output reduction to frequency deviation. The factor is applied to the output of *generation registered facilities* that are members of the set DAMPINGGENERATORS. Supplied by the *PSO* in accordance with section G.5.11 of Appendix 6G.
$EstimatedReactivePowerFlow_{k}$	The estimated net reactive power flow along

	dispatch network line k at the end of the *dispatch period*. This may be positive or negative. Calculated in accordance with section D.10.1
EstIntertieContribution	A scaling factor to represent the estimated contribution of the *intertie* to the calculation of PowerSystemResponse. Determined based on *intertie* status, in accordance with section D.13B.1.
$EstLoadDamping_c$	A scaling factor to represent the estimated contribution of load damping to the calculation of PowerSystemResponse, for *reserve class c*. This factor is the ratio of the estimated demand reduction to frequency deviation. Supplied by the *PSO* in accordance with Appendix 6G section G.5.10.
$EstReserveEffectiveness_r$	The estimated *reserve* effectiveness of *reserve* from *reserve offer r*, calculated in accordance with section D.11. In the case of a *generation registered facility*, it is used when calculating the effective risk due to a failure of the *generation registered facility*.
$ExcessGenerationBlockMax_{n,j}$	The maximum violation for block *j* of *energy* surplus at *dispatch network node n*. Set by the *EMC* in accordance with Appendix 6J.
$ExcessGenerationPenalty_{n,j}$	The per MW constraint violation cost associated with block *j* of *energy* surplus at *dispatch network node n*. Set from the *values* in Appendix 6J.
$ExpectedStartGeneration_g$	The forecast generation level at the beginning of a given *dispatch period* of a *generation registered facility* associated with *energy offer g* for that *dispatch period,* which shall be determined in accordance with section D.12.5.
$ExpectedStartGeneration_{es}$	The forecast generation level at the beginning of a given *dispatch period* of an *energy storage facility* associated with *energy storage offer es* for that *dispatch period*, which shall be determined in accordance with section D.12A.5.
$ExpectedStartSoC_{es}$	The forecast *SoC* level at the beginning of a given *dispatch period* of an *energy storage facility* associated with *energy storage offer es*

	for that *dispatch period,* which shall be determined in accordance with sections D.12B.1 to D.12B.5.
$FixedLosses_k$	The fixed losses attributed to *dispatch network line k*. Received from the *PSO* in accordance with Appendix 6G section G.4.4.
$GenerationBlockMax_{g,j}$	The maximum MW which can be scheduled from block $j \in GENERATIONOFFERBLOCKS_g$ for *energy offer* $g \in$ ENERGYOFFERS. Set from the *price-quantity pairs* for valid *energy offers* referred to in section 5.2.2.4 of Chapter 6, or from the *PSO intertie schedules* in accordance with section D.9A.6.1.
$GenerationEndMax_g$	The maximum end of *dispatch period* MW output for the *generation registered facility* associated with *energy offer g,* given its forecast status at the beginning of the *dispatch period*. Calculated in accordance with section D.12.
$GenerationEndMin_g$	The minimum end of *dispatch period* MW output for the *generation registered facility* associated with *energy offer g,* given its forecast status at the beginning of the *dispatch period*. Calculated in accordance with section D.12.
$GenerationOfferPrice_{g,j}$	The per MWh price assigned to *energy offer* $g \in$ ENERGYOFFERS applicable to offer block $j \in GENERATIONOFFERBLOCKS_g$. Set from the *price-quantity pairs* for valid *energy offers* referred to in section 5.2.2.4 of Chapter 6 or in the case of offers representing power flows across the *intertie*, set by the *PSO* in accordance with section 2.3 of this Chapter.
$GenerationMax_g$	The maximum generation output for the *generation registered facility* associated with *energy offer g*. Set from the *standing capability data* referred to in Appendix 6E section E.1.1.2.
$GenericSecurityLimit_s$	The minimum limit for *security constraint s*. Received from the *PSO* in accordance with section G.5.1 of Appendix 6G.
$GroupResponseMax_{x,j}$	The maximum response allowed from block *j* of *reserve provider group x*. Received from the

	PSO in accordance with Appendix 6G section G.5.3.
$HighLoad_g$	The *energy* output of the *generation registered facility* associated with *energy offer g*, that is calculated by multiplying the constant, HighLoadFactor, by the parameter, $StandingReserveGenerationMax_g$.
HighLoadFactor	A constant equal to 0.9 that is used in the determination of the parameter, $HighLoad_g$.
$HighLoadReserve_r$	The quantity of *reserve* in MW that can be provided by a *generation registered facility* operating with an *energy* output of $HighLoad_{g(r)}$ and offering *reserve offer r*.
$ILProportionMax_c$	The maximum proportion of the $Risk_c$ that can be covered by *reserve of reserve class c* provided by *load registered facilities*. Received from the *PSO* in accordance with Appendix 6G section G.5.3C.
InfinitePositiveValue	A relatively large positive value applied in sections D.15.1.3, D.17.2.8, D.17.4.2, and D.18.1 as a selector variable coefficient.
$LineAdmittance_k$	The "admittance" [1] of transmission line *k*. Calculated in accordance with section D.9.1.
$LineFlowConst_{k,j}$	The *dispatch network line* flow (in the conventional forward direction) associated with point *j* of the loss representation of line *k*. Since losses are assigned equally to each end of the line, the flow is notionally measured at the "midpoint" of the line. A negative value indicates flow in the conventional reverse direction. Calculated in accordance with section D.9.3.
$LineLossConst_{k,j}$	The *dispatch network line* loss associated with point *j* of the loss representation of *dispatch network line k*. Includes both fixed and variable losses. Calculated in accordance with section

[1] Technically, the susceptance "B" of the branch is used. However the loose use of "admittance" is widespread, and is maintained here.

	D.9.4.
$LineMaxForward_k$	The forward maximum available capacity of transmission line $k \in$ LINES. Calculated in accordance with section D.10.
$LineMaxReverse_k$	The reverse maximum available capacity of transmission line $k \in$ LINES. A negative quantity. Calculated in accordance with section D.10.
$LineRatingForward_k$	The operational capacity rating of *dispatch network line k* in the conventional forward direction. Received from the *PSO* in accordance with Appendix 6G section G.4.3.
$LineRatingReverse_k$	The operational capacity rating of *dispatch network line k* in the conventional reverse direction. Received from the *PSO* in accordance with Appendix 6G section G.4.3.
$LowLoad_g$	The lowest *load* in MW at which the *generation registered facility* associated with *energy offer g*, can provide *reserve* that meets the requirements of the *transmission code*.
$LowLoadReserve_r$	The quantity of *reserve* in MW that can be provided by a *generation registered facility* operating with an *energy* output of $LowLoad_g$ and offering *reserve offer r*.
$MaxCapacity_{es}$	The maximum *energy* storage capacity, in MWh, of the *energy storage facility* associated with *energy storage offer es*. Set from the *standing capability data* referred to in Appendix 6E section E.1A.1.11.
$MaximumChargeLimit_{es}$	The maximum rate, in MW, at which an *energy storage facility* can withdraw electrical *energy* from the *transmission system*. Received from the *PSO* in accordance with Appendix 6E section E.1A.1.2.
$MaximumDischargeLimit_{es}$	The maximum discharge limit representing the maximum rate, in MW, at which, an *energy storage facility* can inject electrical *energy* into the *transmission system*. Received from the *PSO* in accordance with Appendix 6E section

	E.1A.1.3.
$MaxLineRating_k$	The largest absolute value operational capacity of the *dispatch network line k* in either direction. Calculated in accordance with section D.9.3
$MaxResponse_l$	The maximum change in generation output possible for *regulation* purposes for *regulation offer l*, assuming no underlying energy ramp. Calculated in accordance with section D.13.3.
$MaxResponse_r$	The maximum change in generation output possible for *reserve* purposes for *reserve offer r*, assuming no underlying energy ramp. Calculated in accordance with section D.13.1.
$MaxSoC_{es}$	The maximum *SoC* acceptable to the *energy storage facility* associated with *energy storage offer es*. Set from the *standing capability data* referred to in Appendix 6E section E.1A.1.12.
$MediumLoad_g$	The *energy* output of the *generation registered facility* associated with *energy offer g*, that is calculated by multiplying the constant, MediumLoadFactor, by the parameter, $StandingReserveGenerationMax_{g.}$
MediumLoadFactor	A constant equal to 0.75 that is used in the determination of the parameter, $MediumLoad_{g.}$
$MediumLoadReserve_r$	The quantity of *reserve* in MW that can be provided by a *generation registered facility* operating with an *energy* output of $MediumLoad_{g(r)}$ and offering *reserve offer r*.
MinimumRegulation	The minimum *regulation* required to correct any *power system* frequency variations or imbalances between *load* and output from *generation facilities*. Received from the *PSO* in accordance with section G.5.6A of Appendix 6G.
$MinimumRisk_c$	The minimum contingency risk to be covered by the aggregate system response in *reserve class c*. Received from the *PSO* in accordance with section G.5.4 of Appendix 6G.
$MinimumStableLoad_g$	The minimum output level in MW of a *generation registered facility* associated with

	energy offer g, at which the *generation registered facility* can maintain stable operation. Set in accordance with section E.1.1.14 of Appendix 6E. For other *generation registered facilities*, this takes on a value of zero.
$MinSoC_{es}$	The minimum *SoC* acceptable to the *energy storage facility* associated with *energy storage offer es*. Set from the *standing capability data* referred to in Appendix 6E section E.1A.1.13.
$MultiGroupLineWeights_{s,k}$	The parameter associated with the artificial *dispatch network line k* and the multi-unit constraint *s*, which constrains the ratio of injections for the injection points of a *multi-unit facility*. Set in accordance with section D.8.7 and D.8.8.
$NumPoints_{k}$	The number of line flow/line loss points used to represent *dispatch network line k*. Set by the *EMC*.
$OfferedCapacity_{g}$	The maximum combined capacity of the *generation registered facility* for *energy*, *reserve* and *regulation* stated in *energy offer g* under section 5.2.2.5 of Chapter 6.
$OfferedCapacity_{es}$	The maximum combined transfer limit of the *energy storage facility* for *energy*, *reserve* and *regulation* stated in *energy storage offer es* under section 5.2B.2.5 of Chapter 6.
$PriorScheduledGeneration_{g}$	In respect of a *generation registered facility* associated with an *energy offer g* for a given *dispatch period*, either: (a) the scheduled *energy* in the *real-time dispatch schedule* for that *generation registered facility* for the prior *dispatch period*, or (b) in the event that such *real-time dispatch schedule* is not available, that *generation registered facility's* $StartGeneration_{g}$.
$PriorScheduledGeneration_{es}$	In respect of an *energy storage facility* associated with an *energy storage offer es* for a given *dispatch period*, either: (a) the scheduled *energy* in the *real-time*

	dispatch schedule for that *energy storage facility* for the prior *dispatch period*, or (b) in the event that such *real-time dispatch schedule* is not available, that *energy storage facility's* $StartGeneration_{es}$.
$PriorScheduledPurchase_{p}$	The MW quantity of scheduled *energy* withdrawal for the *LRF with REB* associated with *energy bid p* for the immediately preceding *dispatch period*. Determined in accordance with section D.12.10 to D.12.13.
PriResSustainTime	The required sustain time for primary *reserve class*, in seconds. Set in accordance with Appendix 5A section A.2.2.
$Proportion_{p,n}$	The proportion of the *bid* quantity from *energy bid p* that is deemed to be at *dispatch network node n*, where $p \in$ RESTRICTEDENERGYBIDS, $n \in NODES_p$ and $\sum_{n \in NODES_p} Proportion_{p,n} = 1$.
$Proportion_{u}$	The default proportion of generation for *generating unit u* of a *multi-unit facility*, specified by the *EMC* in accordance with section D.7.3. The number specified must be greater than zero.
$PSTTapPosition_{k}$	The integer value assigned to the tap position of the phase-shifting transformer of *pst line k.* Used in accordance with Appendix 6D section D.13C.
$PurchaseBidPrice_{p,j}$	The per MW price assigned to *energy bid* $p \in$ ENERGYBIDS applicable to *energy bid* block $j \in PURCHASEBIDBLOCKS_p$. Set in accordance with section D.9A.
$PurchaseBlockMax_{p,j}$	The maximum MW to be scheduled in block $j \in PURCHASEBIDBLOCKS_p$ for *energy bid* $p \in$ ENERGYBIDS. Set from the *nodal load forecast* in accordance with section D.9A.3.1, from the *intertie schedules* in accordance with section D.9A.5.1, or from *energy bids* submitted for *LRFs with REB*.
$PurchaseEndMax_{p}$	The maximum end-of-*dispatch period* MW *energy* withdrawal for the *LRF with REB* associated with *energy bid p*. Calculated in

	accordance with section D.12.8.
$PurchaseEndMin_p$	The minimum end-of-*dispatch period* MW *energy* withdrawal for the *LRF with REB* associated with *energy bid p*. Calculated in accordance with section D.12.9.
RampingTime	10 minutes, or such other time period as may be determined by the *EMC* in consultation with the *PSO*.
$RawReserveBlockMax_{r,j}$	The maximum MW to be scheduled in block $j \in RAWRESERVEBLOCKS_r$ for *reserve offer* $r \in$ RAWRESERVEOFFERS. Set from the *price-quantity pairs* for valid *reserve offers* referred to in section 5.3.2.5 of Chapter 6.
$Reactance_k$	The reactance of *dispatch network line k*. Received from the *PSO* in accordance with Appendix 6G section G.4.4.
$RegulationBlockMax_{l,j}$	The maximum MW to be scheduled in block $j \in REGULATIONOFFERBLOCKS_r$ for *regulation offer* $l \in$ REGULATIONOFFERS. Set from the *price-quantity pairs* for valid *regulation offers* referred to in section 5.4.3.4 of Chapter 6.
$RegulationMax_g$	The maximum output for which *automatic generator control* (*AGC*) or other signals acceptable to the *PSO* can operate the *generation registered facility* associated with *energy offer g* to provide *regulation* capability. Calculated in accordance with section D.9A.8.
$RegulationMax_{es}$	The maximum *energy* transfer level at which *automatic generator control* (*AGC*) or other signals acceptable to the *PSO* can operate the *energy storage facility* associated with *energy storage offer es* to provide *regulation* capability. Calculated in accordance with section D.9A.8A.
$RegulationMin_g$	The minimum output for which *automatic generator control* (*AGC*) or other signals acceptable to the *PSO* can operate the *generation registered facility* associated with *energy offer g* to provide *regulation* capability. Set from the *standing capability data* referred to in Appendix 6E section E.1.1.10.

$\text{RegulationMin}_{es}$	The minimum *energy* transfer level at which *automatic generator control* (*AGC*) or other signals acceptable to the *PSO* can operate the *energy storage facility* associated with *energy storage offer es* to provide *regulation* capability. Set from the *standing capability data* referred to in Appendix 6E section E.1A.1.10.
$\text{RegulationOfferPrice}_{l,j}$	The per MW price assigned to *regulation offer* $l \in$ REGULATIONOFFERS applicable to *offer* block $j \in \text{REGULATIONOFFERBLOCKS}_l$. Set from the *price-quantity pairs* for valid *regulation offers* referred to in section 5.4.3.4 of Chapter 6.
RegulationRequirement	The MW amount of *regulation* required. Received from the *PSO* in accordance with Appendix 6G section G.5.6.
RegulationResponsePeriod	The allowable response time period for regulation, in seconds.
RegulationResponseRatio	The ratio that converts energy ramping to units that may be compared with those used for ramping due to *regulation*. Calculated in accordance with section D.13.4.
RemainingTime	The length in seconds remaining in the dispatch period. This shall be the lesser of 1800 and the number of seconds from when the schedule is expected to be implemented until the end of the *dispatch* period. Calculated from the system clock and a parameter set by the *EMC* representing the estimated elapsed time to produce a schedule.
$\text{ReserveGenerationMax}_r$	The maximum combined generation and *reserve* of the relevant class that can be provided by the *generation registered facility* or *energy storage facility* associated with *reserve offer r*. Calculated in accordance with section D.9A.7 and D.9A.7A.
$\text{ReserveOfferPrice}_{r,j}$	The per MW price assigned to *reserve offer* $r \in$ RAWRESERVEOFFERS applicable to *offer* block $j \in \text{RAWRESERVEBLOCKS}_r$. Set from the *price-quantity pairs* for valid *reserve offers* referred to in section 5.3.2.5 of Chapter 6.

$ReserveProportion_r$	The ratio limiting the quantity of *reserve* that can be provided by a *generation registered facility* to a proportion of the generation output respectively. Set from the values stated in valid *reserve offers* referred to in section 5.3.2.6 of Chapter 6.
$ReserveProportionCombined_r$	The maximum of $ReserveProportion_r$ and $ReserveResponseRatio_r$. Calculated in accordance with section D.13.5.
$ReserveResponsePeriod_c$	The allowable response time period for *reserve class c*, in seconds. Set in accordance with Appendix 5A section A.2.
$ReserveResponseRatio_r$	The ratio that converts *energy* ramping to comparable units to ramping due to *reserve* for *reserve offer r*. Calculated in accordance with section D.13.2.
$Resistance_k$	The resistance of *dispatch network line k*. Received from the *PSO* in accordance with Appendix 6G section G.4.4.
$ResponseDelay_r$	The time delay, in seconds, before the *generation registered facility* associated with raw *reserve offer r* begins to respond following a *contingency event*. Set from the *standing capability data* referred to in section E.1.1.11 of Appendix 6E.
$RevisedMaxLineRating_k$	The new max line rating that is calculated based on the number of additional flow/line points used to represent *dispatch network line k* for the purpose of constraint relaxation.
$RiskAdjustmentFactor_c$	The factor which re-scales the risk to be met, in *reserve class c*, according to system conditions (e.g. inertia) at the time. Received from the *PSO* in accordance with Appendix 6G section G.5.5.
$SecurityGroupGenerationWeight_{s,g}$	The weighting attached to *energy offer g*'s *dispatched* generation in *security constraint s*. Received from the *PSO* in accordance with section G.5.1 of Appendix 6G.
$SecurityGroupLineWeight_{s,k}$	The weighting attached to *dispatch network line k*'s flow in *security constraint s*. Received from

	the *PSO* in accordance with section G.5.1 of Appendix 6G.
$SecurityGroupNodeWeight_{s,n}$	The weighting attached to *dispatch network node n*'s net injection in *security constraint s*. Received from the *PSO* in accordance with section G.5.1 of Appendix 6G.
$SecurityGroupStorageTransferWeight_{s,es}$	The weighting attached to *energy storage offer es's dispatched* generation in *security constraint* s. Received from the *PSO* in accordance with section G.5.1 of Appendix 6G.
$SoCChargeLimitMWh_{es}$	The MWh limit on *energy* charging for the *energy storage facility* associated with *energy storage offer es*. This limit is applied in order to ensure *energy storage facility* associated with *energy storage offer es* operates below $MaxSoC_{es}$ given $ExpectedStartSoC_{es}$. Calculated in accordance with section D.12B.7.
$SoCDischargeLimitMWh_{es}$	The MWh limit on *energy* discharging for the *energy storage facility* associated with *energy storage offer es.* This limit is applied in order to ensure *energy storage facility* associated with *energy storage offer es* operates above $MinSoC_{es}$ given $ExpectedStartSoC_{es}$. Calculated in accordance with section D.12B.6.
$StandingReserveGenerationMax_{g(r)}$	The maximum combined generation and *reserve* of the relevant class that can be provided by the *generation registered facility* associated with *reserve offer r* in *standing capability data*. Set in accordance with Appendix 6E, section E.1.1.6.
$StartGeneration_{g}$	The forecast generation level at the beginning of a given *dispatch period* of a *generation registered facility* associated with *energy offer g* for that *dispatch period*. For *multi-unit facilities*, this is calculated in accordance with sections D.8.3 to D.8.6. For other *generation registered facilities* this is calculated in accordance with sections D.12.1 to D.12.4.
$StartGeneration_{u}$	The forecast generation level at the beginning of a given *dispatch period* of *generating unit u*. Received from the *PSO* in accordance with

	section G.3.1 of Appendix 6G.
$StartGeneration_{es}$	The forecast generation level at the beginning of a given *dispatch period* of a *generation registered facility* associated with *energy storage offer es* for that *dispatch period*. Calculated in accordance with sections D.12A.1 to D.12A.4.
$StartSoC_{es}$	The *SoC* level of an *energy storage facility* associated with *energy storage offer es* for that *dispatch period*, as received from the *PSO* in accordance with section G.3.4 of Appendix 6G.
StatusDataLifeMax	The maximum interval, measured in seconds, between the start of the *dispatch period* for which the *EMC* will use the status data on the network elements referred to in section D.6.1.2 and the compilation of the data by the *PSO*. Defined by the *EMC* in accordance with section D.6.6.
SysError	The total across the dispatch network of all of the differences between the line losses calculated within the linear program and the line losses calculated after the linear program has solved. Calculated in accordance with section D.22.4.
SystemLoadResponseMax	The maximum of the aggregate of *reserve* response and *load curtailment* allowed in respect of *load registered facilities* on a system-wide basis. Received from the *PSO* in accordance with section G.5.3D of Appendix 6G.
T1Margin	A margin parameter set by *EMC* to determine the forward maximum available capacity for the *dispatch network lines* referred to in section D.8.2.
$TapMax_k$	The largest of the integer values assigned to each of the tap positions of the phase-shifting transformer of *pst line k*. Received from the *PSO* in accordance with Appendix 6G section G.4.4A.
$TapMin_k$	The smallest of the integer values assigned to each of the tap positions of the phase-shifting transformer of *pst line k*. Received from the *PSO*

	in accordance with Appendix 6G section G.4.4A.
$TapZero_k$	The integer value assigned to the tap position of the phase-shifting transformer of *pst line k that* results in a zero degree phase angle shift on that line *k*. Received from the *PSO* in accordance with Appendix 6G section G.4.4A.
TieBreakingPenaltyFactor	A factor having the value of 10^{-6}, or such other value as may be determined by the *EMC*.
$UpRampRate_g$, $UpRampRate_{es}$ or $UpRampRate_p$	The maximum ramp-up rate of the *generation registered facility* that the *energy offer g* is for, the *energy storage facility* that the *energy storage offer es* is for, or the *LRF with REB* that the *energy bid p* is for, in MW/minute. Set from the values stated in valid *energy offers* referred to in section 5.2.2.6 of Chapter 6, in valid *energy storage offers* referred to in section 5.2B.2.6 of Chapter 6, or in valid *restricted energy bids* referred to in section 5.2A.2.6 of Chapter 6.
$ViolationGroupBlockMax_{y,j}$	The maximum MW violation allowed in block *j* of violation constraint group *y*. Set from the values in Appendix 6J where such values are specified, unless otherwise set by the *PSO* in accordance with section 2.3 of Chapter 6.
$ViolationGroupBlockPenalty_{y,j}$	The per MW *constraint violation cost* associated with block *j* of violation constraint group *y*. Set from the values in Appendix 6J where such values are specified, unless otherwise set by the *PSO* in accordance with section 2.3 of Chapter 6.
$ViolationGroupProportion_c$	A constant equal to 0.2 for primary *reserve* and 0.3 for contingency *reserve*, that is used in the determination of violation group block quantities in section D.21.3.
$ZoneResponseMax_z$	The maximum of the aggregate of *reserve* response and *load curtailment* allowed in respect of *load registered facilities* in *load zone z*. Received from the *PSO* in accordance with section G.5.3B of Appendix 6G.

D.4 VARIABLES

D.4.1 Primal Linear Programme Variables: Unless otherwise noted, all primal linear programme variables are assumed to be non-negative.

CurtailedLoad_p	The MW amount of *energy bid* $p \in$ RESTRICTEDENERGYBIDS that is not scheduled to be withdrawn.
$\text{DeficitGenerationBlock}_{n,j}$	The block *j* MW deficit generation at node *n*.
DeficitMSL_g	The MW amount by which the constraint in section D.15.1.3.2 that limits the *dispatch* of *energy* for the *generation registered facility* associated with *energy offer g* to at least its minimum stable load is violated.
DeficitMulti_s	The MW deficit for multi-unit constraints.
DeficitRegGen_l	The MW amount by which the constraint giving the lower bound of output for regulation capability is breached for the *generation registered facility* (including *energy storage facility*) associated with *regulation offer l*.
DeficitRegulation	The MW deficit of *regulation*.
DeficitReserve_c	The MW deficit of *reserve class c*.
DeficitSecurity_s	The MW deficit for *security constraint s*.
$\text{DeficitWLineFlow}_k$	The MW flow on *dispatch network line k* below the flow consistent with the line flow/line loss weight variables.
$\text{EffectiveReserve}_x$	The total effective *reserve* contribution from all *reserve offers* cleared from *reserve provider group x*.
~~$\text{EnergyStorageBlock}_{es}$~~ $\text{EnergyStorageBlock}_{es,j}$	The MW scheduled in block *j* of *energy storage offer es*. This variable can be positive or negative, with a positive value indicating discharging and a negative value indicating charging.
$\text{EnergyStorageCharging}_{es}$	The charging MW amount scheduled for *energy storage offer es*.
$\text{EnergyStorageDischarging}_{es}$	The discharging MW amount scheduled for

	energy storage offer es.
$EnergyStorageTransfer_{es}$	The total MW transfer scheduled for *energy storage offer es*. This variable can be positive or negative, with a positive value indicating discharging and a negative value indicating charging.
$EnergyTieBreakSlack1_{o}$ $EnergyTieBreakSlack2_{o}$	The variables representing the extent to which the *energy* tie-breaking constraint associated with $TIEDENERGYOFFERBLOCKPAIR_{o}$ in section D.20A.1 is violated.
$ExcessCharging_{es}$	The MW amount by which the constraint giving the combined limit for the *energy* and *regulation* schedules for *energy storage facility* associated with *energy storage offer es* is exceeded.
$ExcessContingencyDischarging_{es}$	The MW amount by which the constraint giving the combined limit for the contingency *reserve*, *energy* and *regulation* schedules for *energy storage facility* associated with *energy storage offer es* is exceeded.
$ExcessDischarging_{es}$	The MW amount by which the constraint giving the combined limit for the *reserves*, *energy* and *regulation* schedules for *energy storage facility* associated with *energy storage offer es* is exceeded.
$ExcessDownRamp_{g}$, $ExcessDownRamp_{es}$ or $ExcessDownRamp_{p}$	The MW amount by which the maximum down ramp of the *generation registered facility* associated with *energy offer g*, the *energy storage facility* associated with *energy storage offer es*, or the *LRF with REB* associated with *energy bid p*, is exceeded.
$ExcessGenerationBlock_{n,j}$	The block *j* MW excess generation at *dispatch network node n*.
$ExcessLineFlowForward_{k}$	The MW flow on *dispatch network line k* above $LineMaxForward_{k}$, the maximum capacity in the forward direction.
$ExcessLineFlowReverse_{k}$	The MW flow on *dispatch network line k* below $LineMaxReverse_{k}$, the maximum capacity in the reverse direction.
$ExcessPrimaryDischarging_{es}$	The MW amount by which the constraint giving

	the combined limit for the primary *reserve*, *energy* and *regulation* schedules for *energy storage facility* associated with *energy storage offer es* is exceeded.
ExcessResGen Segment1$_r$	The MW amount by which the Reserve Generation Segment 1 constraint limiting the total simultaneous *dispatch* of generation and *reserve* (of the class to which *reserve offer r* belongs) from the same *generation registered facility* is exceeded.
ExcessResGen Segment2$_r$	The MW amount by which the Reserve Generation Segment 2 constraint limiting the total simultaneous *dispatch* of generation and *reserve* (of the class to which *reserve offer r* belongs) from the same *generation registered facility* is exceeded.
ExcessResGen Segment3$_r$	The MW amount by which the Reserve Generation Segment 3 constraint limiting the total simultaneous *dispatch* of generation and *reserve* (of the class to which *reserve offer r* belongs) from the same *generation registered facility* is exceeded.
ExcessWLineFlow$_k$	The MW flow on *dispatch network line k* above the flow consistent with the line flow/line loss weight variables.
ExcessMulti$_s$	The MW excess for multi-unit constraint *s*.
ExcessRawReserve$_r$	The MW amount by which the constraint limiting raw *reserve* from *reserve offer r* to a proportion of generation at the associated *generation registered facility*, is exceeded.
ExcessRegGen$_l$	The MW amount by which the constraint giving the upper bound of output for regulation capability is exceeded for the *generation registered facility* (including *energy storage facility*) associated with *regulation offer l*.
ExcessRegRamp$_l$	The MW amount by which the constraint giving the combined limit for ramping and regulation is exceeded for the *generation registered facility* associated with *regulation offer l*.
ExcessResGen$_r$	The MW amount by which the constraint limiting the total simultaneous *dispatch* of generation, *regulation* and *reserve* (of the class to which *reserve offer r* belongs) from the same *generation*

	registered facility (including *energy storage facility*) is exceeded.
$ExcessResPropRamp_r$	The MW amount by which the constraint giving the combined limit for ramping and *reserve* response as a fraction of generation output is exceeded for the *generation registered facility* associated with *reserve offer r*.
$ExcessResRamp_r$	The MW amount by which the constraint giving the combined limit for ramping and *reserve* response is exceeded for the *generation registered facility* associated with *reserve offer r*.
$ExcessMSL_g$	The MW amount by which the constraint in section D.15.1.3.1 that limits the *dispatch* of *energy* for the *generation registered facility* associated with *energy offer g* to zero is violated.
$ExcessUpRamp_g$, $ExcessUpRamp_{es}$ or $ExcessUpRamp_p$	The MW amount by which the maximum up ramp of the *generation registered facility* associated with *energy offer g*, the *energy storage facility* associated with *energy storage offer es*, or the *LRF with REB* associated with *energy bid p*, is exceeded.
$FacilityLineFlowViolation_g$	The total MW violation of connection line flow constraints associated with the *generation registered facility* that *energy offer g* is for.
$FacilityLineFlowViolation_{es}$	The total MW violation of connection line flow constraints associated with the *energy storage facility* that *energy storage offer es* is for.
$FacilityMSLViolation_g$	The total MW violation of the minimum stable load constraints associated with the *generation registered facility* that *energy offer* g is for.
$FacilityMultiUnitViolation_g$	The total MW violation of the multi-unit constraints associated with the *multi-unit facility* that *energy offer g* is for.
$FacilityRampViolation_g$	The total MW violation of the ramping constraints associated with the *generation registered facility* that *energy offer g* is for.
$FacilityRampViolation_{es}$	The total MW violation of the ramping constraints associated with the *energy storage facility* that *energy storage offer es* is for.

$\text{FacilityRampViolation}_{p}$	The total MW violation of ramping constraints associated with the *LRF with REB* associated with *energy bid p*.
$\text{FacilityRegulationViolation}_{g}$	The total MW violation of the *regulation* constraints associated with the *generation registered facility* that *energy offer g* is for.
$\text{FacilityRegulationViolation}_{es}$	The total MW violation of the *regulation* constraints associated with the *energy storage facility* that *energy storage offer es* is for.
$\text{FacilityReserveViolation}_{g}$	The total MW violation of the *reserve* constraints associated with the *generation registered facility* that *energy offer g* is for.
$\text{FacilityReserveViolation}_{es}$	The total MW violation of the *reserve* constraints associated with the *energy storage facility* that *energy storage offer es* is for.
$\text{FacilitySoCViolation}_{es}$	The total MW violation of the *SoC* constraints associated with the *energy storage facility* that *energy storage offer es* is for.
$\text{GenerationBlock}_{g,j}$	The MW generation scheduled in block *j* of *energy offer g*.
Generation_{g} or Generation_{h}	The total MW amount scheduled for *energy offer g* or *h*, respectively.
$\text{GroupResponse}_{x,j}$	The *jth* block of *reserve* response from *reserve offers* from *reserve provider group x*.
$\text{LoadEnergyReserveSelector}_{p(r)}$	Binary integer variable associated with the *LRF with REB* with *reserve offer r* and *energy bid p(r)*. A value of 0 indicates that it will be scheduled to provide *reserve* and must therefore be scheduled for its *energy* withdrawal in full, while a value of 1 indicates that it is not scheduled to provide *reserve*, and therefore need not be scheduled for its *energy* withdrawal in full.
LineFlow_{k}	The MW flow scheduled for *dispatch network line k* in the conventional direction of flow. This variable can be positive or negative, with negative values indicating flows in the reverse direction.
LineLoss_{k}	The MW losses for *dispatch network line k*.

$MSLSelector_g$	Binary integer variable associated with *energy offer g*, used for the modelling of a *generation registered facility's* minimum stable load level in section D.15.1.3.
$NodeAngle_n$	The voltage angle at *dispatch network node n*. This variable can be positive or negative.
$NodeNetInjection_n$	The net injection of electricity at *dispatch network node n*. This variable can be positive or negative.
$PurchaseBlock_{p,j}$	The MW *load* scheduled in block *j* of *energy bid p*.
$Purchase_p$	The total MW amount scheduled for *energy bid p*.
$Purchase_{p,n}$	The MW amount of *energy bid p* ∈ RESTRICTEDENERGYBIDS that is scheduled to be withdrawn from *dispatch network node n* ∈ $NODES_p$.
$RawReserveBlock_{r,j}$	The MW *reserve* scheduled in block *j* of *reserve offer r*.
$RawReserve_r$	The total MW amount scheduled for *reserve offer r*.
$RegulationBlock_{l,j}$	The MW *regulation* scheduled in block *j* of *regulation offer l*.
$Regulation_l$	The total MW amount scheduled for *regulation offer l*.
$RegulationEligibilitySwitch_l$	Binary integer variable associated with *regulation offer l*, used for modelling of regulation-generation constraints in section D.18.1.
$RegulationTieBreakSlack1_o$ $RegulationTieBreakSlack2_o$	The variables representing the extent to which the *regulation* tie-breaking constraint associated with $TIEDREGULATIONOFFERBLOCKPAIR_o$ in section D.20A.3 is violated.
$ReserveEligibilitySwitch_{g(r)}$	Binary integer variable, associated with the *generation registered facility* with *reserve offer r* and *energy offer g*, used for modelling of reserve-generation constraints in section D.17.2.8.
$ReserveTieBreakSlack1_o$	The variables representing the extent to which the *reserve* tie-breaking constraint associated with

$ReserveTieBreakSlack2_o$	$TIEDRESERVEOFFERBLOCKPAIR_o$ in section D.20A.2 is violated.
$Risk_c$	The MW risk to be covered by aggregate system response for *reserve class c*.
TieBreakingPenalties	The sum of all tie-breaking penalties arising from the violation of any tie-breaking constraints set out in section D.20A.
TotalPurchase	The total MW amount scheduled for all *energy bids p*, where $p \in$ ENERGYBIDS, $p \notin$ INTERTIEENERGYBIDS.
$ViolationGroupBlock_{y,j}$	The MW violation attributed to block *j* of violation constraint group *y*.
ViolationPenalties	The aggregate violation penalty cost of all constraint violations, as determined by the linear program. This aggregate amount is a sum formed by multiplying each violation group block penalty within the linear program, except those for *energy* deficit and excess, by its associated violation group block.
$Weight_{k,j}$	The weighting variable used in the *dispatch network line* loss and flow equations to constrain the losses to be weighted combinations of points on the loss curve. The weight given to point *j* on the representation of *dispatch network line k*. These variables are constrained to be in the range 0 to 1.
$ZoneResponse_{z,c}$	The total *reserve* response of *reserve class c* from *load registered facilities* in *load zone z*.

D.4.2 Linear Program Dual Variables

$EnergyPrice_n$	The dual variable corresponding to constraint D.16.1.2 for the *dispatch network node n*. Calculated as part of the solution to the linear program.
$ReservePrice_c$	The dual variable corresponding to constraint D.17.3.4 for the *reserve class c*. Calculated as part of the solution to the linear program.
RegulationPrice	The dual variable corresponding to constraint

	D.18.2.1. Calculated as part of the solution to the linear program.

D.4.3 Unless otherwise stated, a reference to a *generation registered facility* in this D.4 does not include a reference to a *generation registered facility* that is an *energy storage facility*.

D.5 FUNCTIONS

D.5.1 Unless otherwise stated, a reference to a *generation registered facility* in this D.5 does not include a reference to a *generation registered facility* that is an *energy storage facility*.

c(r)	References the *reserve class* associated with *reserve offer r*, and to which it contributes.
es(l)	References the *energy storage offer es* that has the same associated *generation registered facility that is* an *energy storage facility* as the *regulation offer l*
es(r)	References the *energy storage offer es* that has the same associated *generation registered facility that is* an *energy storage facility* as the *reserve offer r*
g(k)	References the *energy offer g* associated with the *generation registered facility* which is connected to the dispatch network by *dispatch network line* $k \in$ ARTIFICIALLINES1$\cup$ARTIFICIALLINES2.
g(l)	References the *energy offer g* that has the same associated *generation registered facility* as the *regulation offer l*.
(g(o),j(o)), (g'(o),j'(o))	References respectively each of the *price-quantity pairs* identified under section D.9C.2 belonging to TIEDENERGYOFFERBLOCKPAIR$_o$.
(g(o), j(o)), (es(o), j'(o))	References respectively each of the *price-quantity pairs* identified under section D.9C.5 belonging to TIEDENERGYOFFERBLOCKPAIR$_o$.
(es(o), j(o)), (es'(o), j'(o))	References respectively each of the *price-quantity pairs* identified under sections D.9C.6 and D.9C.7 belonging to TIEDENERGYOFFERBLOCKPAIR$_o$.
g(r)	References the *energy offer g* that has the same associated *generation registered facility* as the *reserve offer r*.
g(s)	References the *energy offer g* for the *multi-unit facility* that is associated with the multiconstraint $s \in$ MULTIUNITCONSTRAINTS.
k(g)	References the *dispatch network line* $k \in$ ARTIFICIALLINES1$\cup$ARTIFICIALLINES2 that connects the *generation registered facility* associated with *energy offer g* to the dispatch network.

k(es)	References the *dispatch network line* $k \in$ ARTIFICIALLINES2 that connects the *energy storage facility* associated with *energy storage offer es* to the dispatch network.
k(ST,g), k(GT,g), k(GT1,g), k(GT2,g)	References the artificial *dispatch network line* added to connect the *generation registered facility* associated with *energy offer g* to the connection point of the steam unit, the single gas turbine, or the first or second gas turbine of that *multi-unit facility* respectively.
l(g)	References the *regulation offer l* that has the same associated *generation registered facility* as the *energy offer g*.
l(es)	References the *regulation offer l* that has the same associated *energy storage facility* as the *energy storage offer es*.
(l(o),j(o)), (l'(o),j'(o))	References respectively each of the *price-quantity pairs* identified under section D.9C.4 belonging to $\text{TIEDREGULATIONOFFERBLOCKPAIR}_o$.
l(r)	References the *regulation offer l* that has the same associated *generation registered facility* or *energy storage facility* as the *reserve offer r*.
m(g)	References the *market network node m* corresponding to the *energy offer g*.
m(es)	References the *market network node m* corresponding to the *energy storage offer es*.
n(m)	References the *dispatch network node n* corresponding to *market network node m*.
NodeAtEndOf(k)	References the end *dispatch network node* of transmission line *k* in the conventional direction of flow.
NodeAtStartOf(k)	References the start *dispatch network node* of transmission line *k* in the conventional direction of flow.
n(u)	References the *dispatch network node n* corresponding to the default bus for *generating unit u*.
p(r)	References the *energy bid p* that has the same associated *LRF with REB* as the *reserve offer r*.
r(g,c), r(h,c), r(es,c)	References the *reserve offer r* that has the same associated *generation registered facility* as the *energy offer g* or *h,* or the same *energy storage facility* as the *energy storage offer es,* and

	applies to *reserve class c.*
(r(o),j(o)), (r'(o),j'(o))	References respectively each of the *price-quantity pairs* identified under section D.9C.3 belonging to $TIEDRESERVEOFFERBLOCKPAIR_o$.
s(g)	References the multi-unit constraint *s* associated with the *multi-unit facility* that the *energy offer g* is for.
u(k)	References the *generating unit u* of a *multi-unit facility* that is associated with the *dispatch network line* $k \in$ ARTIFICIALLINES1$\cup$ARTIFICIALLINES2.
u(ST), u(GT), u(GT1), u(GT2)	References the unit of a *multi-unit facility* that is the steam unit, the single gas turbine, or the first or second gas turbine of that *multi-unit facility* respectively.
x(g,c)	References the *reserve provider group* that *generation registered facility g* is associated with in respect of *reserve class c*.
x(es,c)	References the *reserve provider group* that *energy storage facility es* is associated with in respect of *reserve class c*.
y(k), y(c), y(g), y(es), y(p), y(s), y(regulation)	References the violation constraint group associated with line *k*, the *reserve* requirement for *reserve class c*, the *generation registered facility* associated with *energy offer g*, the *energy storage facility* associated with *energy storage offer es,* the *LRF with REB* associated with *energy bid p*, the *security constraint s*, the multi-unit constraint *s*, or the *regulation* requirement, respectively.

SECTION B: PRE-PROCESSING

D.6 DISPATCH NETWORK DERIVATION

D.6.1 The *EMC* shall use the following information on network elements when deriving the dispatch network for a *dispatch period*:

D.6.1.1 standing data on the network elements;

D.6.1.2 status data on the network elements; and/or

D.6.1.3 the *outage* schedule for the network elements.

For avoidance of doubt, the information stated in sections D.6.1.1 and D.6.1.2 shall be used for deriving the dispatch network for a *dispatch period* in the *real-time schedule*, whereas the information stated in sections D.6.1.1 and D.6.1.3 shall be used for deriving the dispatch network for a *dispatch period* in the *short-term schedule, pre-dispatch schedule* and *market outlook scenario*.

D.6.2 The information referred to in section D.6.1.1 shall be provided to the *EMC* by the *PSO* in accordance with Appendix 6G section G.1.1 and G.4.1.

D.6.3 In accordance with sections 2.1.2 and 2.1.3 of Chapter 6, the *EMC* may simplify the dispatch network by combining series elements in single *dispatch network lines*, but shall ensure that the essential *connectivity* of the physical *transmission system* is maintained. The simplification process may involve any of the following:

D.6.3.1 Eliminate intermediate network elements between branches or facilities (units or loads) and the buses they are electrically connected to, while maintaining the electrical connectivity status between the remaining network elements.

D.6.3.2 Eliminate network elements that are spurious to the dispatch network model, e.g. elements that do not facilitate a connection between the primary network elements (buses, branches and facilities).

D.6.3.3 Merge buses that are electrically equivalent (connected by an essentially loss-less connection) into a single node.

D.6.3.4 Create notional loss-less lines between buses that are electrically equivalent.

D.6.3.5 Eliminate branches that do not terminate, either directly or through a series of network elements, at a bus at each end of the branch.

D.6.3.6 Eliminate isolated sections of the resulting dispatch network model where the section does not include any bus that is the nominated default *market network node* for a *generating unit* in accordance with section D.7.2 or D.7.3.

D.6.4 In accordance with section 2.1.2 and 2.1.3 of Chapter 6, the *EMC* may expand the dispatch network by the addition of artificial *dispatch network lines* and artificial *dispatch network nodes* for the purpose of modelling the connectivity of *generation registered facilities* and *interties* for any *dispatch period*. The expansion may involve any of the following:

D.6.4.1 The addition of *dispatch network nodes* and *dispatch network lines* in accordance with section D.8.2 to represent *multi-unit facilities*.

D.6.4.2 The addition of *dispatch network nodes* and *dispatch network lines* in accordance with section D.6.5 in the circumstances described therein.

D.6.5 In the case where a *dispatch period* is involved in the calculation of a *real-time dispatch schedule*, *short-term schedule*, *pre-dispatch schedule* or *market outlook scenario*, then:

D.6.5.1 in respect of each *generating unit* (for each *generation registered facility*) which is not represented as *synchronised* in the *dispatch network data* for that *dispatch period*, the *EMC* shall change the dispatch network for that *dispatch period* by adding an artificial *dispatch network node* for such *generating unit* connecting each such *generating unit* to its artificial *dispatch network node*; and

D.6.5.2 for each of the *generating units* referred to in section D.6.5.1 above that satisfies one of the following:

a. the *generating unit* is not a constituent unit of a *generation registered facility* that is a *multi-unit facility*;

b. the *generating unit* is a constituent unit of a *generation registered facility* that is a *multi-unit facility*, and the *generating unit* is not *islanded*; or

c. the *generating unit* is a constituent unit of a *generation registered facility* that is a *multi-unit facility*, and all the *generating units* of that *generation registered facility* are *islanded*,

the *EMC* shall add an artificial *dispatch network line* to connect the artificial *dispatch network node* described in section D.6.5.1 to a default bus for the *generating unit* described in section D.7.2 or D.7.3, as the case may be.

D.6.5A An artificial *dispatch network line* defined for the purposes of section D.6.5.2 shall not include the constraints in section D.21.1, and shall:

D.6.5A.1 have the same electrical characteristics as the corresponding default line that is designated by *PSO* in section D.7.2A or D.7.3A, as the case may be; or

D.6.5A.2 have electrical characteristics determined by the *EMC* if no corresponding default line is designated by *PSO*.

Explanatory Note: The effect of this section is that in the preparation of real-time dispatch schedule, short-term schedule, pre-dispatch schedule and market outlook scenarios, the MCE will model unsynchronised units (based on the dispatch network data) as connected provided they satisfy one of the conditions described in section D.6.5.2.

D.6.6 For the purpose of determining when the status data on the network elements is no longer recent enough for use in the preparation of a *short-term schedule* or a *real-time dispatch schedule* in accordance with section D.6.5, the *EMC* shall define, prior to the *market commencement date* and in consultation with the *PSO*, and shall thereafter maintain and update as required, in consultation with the *PSO*, the parameter StatusDataLifeMax.

D.6.7 For the avoidance of doubt, a reference to a *generation registered facility* in this section D.6 shall include a reference to a *generation registered facility* that is an *energy storage facility*.

D.7 MARKET NETWORK NODES

D.7.1 A *market network node* for each *generation registered facility* and each *generation settlement facility* that is not a *pseudo generation settlement facility*, *in* each *dispatch period*, shall be determined in accordance with sections D.7.2 to D.7.5.

D.7.2 The *PSO* shall:

D.7.2.1 designate a main default bus, and an alternate default bus which is in the same substation/switchhouse as the main default bus, for each *generation registered facility* that is not a *multi-unit facility*; and

D.7.2.2 designate a main default bus and an alternate default bus (whether in the same substation/switchhouse or otherwise) for each *generation settlement facility* that is not a *pseudo generation settlement facility*,

representing the most likely *connection* point for that *generation facility*.

D.7.2A The *PSO* shall, wherever possible, designate a default line for each *generation registered facility* that is not a *multi-unit facility* and each *generation settlement facility* that is not a *pseudo generation settlement facility*, representing the most likely *connection* line for that *generation facility*.

D.7.3 The *PSO* shall designate a main default bus, and an alternate default bus which is in the same substation/switchhouse as the main default bus, for each *generating unit* of each *generation registered facility* that is a *multi-unit facility*, representing the most likely *connection* point for that *generating unit*. For each *generating unit*, *u*, of each *generation registered facility* that is a *multi-unit facility*, the *EMC* shall specify on reasonable grounds, the parameter Proportion_u to be employed in:

D.7.3.1 combining the prices of the nodes corresponding to the designated main default buses into the *market energy price*, via section D.24.1.2;

D.7.3.2 forming ratio constraints to be applied to transmission flows out of those nodes, via section D.8.7; and

D.7.3.3 setting flow limits on the transmission flows out of those nodes, via section D.8.9.

D.7.3A In the event where both the designated main and alternate default buses of a *generation facility* referred to in section D.7.2 above or a *generating unit* referred to in section D.7.3 above are represented in the *dispatch network data* as *disconnected* from the *PSO controlled system*, the *EMC* shall, in consultation with the *PSO*, select a suitable bus for that *generation facility* or *generating unit*, as the case may be, to be used for the *market clearing engine* re-run for *settlement* purposes.

D.7.3B The *PSO* shall, wherever possible, designate a default line for each *generating unit* of each *generation registered facility* that is a *multi-unit facility*, representing the most likely *connection* line for that *generating unit*.

D.7.4 If a *generation registered facility* is not a *multi-unit facility* and is either represented as *synchronised* in the *dispatch network data*, or is connected to the dispatch network in accordance with section D.6.5, then the *dispatch network node* representing the point of connection in the *dispatch network data* shall be designated the *market network node* for that *generation facility*.

D.7.5 [Deleted and Intentionally Left Blank]

D.7.6 If a *generation registered facility* is a *multi-unit facility* and is either represented as *synchronised* in the *dispatch network data* or is connected to the dispatch network in accordance with section D.6.5, then the artificial *dispatch network node* added to the dispatch network in accordance with section D.8.2 shall be designated the *market network node* for that *generation facility*.

D.7.7 [Deleted and Internationally Left Blank]

D.7.8 The *market network node* for a *generation settlement facility* that is not a *pseudo generation settlement facility* shall be the *dispatch network node* corresponding to:

D.7.8.1 the main default bus, if the main default bus is represented as *connected* in the *dispatch network data*; or

D.7.8.2 the alternate default bus,

designated by the *PSO* as being the default *connection* point for that *generation facility*.

D.7.9 A *market network node* shall be assigned by the *EMC* for each *pseudo generation settlement facility*.

D.7.10 For the avoidance of doubt, a reference to a *generation registered facility* in this section D.7 shall include a reference to a *generation registered facility* that is an *energy storage facility*.

D.8 REPRESENTATION OF MULTI-UNIT FACILITIES

D.8.1 For *generation registered facilities* that are *multi-unit facilities*, the arrangements in this section D.8 shall apply.

Explanatory Note: The tables in these sections cover all multi-unit facility configurations in Singapore at market start. However, any additional configurations will need to be addressed with additions to the tables via the rules change process.

D.8.2 The *EMC* shall add an artificial *dispatch network node* for each *generation registered facility* that is a *multi-unit facility*. Each *generation registered facility* that is a *multi-unit facility* shall be connected to the dispatch network at its artificial *dispatch network node*, which in turn is connected to each of the nodes where the constituent *generating units* are connected, and such connection shall be achieved by the use of additional *dispatch network lines*, with a conventional direction defined to be from the artificial *dispatch network node* to the connection nodes. However, *dispatch network lines* used for this purpose shall not include constraints in sections D.16.2.1, D.16.2.3, D.16.3.1, D.16.3.2, D.16.3.3 and D.21.1 for that line.

D.8.3 In the case where the *dispatch period* is being produced for a *real-time dispatch schedule*, or where the *dispatch period* is the first *dispatch period* of the multiple *dispatch periods* involved in the calculation of a *short-term schedule*, then the initial generation levels StartGeneration_g for *multi-unit facilities* shall be calculated from the initial generation levels of the constituent *generating units*, subject to section D.8.3.1 to D.8.3.4, in accordance with the following table:

For *multi-unit facilities g* comprising one gas turbine and one steam turbine which is not shared with another *generation registered facility*: $\text{StartGeneration}_g = \sum_{u \in \text{UNITS}_g} \text{StartGeneration}_u$
For *multi-unit facilities g* comprising one gas turbine and one steam turbine which is shared with another *generation registered facility*, which other *generation registered facility* comprises a gas turbine and the shared steam turbine: $\text{StartGeneration}_g = \text{StartGeneration}_{u(GT)} + \frac{\text{StartGeneration}_{u(GT)}}{\text{StartGeneration}_{u(GT)} + \text{StartGeneration}_{u(GT2)}} \times \text{StartGeneration}_{u(ST)}$ where: $\text{StartGeneration}_{u(ST)}$ is the initial generation of the shared steam turbine. $\text{StartGeneration}_{u(GT)}$ is the initial generation of the gas turbine for the

current *generation registered facility*.

$StartGeneration_{u(GT2)}$ is the initial generation of the gas turbine for the *generation registered facility* which shares the steam turbine with the current *generation registered facility*.

However, if the initial generation of both gas turbines is zero, then the following formula will be used to calculate $StartGeneration_g$ for the *generation registered facility*:

$$StartGeneration_g = 0.5 \times StartGeneration_{u(ST)}$$

For *multi-unit facilities g* comprising two gas turbines and one steam turbine which is not shared with another *generation registered facility*:

$$StartGeneration_g = \sum_{u \in UNITS_g} StartGeneration_u$$

D.8.3.1 In the event that the time difference between the start of the *dispatch period* and the time at which the *PSO* compiled the most recently received status data on the network elements referred to in section D.6.1.2 is greater than StatusDataLifeMax, or in the event that a value $StartGeneration_u$ for any *generating unit* of a *multi-unit facility* is not included in the most recently received status data on the network elements referred to in D.6.1.2, then the initial generation level $StartGeneration_g$ for the corresponding *multi-unit facility* shall be the same as the corresponding value $Generation_g$ for the same *generation registered facility* in the *real-time dispatch schedule* for the *dispatch period* current at the time when the calculation of the *real-time dispatch schedule* or the *short-term schedule* commences.

D.8.3.2 In the event that no such *real-time dispatch schedule* is available, the initial generation level $StartGeneration_g$ for the *multi-unit facility* shall be the same as the corresponding value of $Generation_g$ for the same *generation registered facility* in the latest available *short-term schedule* (based on normal *load* forecast) for the *dispatch period* current at the time when the calculation of the *real-time dispatch schedule* or the *short-term schedule* commences.

D.8.3.3 In the event that no such *short-term schedule* is available, the initial generation level $StartGeneration_g$ for the *multi-unit facility* shall be the same as the corresponding value of $Generation_g$ for the same *generation registered facility* in the latest available *pre-dispatch schedule* for the *dispatch period* current at the time when the calculation of the *real-time dispatch schedule* or the *short-term schedule* commences.

D.8.3.4 In the event that no such *pre-dispatch schedule* is available, then the *EMC* shall use a value of zero for StartGeneration_g for the *multi-unit facility.*

D.8.4 In the case where the *dispatch period* is involved in the calculation of a *pre-dispatch schedule* and is the first *dispatch period* of the multiple *dispatch periods* involved in the calculation of the *pre-dispatch schedule*, then the initial generation levels StartGeneration_g for *multi-unit facilities* shall be the same as the corresponding values Generation_g for the same *generation registered facility* in the latest available *short-term schedule* based on normal *load* forecast) for the *dispatch period* immediately preceding the first *dispatch period* of the *pre-dispatch schedule.*

D.8.4.1 In the event that no such *short-term schedule* is available, then the value of StartGeneration_g for the *multi-unit facility* shall be the corresponding value Generation_g in the latest available *pre-dispatch schedule* for the *dispatch period* immediately preceding the first dispatch period of the *pre-dispatch schedule* to be calculated in D.8.4.

D.8.4.2 In the event that no such *pre-dispatch schedule* is available, then the value of StartGeneration_g for the *multi-unit facility* shall equal to zero.

D.8.5 In the case where the *dispatch period* is involved in the calculation of a *market outlook scenario,* and is the first *dispatch period* of the multiple *dispatch periods* involved in the calculation of the *market outlook scenario*, then the initial generation levels StartGeneration_g for *multi-unit facilities* shall be the same as the corresponding values Generation_g for the same *generation registered facility* in the most recently released *pre-dispatch schedule* with a *nodal load forecast* corresponding to the *market outlook scenario* being calculated, and shall be taken from the *dispatch period* in such *pre-dispatch schedule* immediately preceding the first *dispatch period* required in the calculation of the *market outlook scenario*, provided that such *pre-dispatch schedule* contains the appropriate *dispatch period*. If such *pre-dispatch schedule* does not contain the appropriate *dispatch period*, then initial generation levels StartGeneration_g for *multi-unit facilities* shall be taken to be zero.

D.8.6 In the case where the *dispatch period* is involved in the calculation of a *short-term schedule*, a *pre-dispatch schedule* or a *market outlook scenario,* but is not the first *dispatch period* of the multiple *dispatch periods* involved in the calculation of the *short-term schedule, pre-dispatch schedule* or *market outlook scenario*, then the initial generation levels StartGeneration_g for *multi-unit facilities* shall be the same as the corresponding values Generation_g for the same *generation registered*

facility for the immediately preceding *dispatch period* in that *short-term schedule, pre-dispatch schedule* or *market outlook scenario.*

D.8.7 Constraints of the form specified in section D.20.2 will be placed on the *dispatch network lines* referred to in section D.8.2, with the $\text{MultiGroupLineWeight}_{s,k}$ coefficients for the LineFlow_k variables set in accordance with the following table:

<table>
<tr><td colspan="2">For multi-unit facilities g comprising one gas turbine and one steam turbine:</td></tr>
<tr><td>Where the gas turbine and steam turbine are each represented as synchronised in the dispatch network data or connected to the dispatch network in accordance with section D.6.5</td><td>Constraint s:
$\frac{1}{\text{Proportion}_{u(GT)}} \times \text{LineFlow}_{k(GT,g)}$
$-\frac{1}{\text{Proportion}_{u(ST)}} \times \text{LineFlow}_{k(ST,g)}$
$+\text{DeficitMulti}_s - \text{ExcessMulti}_s = 0$</td></tr>
<tr><td colspan="2">Explanatory Note: The constraint above is applied in both the case where the steam turbine is shared with another gas turbine that is part of a separate generation registered facility, and the case where the steam turbine is not shared.</td></tr>
<tr><td colspan="2">For multi-unit facilities g comprising two gas turbines and one steam turbine which is not shared with another generation registered facility:</td></tr>
<tr><td>Where the steam turbine and at least one of the two gas turbines are each represented as synchronised in the dispatch network data or connected to the dispatch network in accordance with section D.6.5</td><td>Constraint s:
$\sum_{u(GTi) \in \text{CONNECTEDUNITS}_g} \frac{1}{\text{Proportion}_{u(GTi)}} \times \text{LineFlow}_{k(GTi,g)}$
$-\frac{2}{\text{Proportion}_{u(ST)}} \times \text{LineFlow}_{k(ST,g)}$
$+\text{DeficitMulti}_s - \text{ExcessMulti}_s = 0$</td></tr>
<tr><td colspan="2">Explanatory Note: The constraint above assumes that, in a multi-unit facility comprising two gas turbines and one steam turbine, each of the gas turbines is capable of driving exactly half of the capacity of the steam turbine. They are not applicable to more general configurations.</td></tr>
</table>

D.8.8 The variable LineFlow_k shall have a lower bound of a negative value specified by *EMC* for the *dispatch network lines* referred to in section D.8.2.

Explanatory Note: The allowance for a very small reverse capability on the dispatch network lines is to allow a shadow price to be derived at the dispatch network node which is based on the local system marginal price.

D.8.9 The parameter LineMaxForward_k shall have a value calculated as follows for the *dispatch network lines* referred to in section D.8.2.

$$\text{LineMaxForward}_k = \frac{\text{Proportion}_{u(k)}}{\sum_{u \in \text{UNITS}_{g(k)}} \text{Proportion}_u} \times \text{GenerationMax}_{g(k)} \times (1 + \text{T1Margin})$$

where "T1Margin" is a margin parameter determined by the *EMC*.

D.8.10 Unless otherwise stated, a reference to a *generation registered facility* in this D.8 does not include a reference to a *generation registered facility* that is an *energy storage facility*.

D.9 LINE ADMITTANCE AND LINE LOSS APPROXIMATION

D.9.1 $$\text{LineAdmittance}_k = -\frac{\text{Reactance}_k}{\text{Resistance}_k^2 + \text{Reactance}_k^2}$$

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

D.9.1A $\text{PhaseAngleShift}_k = \text{PSTTapOffset}_k \times \text{DegreeShiftPerTap}_k$

$\{k \in \text{PSTLINES}, k \notin \text{ARTIFICIALLINES}\}$

where $\text{PSTTapOffset}_k = \text{PSTTapPosition}_k - \text{TapZero}_k$

$\{k \in \text{PSTLINES}, k \notin \text{ARTIFICIALLINES}\}$

$\text{PhaseAngleShift}_k = 0$

$\{k \notin \text{PSTLINES}\}$

D.9.2 The *EMC* shall determine NumPoints_k, the number of line flow/line loss points required in the set DISCRSUB_k in order to define the linear approximation of the quadratic loss curve for each *dispatch network line* k, except for the artificial *dispatch network lines* added under sections D.6.3.4 or D.8.2.

D.9.3 $\text{MaxLineRating}_k = \text{maximum}(\text{LineRatingForward}_k, \text{LineRatingReverse}_k)$

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

$\{k,j \mid j \in \{1,\ldots,\text{NumPoints}_k\}$, where $k \in \text{LINES}, k \notin \text{ARTIFICIALLINES1} \cup \text{ARTIFICIALLINES3}\}$

D.9.4 $\text{LineLossConst}_{k,j} = \text{FixedLosses}_k + \text{Resistance}_k \times \text{LineFlowConst}_{k,j}^2$

$\{k,j \mid j \in \{1,\ldots,\text{NumPoints}_k\}$, where $k \in \text{LINES}, k \notin \text{ARTIFICIALLINES1} \cup \text{ARTIFICIALLINES3}\}$

D.9A ENERGY BIDS AND OFFERS

D.9A.1 The set ENERGYOFFERS shall comprise all valid *energy offers* for the *dispatch period* received by the *EMC*, together with *offers* created by the *EMC* in accordance with section D.9A.4.

D.9A.1A The set ENERGYSTORAGEOFFERS shall comprise all valid *energy storage offers* for the *dispatch period* received by the *EMC*.

D.9A.2 The set ENERGYBIDS shall comprise all valid *restricted energy bids* associated with *LRFs with REB* for the *dispatch period* received by the *EMC*, together with *bids* to purchase *energy* at the relevant *dispatch network nodes* created by the *EMC* in accordance with sections D.9A.3 and D.9A.4.

D.9A.3 For each *dispatch network node* for which a *load* is forecast in the *nodal load forecast* referred to in sections 7.2 or 9.1.1 of this Chapter 6, the *EMC* shall create an *energy bid* corresponding to that *load*, which shall have the following characteristics:

D.9A.3.1 the MW quantity of the *energy bid* shall equal the quantity for that *dispatch network node* in the *nodal load forecast*; and

D.9A.3.2 the price of the *energy bid* shall equal 10×*VoLL* as specified in Appendix 6J.

D.9A.4 For each *intertie* for which it has received an *intertie schedule* pursuant to section G.4.5 of Appendix 6G, the *EMC* shall create either an *energy* bid for the corresponding *dispatch network node*, in the case where the *intertie schedule* represents a planned export of *energy* out of Singapore, or shall create an *energy offer* for the corresponding *dispatch network node*, in the case where the *intertie schedule* represents a planned import of *energy* into Singapore.

D.9A.5 An *energy bid* created in accordance with section D.9A.4 shall have the following characteristics:

D.9A.5.1 the MW quantity of the *energy bid* shall equal the quantity in the corresponding *intertie schedule*; and

D.9A.5.2 the price of the *energy bid* shall equal 10×*VoLL* as specified in Appendix 6J.

D.9A.6 An *energy offer* created in accordance with section D.9A.4 shall have the following characteristics:

D.9A.6.1 the MW quantity of the *energy offer* shall equal the quantity of the *intertie schedule*; and

D.9A.6.2 the price of the *energy offer* shall equal EnergyPriceMin, as specified in Appendix 6J.

D.9A.7 The parameter $ReserveGenerationMax_{r}$ associated with each *reserve offer* associated with a *generation registered facility* shall equal the smaller of:

D.9A.7.1 the *standing capability data* referred to in section E.1.1.6 of Appendix 6E for the associated *generation registered facility* for the appropriate *reserve class*; and

D.9A.7.2 $OfferedCapacity_{g(r)}$.

D.9A.7A The parameter $ReserveGenerationMax_{r}$ associated with each *reserve offer* associated with an *energy storage facility* shall equal the smaller of:

D.9A.7A.1 the *standing capability data* referred to in section E.1A.1.7 of Appendix 6E for the associated *energy storage facility* for the appropriate *reserve class*; and

D.9A.7A.2 $OfferedCapacity_{es(r)}$.

D.9A.8 The parameter $RegulationMax_{g(l)}$ associated with each *regulation offer* associated with a *generation registered facility* shall equal the smaller of:

D.9A.8.1 the *standing capability data* referred to in section E.1.1.9 of Appendix 6E for the associated *generation registered facility*; and

D.9A.8.2 $OfferedCapacity_{g(l)}$.

D.9A.8A The parameter $RegulationMax_{es(l)}$ associated with each *regulation offer* associated with an *energy storage facility* shall equal the smaller of:

D.9A.8A.1 the *standing capability data* referred to in section E.1A.1.9 of Appendix 6E for the associated *energy storage facility*; and

D.9A.8A.2 $OfferedCapacity_{es(l)}$.

D.9A.9 Unless otherwise stated, a reference to a *generation registered facility* in this D.9A does not include a reference to a *generation registered facility* that is an *energy storage facility.*

D.9B VALIDATION TEST EQUATIONS

The following validation test equations will be used to validate the *reserve* envelope data:

D.9B.1 The parameter, $LowLoad_{g,}$ must be greater than zero.

$$LowLoad_{g(r)} > 0$$

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

D.9B.2 The parameter, $LowLoad_g$, must be less than the parameter, $MediumLoad_g$.

$$LowLoad_{g(r)} < MediumLoad_{g(r)}$$

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

D.9B.3 The LowLoadReserve point must lie on or above the line joining the origin to the MediumLoadReserve point.

$$LowLoadReserve_r \geq Slope \times LowLoad_{g(r)}$$

$$\{r \in GENCONRESERVEOFFERS\}$$

where:

$$Slope = MediumLoadReserve_r / MediumLoad_{g(r)}$$

D.9B.4 The MediumLoadReserve point must lie on or above the line joining the LowLoadReserve point to the HighLoadReserve point.

$$MediumLoadReserve_r \geq LowLoadReserve_r + Slope \times (MediumLoad_{g(r)} - LowLoad_{g(r)})$$

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

where:

$$Slope = (HighLoadReserve_r - LowLoadReserve_r) / (HighLoad_{g(r)} - LowLoad_{g(r)})$$

D.9B.5 The HighLoadReserve point must lie on or above the line joining the MediumLoadReserve point to the StandingReserveGenerationMax point.

$$HighLoadReserve_r \geq MediumLoadReserve_r + Slope \times (HighLoad_{g(r)} - MediumLoad_{g(r)})$$

$$\{r \in GENRESERVE\ OFFERS\}$$

where:

$$Slope = -MediumLoad\ Reserve_r / (StandingReserveGenerationMax_{g(r)} - MediumLoad_{g(r)})$$

Explanatory note: The equations in this section are used to validate convexity of the reserve envelope. This validation is part of the pre-processing of the standing capability data so as to ensure that the MCE receives inputs that will produce valid results.

D.9C TIED OFFERS

D.9C.1 The sets derived in this section D.9C shall be used for the purpose of tie-breaking constraints under D.20A.

D.9C.2 If a *price-quantity pair (g,j)* of $\text{GENERATIONOFFERBLOCKS}_g$ and a *price-quantity pair (g',j')* of $\text{GENERATIONOFFERBLOCKS}_{g'}$ meet the following condition, they shall be assigned to a set, $\text{TIEDENERGYOFFERBLOCKPAIR}_o$:

$$\text{GenerationOfferPrice}_{(g(o),j(o))} = \text{GenerationOfferPrice}_{(g'(o),j'(o))}$$

$\{g(o)=g, \in \text{ENERGYOFFERS}$
$g'(o)=g' \neq g, \in \text{ENERGYOFFERS}$
$j(o)=j, \in \text{GENERATIONOFFERBLOCKS}_{g(o)}$ and
$j'(o)=j', \in \text{GENERATIONOFFERBLOCKS}_{g'(o)}\}$

D.9C.3 If a *price-quantity pair (r,j)* of $\text{RAWRESERVEBLOCKS}_r$ and a *price-quantity pair (r',j')* of $\text{RAWRESERVEBLOCKS}_{r'}$ meet the following condition, they shall be assigned to a set, $\text{TIEDRESERVEOFFERBLOCKPAIR}_o$:

$$\frac{\text{ReserveOfferPrice}_{(r(o),j(o))}}{\text{EstReserveEffectiveness}_{r(o)}} = \frac{\text{ReserveOfferPrice}_{(r'(o),j'(o))}}{\text{EstReserveEffectiveness}_{r'(o)}}$$

$\{r(o)=r, \in \text{RAWRESERVEOFFERS}$
$r'(o)=r' \neq r, \in \text{RAWRESERVEOFFERS}$
$c(r)=c(r'), \in \text{RESERVECLASSES}$
$j(o)=j, \in \text{RAWRESERVEBLOCKS}_{r(o)}$
$j'(o)=j', \in \text{RAWRESERVEBLOCKS}_{r'(o)}$
$\text{EstReserveEffectiveness}_{r(o)} \neq 0$
and $\text{EstReserveEffectiveness}_{r'(o)} \neq 0\}$

D.9C.4 If a *price-quantity pair (l,j)* of $\text{REGULATIONOFFERBLOCKS}_l$ and a *price-quantity pair (l',j')* of $\text{REGULATIONOFFERBLOCKS}_{l'}$ meet the following condition, they shall be assigned to a set, $\text{TIEDREGULATIONOFFERBLOCKPAIR}_o$:

$$\text{RegulationOfferPrice}_{(l(o),j(o))} = \text{RegulationOfferPrice}_{(l'(o),j'(o))}$$

$\{l(o)=l, \in \text{REGULATIONOFFERS}$
$l'(o)= l' \neq l, \in \text{REGULATIONOFFERS}$
$j(o)=j, \in \text{REGULATIONOFFERBLOCKS}_{l(o)}$
$j'(o)=j', \in \text{REGULATIONOFFERBLOCKS}_{l'(o)}\}$

D.9C.5 If a *price-quantity pair (g,j)* of $\text{GENERATIONOFFERBLOCKS}_{g}$ and a *price-quantity pair (es,j')* of $\text{ENERGYSTORAGEOFFERBLOCKS}_{es}$ meet the following condition, they shall be assigned to a set, $\text{TIEDENERGYOFFERBLOCKPAIR}_{o}$:

$$\text{GenerationOfferPrice}_{(g(o),j(o))} = \text{EnergyStorageOfferPrice}_{(es(o),j'(o))}$$

$\{g(o)=g, \in \text{ENERGYOFFERS}$
$es(o)=es, \in \text{ENERGYSTORAGEOFFERS}$
$j(o)=j, \in \text{GENERATIONOFFERBLOCKS}_{g(o)}$ and
$j'(o)=j', \in \text{ENERGYSTORAGEOFFERBLOCKS}_{es(o)}$
where $\text{EnergyStorageBlockLimit}_{es,j'} > 0\}$

D.9C.6 If a *price-quantity pair (es,j)* of $\text{ENERGYSTORAGEOFFERBLOCKS}_{es}$ and a *price-quantity pair (es',j')* of $\text{ENERGYSTORAGEOFFERBLOCKS}_{es'}$ meet the following condition, they shall be assigned to a set, $\text{TIEDENERGYOFFERBLOCKPAIR}_{o}$:

$$\text{EnergyStorageOfferPrice}_{(es(o),j(o))} = \text{EnergyStorageOfferPrice}_{(es'(o),j'(o))}$$

$\{es(o)=es, \in \text{ENERGYSTORAGEOFFERS},$
$es'(o)=es' \neq es, \in \text{ENERGYSTORAGEOFFERS},$
$j(o)=j, \in \text{ENERGYSTORAGEOFFERBLOCKS}_{es(o)}$
where $\text{EnergyStorageBlockLimit}_{es,j} > 0$, and
$j'(o)=j', \in \text{ENERGYSTORAGEOFFERBLOCKS}_{es'(o)}$
where $\text{EnergyStorageBlockLimit}_{es',j'} > 0\}$

D.9C.7 If a *price-quantity pair (es,j)* of $\text{ENERGYSTORAGEOFFERBLOCKS}_{es}$ and a *price-quantity pair (es',j')* of $\text{ENERGYSTORAGEOFFERBLOCKS}_{es'}$ meet the following condition, they shall be assigned to a set, $\text{TIEDENERGYOFFERBLOCKPAIR}_{o}$:

$$\text{EnergyStorageOfferPrice}_{(es(o),j(o))} = \text{EnergyStorageOfferPrice}_{(es'(o),j'(o))}$$

$\{es(o)=es, \in \text{ENERGYSTORAGEOFFERS}$
$es'(o)=es' \neq es, \in \text{ENERGYSTORAGEOFFERS}$
$j(o)=j, \in \text{ENERGYSTORAGEOFFERBLOCKS}_{es(o)}$
where $\text{EnergyStorageBlockLimit}_{es,j} < 0$ and
$j'(o)=j', \in \text{ENERGYSTORAGEOFFERBLOCKS}_{es'(o)}$
where $\text{EnergyStorageBlockLimit}_{es',j'} < 0\}$

D.10 ESTIMATED REACTIVE POWER FLOW

D.10.1 $EstimatedReactivePowerFlow_k$ shall equal the value for estimated reactive power flow at the beginning of the *dispatch period*, received from the *PSO* in accordance with Appendix 6G section G.4.6.

D.10.2 $$LineMaxForward_k = \sqrt{Max(LineRatingForward_k^2 - EstimatedReactivePowerFlow_k^2, 0)}$$

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

D.10.3 $$LineMaxReverse_k = -\sqrt{Max(LineRatingReverse_k^2 - EstimatedReactivePowerFlow_k^2, 0)}$$

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

D.11 ESTIMATED RESERVE EFFECTIVENESS

D.11.1 $EstReserveEffectiveness_{r(g,c)} = Effectiveness_{x(g,c),1}$

$\{g,c \mid g \in RISKGENERATORS, c \in RESERVECLASSES\}$

D.11.2 $EstReserveEffectiveness_{r(es,c)} = Effectiveness_{x(es,c),1}$

$\{es,c \mid es \in ENERGYSTORAGEOFFERS, c \in RESERVECLASSES\}$

D.12 RAMPING CONSTRAINTS

D.12.1 In the case where a *real-time dispatch schedule* is being produced, or where the *dispatch period* is the first *dispatch period* of the multiple *dispatch periods* involved in the calculation of a *short-term schedule,* then the values of StartGeneration_g for each *generation registered facility* in the applicable *dispatch period,* except *multi-unit facilities*, shall be the values received from the *PSO* in accordance with section G.3.1 of Appendix 6G.

D.12.1.1 In the event that a value of StartGeneration_g for any *generating unit* that is not part of a *multi-unit facility* is not updated by the *PSO* or provided to the *EMC* during the *dispatch period* for the time being when the calculation of the *real-time dispatch schedule* or the first *dispatch period* of the multiple *dispatch periods* involved in the calculation of a *short-term schedule* commences, the initial generation level of StartGeneration_g for the *generation registered facility* shall be the same as the corresponding value of Generation_g for the same *generation registered facility* in the *real-time dispatch schedule* for the *dispatch period* with respect to the time when the calculation of the *real-time dispatch schedule* or the *short-term schedule* commences.

D.12.1.2 In the event that no such *real-time dispatch schedule* is available, the initial generation level of StartGeneration_g for the *generation registered facility* shall be the same as the corresponding value of Generation_g for the same *generation registered facility* in the latest available *short-term schedule* (based on normal *load* forecast) for the *dispatch period* with respect to the time when the calculation of the *real-time dispatch schedule* or the *short-term schedule* commences.

D.12.1.3 In the event that no such *short-term schedule* is available, the initial generation level of StartGeneration_g for the *generation registered facility* shall be the same as the corresponding value of Generation_g for the same *generation registered facility* in the latest available *pre-dispatch schedule* for the *dispatch period* with respect to the time when the calculation of the *real-time schedule* or the *short-term schedule* commences.

D.12.1.4 In the event that no such *pre-dispatch schedule* is available, then the *EMC* shall use a value of zero for StartGeneration_g for the *generation registered facility.*

Explanatory Note: StartGeneration_g for multi-unit facilities is set out in section D.8.

D.12.2 In the case where the *dispatch period* is the first *dispatch period* of the multiple *dispatch periods* involved in the calculation of the *pre-dispatch schedule*, then the values of StartGeneration_g for each *generation*

registered facility, except *multi-unit facilities*, shall be the corresponding values of Generation_g in the latest available *short-term schedule* (based on normal *load* forecast) for the *dispatch period* immediately preceding the first *dispatch period* of the *pre-dispatch schedule* for the *dispatch period*

D.12.2.1 In the event that no such *short-term schedule* is available, then the values of StartGeneration_g for each *generation registered facility*, except *multi-unit facilities*, shall be the corresponding values of Generation_g in the latest available *pre-dispatch schedule* for the *dispatch period* immediately preceding the first dispatch period of the *pre-dispatch schedule* to be calculated in D.12.2.

D.12.2.2 In the event that no such *pre-dispatch schedule* is available, then the values of StartGeneration_g for each *generation registered facility*, except *multi-unit facilities*, shall equal to zero.

D.12.3 In the case where the *dispatch period* is the first *dispatch period* of the multiple *dispatch periods* involved in the calculation of the *market outlook scenario*, the initial generation levels of StartGeneration_g for each *generation registered facility*, except *multi-unit facilities*, shall be the same as the corresponding values Generation_g for the same *generation registered facility* in the most recently released *pre-dispatch schedule* with a *nodal load forecast* corresponding to the *market outlook scenario* being calculated, and shall be taken from the *dispatch period* in such *pre-dispatch schedule* immediately preceding the first *dispatch period* required in the calculation of the *market outlook scenario*, provided that such *pre-dispatch schedule* contains the appropriate *dispatch period*. If such *pre-dispatch schedule* does not contain the appropriate *dispatch period*, then initial generation levels StartGeneration_g for such *generation registered facilities* shall be zero.

D.12.4 In the case where the *dispatch period* is involved in the calculation of a *short-term schedule,* a *pre-dispatch schedule* or a *market outlook scenario*, and is not the *first dispatch period* of the multiple *dispatch periods* involved in the calculation of the *short-term schedule, pre-dispatch schedule* or a *market outlook scenario*, the values of StartGeneration_g for each *generation registered facility*, except *multi-unit facilities*, shall be the corresponding values of Generation_g for the immediately preceding *dispatch period* in the *short-term schedule*, *pre-dispatch schedule* or *market outlook scenario* respectively.

D.12.5 $\text{ExpectedStartGeneration}_g$ of a *generation registered facility* associated with an *energy offer g* shall be determined in accordance with the following table:

When the *generation registered facility's* StartGeneration_g is greater than

its PriorScheduledGeneration$_g$, its ExpectedStartGeneration$_g$ shall be the higher of: a) StartGeneration$_g$ – DownRampRate$_{g,t-1}$ × RampingTime; and b) PriorScheduledGeneration$_g$.
When the *generation registered facility's* StartGeneration$_g$ is less than its PriorScheduledGeneration$_g$, its ExpectedStartGeneration$_g$ shall be the lower of: a) StartGeneration$_g$ + UpRampRate$_{g,t-1}$ × RampingTime; and b) PriorScheduledGeneration$_g$.
When the *generation registered facility's* StartGeneration$_g$ is equal to its PriorScheduledGeneration$_g$, its ExpectedStartGeneration$_g$ shall be its PriorScheduledGeneration$_g$.

For the purposes of this section D.12.5 only, DownRampRate$_{g,t-1}$ and UpRampRate$_{g,t-1}$, for a given *generation registered facility* for a given *dispatch period t* to which its *energy offer g* relates, shall be determined using the respective values contained in its valid *energy offer* for the *dispatch period* immediately prior to *dispatch period t*.

D.12.6 GenerationEndMax$_g$= ExpectedStartGeneration$_g$ + (UpRampRate$_g$ / 60 × RemainingTime)

{g∈ENERGYOFFERS, g∉INTERTIEENERGYOFFERS}

D.12.7 GenerationEndMin$_g$ = ExpectedStartGeneration$_g$ − (DownRampRate$_g$ / 60 × RemainingTime)

{g∈ENERGYOFFERS, g∉INTERTIEENERGYOFFERS}

D.12.8 $$\text{PurchaseEndMax}_p = \text{PriorScheduledPurchase}_p + \text{UpRampRate}_p \times \frac{\text{RemainingTime}}{60}$$

{p∈RESTRICTEDENERGYBIDS}

D.12.9 $$\text{PurchaseEndMin}_p = \text{PriorScheduledPurchase}_p - \text{DownRampRate}_p \times \frac{\text{RemainingTime}}{60}$$

{p∈RESTRICTEDENERGYBIDS}

D.12.10 In respect of an *LRF with REB* associated with *energy bid p*, the value of PriorScheduledPurchase$_p$ to be used in a *real-time dispatch schedule* or the first *dispatch period* of the multiple *dispatch periods* involved in the calculation of a *short-term schedule sh*all be the value of Purchase$_p$ in

the *real-time dispatch schedule* for the *dispatch period* with respect to the time when the calculation of the *real-time dispatch schedule* or the *short-term schedule* commences.

D.12.10.1 In the event that no such *real-time dispatch schedule* is available, the value of $\text{PriorScheduledPurchase}_p$ for the *LRF* shall be the corresponding value of Purchase_p in the latest available *short-term schedule* (based on normal *load* forecast) for the *dispatch period* with respect to the time when the calculation of the *real-time dispatch schedule* or the *short-term schedule* commences.

D.12.10.2 In the event that no such *short-term schedule* is available, the value of $\text{PriorScheduledPurchase}_p$ for the *LRF* shall be the corresponding value of Purchase_p in the latest available *pre-dispatch schedule* for the *dispatch period* with respect to the time when the calculation of the *real-time dispatch schedule* or the *short-term schedule* commences.

D.12.10.3 In the event that no such *pre-dispatch schedule* is available, the value of $\text{PriorScheduledPurchase}_p$ for the LRF shall be the total MW quantities in all *price-quantity pairs* of the *energy bid* for that *LRF* with *REB* for the *real-time dispatch schedule* or the first *dispatch period* of the *short-term schedule*, as the case may be, calculated as: $\sum_{j \in \text{PURCHASEBIDBLOCKS}_p} \text{PurchaseBlockMax}_{p,j}$.

D.12.11 In respect of an *LRF with REB* associated with *energy bid p*, the value of $\text{PriorScheduledPurchase}_p$ to be used in the first *dispatch period* of the multiple *dispatch periods* involved in the calculation of a *pre-dispatch schedule* shall be the value of Purchase_p in the latest available *short-term schedule* (based on normal load forecast) for the *dispatch period* immediately preceding the first *dispatch period* of the *pre-dispatch schedule.*

D.12.11.1 In the event that no such *short-term schedule* is available, the value of $\text{PriorScheduledPurchase}_p$ for the LRF shall be the corresponding value of Purchase_p in the latest available *pre-dispatch schedule* for the *dispatch period* immediately preceding the first dispatch period of the *pre-dispatch schedule* to be calculated in D.12.11.

D.12.11.2 In the event that no such *pre-dispatch schedule* is available, the value of $\text{PriorScheduledPurchase}_p$ for the LRF shall be the total MW quantities in all *price-quantity pairs* of the *energy bid* for that *LRF* with *REB* for the first *dispatch period* of the

pre-dispatch schedule, calculated as:
$\sum_{j \in PURCHASEBIDBLOCKS_p} PurchaseBlockMax_{p,j}$.

D.12.12 In respect of an *LRF with REB* associated with *energy bid p*, the value of $PriorScheduledPurchase_p$ to be used in the first *dispatch period* of the multiple *dispatch periods* involved in the calculation of a *market outlook scenario* shall be the value of $Purchase_p$ in the latest available *pre-dispatch schedule* with a *nodal load forecast* corresponding to the *market outlook scenario* being calculated, and shall be taken from the *dispatch period* in such *pre-dispatch schedule* immediately preceding the first *dispatch period* required in the calculation of the *market outlook scenario*, provided that such *pre-dispatch schedule* contains the appropriate *dispatch period*.

D.12.12.1 In the event that no such *pre-dispatch schedule* is available, the value of $PriorScheduledPurchase_p$ for the LRF shall be the total MW quantities in all *price-quantity pairs* of the *energy bid* for that *LRF* with *REB* for the first *dispatch period* of the *market outlook scenario*, calculated as:
$\sum_{j \in PURCHASEBIDBLOCKS_p} PurchaseBlockMax_{p,j}$.

D.12.13 In respect of an *LRF with REB* associated with *energy bid p*, the value of $PriorScheduledPurchase_p$ to be used in each *dispatch period* that is not the first *dispatch period* of the multiple *dispatch periods* involved in the calculation of a *short-term schedule*, *pre-dispatch schedule* or *market outlook scenario* shall be the corresponding value of $Purchase_p$ for the immediately preceding *dispatch period* in the *short-term schedule*, *pre-dispatch schedule* or *market outlook scenario* respectively.

D.12.14 Unless otherwise stated, a reference to a *generation registered facility* in this D.12 does not include a reference to a *generation registered facility* that is an *energy storage facility.*

D.12A RAMPING CONSTRAINTS FOR ENERGY STORAGE FACILITY

D.12A.1 In the case where a *real-time dispatch schedule* is being produced, or where the *dispatch period* is the first *dispatch period* of the multiple *dispatch periods* involved in the calculation of a *short-term schedule,* then the values of StartGeneration$_{es}$ for each *energy storage facility* in the applicable *dispatch period* shall be the values received from the *PSO* in accordance with section G.3.1 of Appendix 6G.

D.12A.1.1 In the event that a value of StartGeneration$_{es}$ for any *energy storage facility* is not updated by the *PSO* or provided to the *EMC* during the *dispatch period* for the time being when the calculation of the *real-time dispatch schedule* or the first *dispatch period* of the multiple *dispatch periods* involved in the calculation of a *short-term schedule* commences, the value of StartGeneration$_{es}$ for the *energy storage facility* shall be the same as the corresponding value of EnergyStorageTransfer$_{es}$ for the same *energy storage facility* in the *real-time dispatch schedule* for the *dispatch period* with respect to the time when the calculation of the *real-time dispatch schedule* or *short-term schedule* commences.

D.12A.1.2 In the event that no such *real-time dispatch schedule* is available, the initial generation level of StartGeneration$_{es}$ for the *energy storage facility* shall be the same as the corresponding value of EnergyStorageTransfer$_{es}$ for the same *energy storage facility* in the latest available *short-term schedule* (based on normal *load* forecast) for the *dispatch period* with respect to the time when the calculation of the *real-time dispatch schedule* or the *short-term schedule* commences.

D.12A.1.3 In the event that no such *short-term schedule* is available, the initial generation level of StartGeneration$_{es}$ for the *energy storage facility* shall be the same as the corresponding value of EnergyStorageTransfer$_{es}$ for the same *energy storage facility* in the latest available *pre-dispatch schedule* for the *dispatch period* with respect to the time when the calculation of the *real-time schedule* or the *short-term schedule* commences.

D.12A.1.4 In the event that no such *pre-dispatch schedule* is available, then the *EMC* shall use a value of zero for StartGeneration$_{es}$ for the *energy storage facility.*

D.12A.2 In the case where the *dispatch period* is the first *dispatch period* of the multiple *dispatch periods* involved in the calculation of the *pre-dispatch schedule*, then the values of $StartGeneration_{es}$ for each *energy storage facility* shall be the corresponding values of $EnergyStorageTransfer_{es}$ in the latest available *short-term schedule* (based on normal *load* forecast) for the *dispatch period* immediately preceding the first *dispatch period* of the *pre-dispatch schedule.*

D.12A.2.1 In the event that no such *short-term schedule* is available, then the values of $StartGeneration_{es}$ for the *energy storage facility* shall be the same as the corresponding value of $EnergyStorageTransfer_{es}$ for the same *energy storage facility* in the latest available *pre-dispatch schedule* for the *dispatch period* immediately preceding the first dispatch period of the *pre-dispatch schedule* to be calculated in D.12A.2.

D.12A.2.2 In the event that no such *pre-dispatch schedule* is available, then the *EMC* shall use a value of zero for $StartGeneration_{es}$ for the *energy storage facility.*

D.12A.3 In the case where the *dispatch period* is the first *dispatch period* of the multiple *dispatch periods* involved in the calculation of the *market outlook scenario*, the values of $StartGeneration_{g}$ for each *energy storage facility* shall be the same as the corresponding values $EnergyStorageTransfer_{es}$ for the same *energy storage facility* in the most recently released *pre-dispatch schedule* with a *nodal load forecast* corresponding to the *market outlook scenario* being calculated, and shall be taken from the *dispatch period* in such *pre-dispatch schedule* immediately preceding the first *dispatch period* required in the calculation of the *market outlook scenario*, provided that such *pre-dispatch schedule* contains the appropriate *dispatch period*. If such *pre-dispatch schedule* does not contain the appropriate *dispatch period*, then initial generation levels the values of $StartGeneration_{es}$ for such *energy storage facilities* shall be zero.

D.12A.4 In the case where the *dispatch period* is involved in the calculation of a *short-term schedule,* a *pre-dispatch schedule* or a *market outlook scenario*, and is not the *first dispatch period* of the multiple *dispatch periods* involved in the calculation of the *short-term schedule, pre-dispatch schedule* or a *market outlook scenario*, the values of $StartGeneration_{es}$ for each *energy storage facility* shall be the corresponding values of $EnergyStorageTransfer_{es}$ for the immediately preceding *dispatch period* in the *short-term schedule*, *pre-dispatch schedule* or *market outlook scenario* respectively.

D.12A.5 ExpectedStartGeneration$_{es}$ of a *generation registered facility* that is an *energy storage facility* associated with an *energy storage offer es* shall be determined in accordance with the following table:

When the *energy storage facility's* StartGeneration$_{es}$ is greater than its PriorScheduledGeneration$_{es}$, its ExpectedStartGeneration$_{es}$ shall be the higher of: a) StartGeneration$_{es}$ – DownRampRate$_{es,t-1}$ × RampingTime; and b) PriorScheduledGeneration$_{es}$.
When the *energy storage facility's* StartGeneration$_{es}$ is less than its PriorScheduledGeneration$_{es}$, its ExpectedStartGeneration$_{es}$ shall be the lower of: a) StartGeneration$_{es}$ + UpRampRate$_{es,t-1}$ × RampingTime; and b) PriorScheduledGeneration$_{es}$.
When the *energy storage facility's* StartGeneration$_{es}$ is equal to its PriorScheduledGeneration$_{es}$, its ExpectedStartGeneration$_{es}$ shall be its PriorScheduledGeneration$_{es}$.

For the purposes of this section D.12A.5 only, DownRampRate$_{es,t-1}$ and UpRampRate$_{es,t-1}$, for a given *energy storage facility* for a given *dispatch period t* to which its *energy storage offer es* relates, shall be determined using the respective values contained in its valid *energy storage offer* for the *dispatch period* immediately prior to *dispatch period t.*

D.12A.6 $$\text{EnergyTransferEndMax}_{es} = \text{ExpectedStartGeneration}_{es} + (\text{UpRampRate}_{es} / 60 \times \text{RemainingTime})$$

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

D.12A.7 $$\text{EnergyTransferEndMin}_{es} = \text{ExpectedStartGenerationes}_{es} - (\text{DownRampRate}_{es} / 60 \times \text{RemainingTime})$$

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

D.12B STATE-OF-CHARGE CONSTRAINTS

D.12B.1 In the case where a *real-time dispatch schedule* is being produced, or where the *dispatch period* is the first *dispatch period* of the multiple *dispatch periods* involved in the calculation of a *short-term schedule,* provided that a value of $StartSoC_{es}$ is updated by the *PSO* or provided to the *EMC* during the *dispatch period* for the time being when the calculation of the *real-time dispatch schedule* or the first *dispatch period* of the multiple *dispatch periods* involved in the calculation of a *short-term schedule* commences, the $ExpectedStartSoC_{es}$ of an *energy storage facility* associated with an *energy storage offer* es shall be determined in accordance with the following table:

When the *energy storage facility* is discharging (i.e., $PriorScheduledGeneration_{es} > 0$), $$ExpectedStartSoC_{es} = StartSoC_{es} - \frac{PriorScheduledGeneration_{es} \times \frac{RampingTime}{60}}{DischargingEfficiency_{es} \times MaxCapacity_{es}}$$
When the *energy storage facility* is charging or idle (i.e., $PriorScheduledGeneration_{es} \leq 0$), $$ExpectedStartSoC_{es} = StartSoC_{es} - \frac{PriorScheduledGeneration_{es} \times \frac{RampingTime}{60} \times ChargingEfficiency_{es}}{MaxCapacity_{es}}$$

D.12B.1.1 In the event that a value of $StartSoC_{es}$ is not updated by the *PSO* or provided to the *EMC* during the *dispatch period* for the time being when the calculation of the *real-time dispatch schedule* or the first *dispatch period* of the multiple *dispatch periods* involved in the calculation of a *short-term schedule* commences, the values of $ExpectedStartSoC_{es}$ for each *energy storage facility* shall be the same as the corresponding value of $EndSoC_{es}$ for the same *energy storage facility* in the *real-time dispatch schedule* for the *dispatch period* with respect to the time when the calculation of the *real-time dispatch schedule* or the *short-term schedule* commences.

D.12B.1.2 In the event that no such *real-time dispatch schedule* is available, the values of $ExpectedStartSoC_{es}$ for each *energy storage facility* shall be the same as the corresponding value of $EndSoC_{es}$ for the same *energy storage facility* in the *short-term schedule* (based on normal *load* forecast) for the *dispatch period* with

respect to the time when the calculation of the *real-time dispatch schedule* or the *short-term schedule* commences.

D.12B.1.3 In the event that no such *short-term schedule* is available, the values of ExpectedStartSoC$_{es}$ for each *energy storage facility* shall be the same as the corresponding value of EndSoC$_{es}$ for the same *energy storage facility* in the *pre-dispatch schedule* for the *dispatch period* with respect to the time when the calculation of the *real-time dispatch schedule* or the *short-term schedule* commences.

D.12B.1.4 In the event that no such *pre-dispatch schedule* is available, then the values of ExpectedStartSoC$_{es}$ for each *energy storage facility* shall equal to MinSoC$_{es}$.

D.12B.2 In the case where the *dispatch period* is the first *dispatch period* of the multiple *dispatch periods* involved in the calculation of the *pre-dispatch schedule*, then the values of ExpectedStartSoC$_{es}$ for each *energy storage facility* shall be the corresponding values of EndSoC$_{es}$ in the latest available *short-term schedule* (based on normal *load* forecast) for the *dispatch period* immediately preceding the first *dispatch period* of the *pre-dispatch schedule.*

D.12B.2.1 In the event that no such *short-term schedule* is available, then the values of ExpectedStartSoC$_{es}$ for each *energy storage facility* shall be the same as the corresponding value of EndSoC$_{es}$ for the same *energy storage facility* in the latest available *pre-dispatch schedule* for the *dispatch period* immediately preceding the first *dispatch period* of the *pre-dispatch schedule* to be calculated in D.12B.2.

D.12B.2.2 In the event that no such *pre-dispatch schedule* is available, then the values of ExpectedStartSoC$_{es}$ for each *energy storage facility* shall equal to MinSoC$_{es}$.

D.12B.3 In the case where the *dispatch period* is the first *dispatch period* of the multiple *dispatch periods* involved in the calculation of the *market outlook scenario*, the values of ExpectedStartSoC$_{es}$ for each *energy storage facility* shall be the same as the corresponding values of EndSoC$_{es}$ for the same *energy storage facility* in the most recently released *pre-dispatch schedule* with a *nodal load forecast* corresponding to the *market outlook scenario* being calculated, and shall be taken from the *dispatch period* in such *pre-dispatch schedule* immediately preceding the first *dispatch period* required in the calculation of the *market outlook scenario*, provided that such *pre-dispatch schedule* contains the appropriate *dispatch period*.

D.12B.3.1 If such *pre-dispatch schedule* does not contain the appropriate *dispatch period*, then the values of

ExpectedStartSoC$_{es}$ for such *energy storage facility* shall equal to MinSoC$_{es}$.

D.12B.4 In the case where the *dispatch period* is involved in the calculation of a *short-term schedule,* a *pre-dispatch schedule* or a *market outlook scenario*, and is not the *first dispatch period* of the multiple *dispatch periods* involved in the calculation of the *short-term schedule, pre-dispatch schedule* or a *market outlook scenario*, the values of ExpectedStartSoC$_{es}$ for each *energy storage facility* shall be the corresponding values of EndSoC$_{es}$ for the immediately preceding *dispatch period* in the *short-term schedule*, *pre-dispatch schedule* or *market outlook scenario* respectively.

D.12B.5 Values of ExpectedStartSoC$_{es}$ determined in accordance with sections D.12B.1 to D.12B.4 shall be further capped within the range [MinSoC$_{es}$, MaxSoC$_{es}$].

D.12B.6 $$\text{SoCDischargeLimitMWh}_{es} = (\text{ExpectedStartSoC}_{es} - \text{MinSoC}_{es}) \times \text{MaxCapacity}_{es}$$

{es∈ENERGYSTORAGEOFFERS}

D.12B.7 $$\text{SoCChargeLimitMWh}_{es} = (\text{MaxSoC}_{es} - \text{ExpectedStartSoC}_{es}) \times \text{MaxCapacity}_{es}$$

{es∈ENERGYSTORAGEOFFERS}

D.13 COMBINED RAMPING CONSTRAINTS

D.13.1 $$\text{MaxResponse}_r = \text{Max}\left(\frac{\sum_{j \in \text{RAWRESERVEBLOCKS}_r} \text{RawReserveBlockMax}_{r,j},}{\frac{\text{UpRampRate}_{g(r)} \times \text{ReserveResponsePeriod}_{c(r)}}{60}}\right)$$

{$r \in$ GENRESERVEOFFERS}

D.13.2 $$\text{ReserveResponseRatio}_r = \frac{\text{ReserveResponsePeriod}_{c(r)} - \text{ResponseDelay}_r}{\text{DispatchPeriod}}$$

{$r \in$ GENRESERVEOFFERS}

D.13.3 $$\text{MaxResponse}_l = \text{Max}\left(\frac{\sum_{j \in \text{REGULATIONOFFERBLOCKS}_l} \text{RegulationBlockMax}_{l,j},}{\frac{\text{UpRampRate}_{g(l)} \times \text{RegulationResponsePeriod}}{60}}\right)$$

{$l \in$ REGULATIONOFFERS}

D.13.4 $$\text{RegulationResponseRatio} = \frac{\text{RegulationResponsePeriod}}{\text{DispatchPeriod}}$$

D.13.5 $$\text{ReservePortionCombined}_r = \text{Max}\left(\text{ReservePortion}_r, \text{ReserveResponseRatio}_r\right)$$

{$r \in$ GENRESERVEOFFERS}

D.13A REGULATION RANGE CONSTRAINTS

D.13A.1 A valid *regulation offer* for a *generation registered facility* that is not an *energy storage facility* for a *dispatch period* shall only be used in the linear program if:

D.13A.1.1 a valid *energy offer* (hereinafter referred to in this section D.13A as *energy offer g)* exists for that *generation registered facility* for that *dispatch period* and the sum of the quantities in that *energy offer g* is greater than RegulationMin_g for that *generation registered facility*;

D.13A.1.2 the $\text{ExpectedStartGeneration}_g$ of that *generation registered facility* is greater than or equal to RegulationMin_g for that *generation registered facility*; and

D.13A.1.3 the $\text{ExpectedStartGeneration}_g$ of that *generation registered facility* is less than or equal to RegulationMax_g for that *generation registered facility*.

D.13A.2 A valid *regulation offer* for a *generation registered facility* that is an *energy storage facility* for a *dispatch period* shall only be used in the linear program if a valid *energy storage offer* exists for that *generation registered facility* for that *dispatch period*.

D.13B INTERTIE STATUS

D.13B.1 The *EMC* shall assign a value to EstIntertieContribution based on the *connection* status of the *intertie* lines advised by the *PSO* in accordance with section G.4.8 of Appendix 6G:

D.13B.1.1 if one or more *intertie* lines are *connected* then EstIntertieContribution is assigned the value received from the *PSO* in accordance with section G.5.7 of Appendix 6G; and

D.13B.1.2 if no *intertie* lines are *connected* then EstIntertieContribution is assigned the value of 1.0 (one).

D.13B.2 The *EMC* shall assign a value to $\text{AcceptableFreqDeviation}_c$, for each *reserve class c*, based on the *connection* status of the *intertie* lines advised by the *PSO* in accordance with section G.4.8 of Appendix 6G:

D.13B.2.1 if one or more *intertie* lines are *connected* then, for each *reserve class c*, $\text{AcceptableFreqDeviation}_c$ is assigned a value that is calculated as the acceptable frequency deviation for the corresponding *reserve class* received from the *PSO* in accordance with section G.5.8 of Appendix 6G, divided by the nominal frequency as provided by the *PSO* in accordance with section G.5.13 of Appendix 6G; and

D.13B.2.2 if no *intertie* lines are *connected* then, for each *reserve class c*, $\text{AcceptableFreqDeviation}_c$ is assigned a value that is calculated as the acceptable frequency deviation for the corresponding *reserve class* received from the *PSO* in accordance with section G.5.9 of Appendix 6G, divided by the nominal frequency as provided by the *PSO* in accordance with section G.5.13 of Appendix 6G.

D.13C LINES WITH PHASE-SHIFTING TRANSFORMERS

D.13C.1 The *EMC* shall use the latest tap position of a phase-shifting transformer of a *pst line* advised by the *PSO* in accordance with Section G.4.4A of Appendix 6G when determining the *real-time schedule*. The *EMC* shall also use the latest tap position for *short-term schedules, pre-dispatch schedules* and the *market outlook scenarios* unless advised otherwise by the *PSO* from time to time.