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.1.1.5 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

ARTIFICIALLINES	The set of *dispatch network lines* that have been artificially added to the dispatch network to model the connection of *generation registered 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.
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.
ENERGYBIDS	The set of all "purchase bids", referenced by *p*. This comprises the *nodal load forecast*, which is bid at a price exceeding *VoLL*, together with demand at the *intertie* nodes to represent any scheduled export flows across the *interties*.
$ENERGYBIDS_n$	The set of all "purchase bids" associated with node *n*. 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.
$EXCESSGENERATIONBLOCKS_n$	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*.
GENRESERVEOFFERS	The subset of RAWRESERVEOFFERS that have been submitted by the *dispatch coordinators* for *generation registered facilities*.

INTERTIEENERGYBIDS	The set comprising *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 multiunit constraint $s \in$ MULTIUNITCONSTRAINTS. Indexed by *k*.
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*.
PSTLINES	The set of *pst lines*. A subset of LINES.
$PURCHASEBIDBLOCKS_p$	The set of bid blocks for the purchase 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*.
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.
RESERVEZONES$_c$	The set of *reserve provider zones* associated with *reserve class c*.
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*.
$UNITS_g$	The set of all constituent generation units that form part of the *generation registered facility* associated with *energy offer g* $\in$ MULTIOFFERS.
VIOLATIONGROUPBLOCKS	The set of all violation penalty blocks, except those for energy deficit and excess. Indexed by *j*.
$VIOLATIONGROUPBLOCKSFAC_y$	The set of violation penalty blocks for violation of violation constraint group *y* which consists of violations associated with facilities. Indexed by *j*.
$VIOLATIONGROUPBLOCKSLIN_y$	The set of violation penalty blocks for violation of violation constraint group *y* which consists of violations associated with lines. Indexed by *j*.
$VIOLATIONGROUPBLOCKSREG_y$	The set of violation penalty blocks for violation of violation constraint group *y* which consists of violations associated with regulation requirements. Indexed by *j*.
$VIOLATIONGROUPBLOCKSRES_y$	The set of violation penalty blocks for violation of violation constraint group *y* which consists of violations associated with reserve requirements. Indexed by *j*.
$VIOLATIONGROUPBLOCKSSEC_y$	The set of violation penalty blocks for violation of violation constraint group *y* 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*.
VIOLATIONGROUPS	The set of violation constraint groups, indexed by *y*. Violation groups are used to group together violations of constraints. Each violation group is associated with only one type of entity: lines, reserve requirement, regulation requirement, facility or security constraint.

D.3 PARAMETERS

$AcceptableFreqDeviation_c$	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*.
$CircuitError_k$	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*.
$DeficitGenerationBlockMax_{n,j}$	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.
DispatchPeriod	The length in seconds of the dispatch period. This shall be 1800.
$DownRampRate_g$	The maximum ramp-down rate of the *generation registered facility* that the *energy offer g* is for, in MW/minute. Set from the values contained in valid *energy offers* referred to in section 5.2.2.6 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.
$EstGTOutputDamping_c$	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 those generators that are members of the set DAMPINGGENERATORS. Supplied by the *PSO* in accordance with Appendix 6G section G.5.11.
$EstimatedReactivePowerFlow_k$	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*, used when calculating the effective risk due to a failure of the associated

	generation registered facility. Calculated in accordance with section D.10.
$\text{ExcessGenerationBlockMax}_{n,j}$	The maximum violation for block *j* of *energy* surplus at *dispatch network node n*. Set by the *EMC* in accordance with Appendix 6J.
$\text{ExcessGenerationPenalty}_{n,j}$	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.
FixedLosses_{k}	The fixed losses attributed to *dispatch network line k*. Received from the *PSO* in accordance with Appendix 6G section G.4.4.
$\text{GenerationBlockMax}_{g,j}$	The maximum MW which can be scheduled from block $j \in \text{GENERATIONOFFERBLOCKS}_g$ 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.
$\text{GenerationEndMax}_{g}$	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.
$\text{GenerationEndMin}_{g}$	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.
$\text{GenerationOfferPrice}_{g,j}$	The per MW price assigned to *energy offer* $g \in$ ENERGYOFFERS applicable to offer block $j \in \text{GENERATIONOFFERBLOCKS}_g$. 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 Appendix 6G section G.5.1.
$GroupResponseMax_{x,j}$	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	The *energy* output of a *generation registered facility* operating at the intersection of Reserve Generation Segment 1 and Reserve Generation Segment 2. Defined as a fraction of $StandingReserveGenerationMax_g$. Equal to 0.90.
$HighLoadReserve_r$	The quantity of *reserve* in MW that can be provided by a *generation registered facility* operating with an *energy* output of HighLoad x $StandingReserveGenerationMax_g$ 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 section D.18.3 as a slack value.
$LineAdmittance_k$	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

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

	indicates flow in the conventional reverse direction. Calculated in accordance with section D.9.3.
$\text{LineLossConst}_{k,j}$	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 D.9.4.
$\text{LineMaxForward}_{k}$	The forward maximum available capacity of transmission line $k \in$ LINES. Calculated in accordance with section D.10.
$\text{LineMaxReverse}_{k}$	The reverse maximum available capacity of transmission line $k \in$ LINES. A negative quantity. Calculated in accordance with section D.10.
$\text{LineRatingForward}_{k}$	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.
$\text{LineRatingReverse}_{k}$	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 *generation registered facility g* can provide *reserve* that meets the requirements of the Transmission Code.
$\text{LowLoadReserve}_{r}$	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* .
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.
MediumLoad	The *energy* output of a *generation registered facility* operating at the intersection of Reserve Generation Segment 2 and Reserve Generation Segment 3. Defined as a fraction of $StandingReserveGenerationMax_g$. Equal to 0.75.
$MediumLoadReserve_r$	The quantity of *reserve* in MW that can be provided by a *generation registered facility* operating with an *energy* output of MediumLoad x $Standing\ ReserveGenerationMax_g$ and offering *reserve offer r*.
$MinimumRisk_c$	The minimum contingency risk to be covered by the aggregate system response in *reserve* class *c*. Received from the *PSO* in accordance with Appendix 6G section G.5.4.
$MultiGroupLineWeights_{s,k}$	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* specified in *energy offer g* under section 5.2.2.5 of Chapter 6.
$Proportion_u$	The default proportion of generation for *generation 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 purchase bid $p \in$ ENERGYBIDS applicable to purchase 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 purchase bid $p \in$ ENERGYBIDS. Set from the *nodal load forecast* in accordance with section D.9A.3.1, or from the *intertie* schedules in accordance with section D.9A.5.1.
$RawReserveBlockMax_{r,j}$	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) can operate the *generation registered facility* associated with *energy offer g* to provide *regulation* capability. Calculated in accordance with section D.9A.8.
$RegulationMin_g$	The minimum output for which *automatic generator control* (AGC) 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.
$RegulationOfferPrice_{l,j}$	The per MW price assigned to *regulation offer* $l \in$ REGULATIONOFFERS applicable to *offer* block $j \in REGULATIONOFFERBLOCKS_l$. 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* associated with *reserve offer r*. Calculated in accordance with section D.9A.7.
$\text{ReserveOfferPrice}_{r,j}$	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.
$\text{ReserveProportion}_{r}$	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 contained in valid *reserve offers* referred to in section 5.3.2.6 of Chapter 6.
$\text{ReserveProportionCombined}_{r}$	The maximum of $\text{ReserveProportion}_{r}$ and $\text{ReserveResponseRatio}_{r}$. Calculated in accordance with section D.13.5.
$\text{ReserveResponsePeriod}_{c}$	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* or interruptible load associated with raw *reserve offer r* begins to respond following a contingency event. Set from the *standing capability data* referred to in Appendix 6E section E.1.1.11.
$RevisedMaxLineRating_k$	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 Appendix 6G section G.5.1.
$SecurityGroupLineWeight_{s,k}$	The weighting attached to *dispatch network line k*'s flow in security constraint *s*. Received from the *PSO* in accordance with Appendix 6G section G.5.1.
$SecurityGroupNodeWeight_{s,n}$	The weighting attached to *dispatch network node n*'s net injection in security constraint *s*. Received from the *PSO* in accordance with Appendix 6G section G.5.1.
$StandingReserveGenerationMax_{g(r)}$	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 beginning of *dispatch period* generation level of the *generation registered facility* associated with *energy offer g*. 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 beginning of *dispatch period* generation level of generation unit *u*. Received from the *PSO* in accordance with Appendix 6G section G.3.1.
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.
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.
$UpRampRate_g$	The maximum ramp-up rate of the *generation registered facility* that the *energy offer g* is for, in MW/minute. Set from the values contained in valid *energy offers* referred to in section 5.2.2.6 of Chapter 6.
$ViolationGroupBlockMax_{y,j}$	The maximum violation of the violation group *y* constraints allowed in violation group block *j*. Set from the *values* in Appendix 6J where such values are specified, otherwise set by the *PSO* in accordance with section 2.3 of this Chapter.
$ViolationGroupPenalty_{y,j}$	The per MW constraint violation cost associated with block *j* of violation variable for group *y*. Set from the *values* in Appendix 6J where such values are specified, otherwise set by the *PSO* in accordance with section 2.3 of this Chapter.
$ZoneResponseMax_{z,c}$	The maximum total *reserve* response of *reserve class c* allowed from *load registered facilities* from *reserve provider zone z*. Received from the *PSO* in accordance with Appendix 6G section G.5.3B.

D.4 VARIABLES

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

$DeficitGenerationBlock_{n,j}$	The block *j* MW deficit generation at node *n*.
$DeficitMulti_s$	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* associated with *regulation offer l*.
DeficitRegulation	The MW deficit of *regulation*.
$DeficitReserve_c$	The MW deficit of class *c reserve*.
$DeficitSecurity_s$	The MW deficit for security constraint *s*.
$DeficitWLineFlow_k$	The MW flow on *dispatch network line k* below the flow consistent with the line flow/line loss weight variables.
$EffectiveReserve_x$	The total effective *reserve* contribution from all *reserve offers* cleared from *reserve provider group x*.
$ExcessDownRampRate_g$	The portion of the MW/sec amount by which the down ramp rate of the *generation registered facility* associated with *energy offer g* 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.
$ExcessResGen Segment1_r$	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* 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* 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*.
$ExcessUpRampRate_g$	The portion of the MW/sec amount by which the up ramp rate of the *generation registered facility* unit associated with *energy offer g* 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.
$FacilityMultiUnitViolation_g$	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.
$FacilityRegulationViolation_g$	The total MW violation of the *regulation* constraints associated with the *generation registered facility* that *energy offer g* is for.
$FacilityReserveViolation_g$	The total MW violation of the *reserve* constraints associated with the *generation registered facility* that *energy offer g* is for.
$GenerationBlock_{g,j}$	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.
$GroupResponse_{x,j}$	The *jth* block of *reserve* response from *reserve offers* from *reserve provider group x*.
$LineFlow_k$	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*.
$NodeAngle_n$	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 purchase bid *p*.
$Purchase_{p}$	The total MW amount scheduled for purchase bid *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.*
$RegulationSegmentSelector1_{l}$ $RegulationSegmentSelector2_{l}$ $RegulationSegmentSelector3_{l}$	Binary integer variables associated with *regulation offer l*, used for modeling of regulation-generation constraints in section D.18.3.
$Risk_{c}$	The MW risk to be covered by aggregate system response for *reserve class c*.
TotalPurchase	The total MW amount scheduled for all purchase bids *p*, where $p \in$ ENERGYBIDS, $p \notin$ INTERTIEENERGYBIDS.
$ViolationGroupBlock_{y,j}$	The block *j* MW violation attributed to violation constraint group *y*.
ViolationPenalties	The sum of all of the violation penalties applied to violations of constraints within the model, except those for energy deficit and excess.
$Weight_{k,j}$	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* from *reserve provider*

	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.5 FUNCTIONS

c(r)	References the *reserve class* associated with *reserve offer r*, and to which it contributes.
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(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(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(r)	References the *regulation offer l* that has the same associated *generation registered facility* as the *reserve offer r*.
m(g)	References the *market network node m* corresponding to the *energy offer g*.
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 *generation unit u.*
r(g,c), r(h,c)	References the *reserve offer r* that has the same associated *generation registered facility* as the *energy offer g* or *h,* and applies to *reserve class c.*
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 *generation 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*.
y(k), y(c), y(g) y(s), y(regulation)	References the violation group associated with line *k*, the *reserve* requirement for *reserve class c*, the *generation registered facility* associated with *energy offer g*, the security or 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 *pre-dispatch schedule* and the *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 section 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 generation unit in accordance with 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 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 the *dispatch period* is involved in the calculation of a *real-time dispatch schedule, short-term schedule, pre-dispatch schedule scenario* or *market outlook scenario*, then the *EMC* shall make the following changes to the dispatch network for the *dispatch period* in respect of each *generation unit* for each *generation registered facility* which is not represented as *synchronised* in the status data on the network elements received from the *PSO*:

D.6.5.1 Add an artificial *dispatch network node* and connect the *generation unit* to the *dispatch network node*.

D.6.5.2 Add an artificial *dispatch network line* connected to the *artificial dispatch network node* described in D.6.5.1, and the default bus for the *generating unit* described in section D.7.2 or D.7.3, as the case may be. An artificial *dispatch network line* used for this purpose shall not include the constraints in section D.21.1, and shall:

a. 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

b. 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 all units as if they are connected, and hence the offers for the period will determine whether they generate in the schedule.

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.7 MARKET NETWORK NODES

D.7.1 A *market network node* for each *generation registered facility* and each *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 designate a main default bus, and an alternate default bus which is in the same substation/switchouse as the main default bus, for each *generation registered facility* that is not a *multi-unit facility* and each *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*, 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/switchouse as the main default bus, for each *generation* unit of each *generation registered facility* that is a *multi-unit facility*, representing the most likely connection point for that *generation* unit. The *EMC* shall specify on reasonable grounds a proportion indicating the ratio by which the prices of the nodes corresponding to the designated main default buses will be combined into the *market network node* energy price.

D.7.3A In the event where both the designated main and alternate default buses of a *generation facilit*y referred to in section D.7.2 above or a *generation* unit referred to in section D.7.3 above are disconnected from the *PSO controlled system*, the *EMC* shall, in consultation with the *PSO*, select a suitable bus for that *generation facility* or *generation* 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 *generation* unit of each *generation registered facility* that is a *multi-unit facility*, representing the most likely connection line for that *generation* 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 deemed to be connected to the dispatch network in accordance in 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 deemed to be connected to the dispatch network in accordance with section D.6.5, then the *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* shall be the *dispatch network node* corresponding to the bus designated by the *PSO* as being the default connection bus for that *generation 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 *generation registered facility* that is a *multi-unit facility* shall be connected to the dispatch network at an 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 the *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 *generation units*, subject to section D.8.3.1, 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.*

$\text{StartGeneration}_{u(GT2)}$ 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*:

$$\text{StartGeneration}_g = 0.5 \times \text{StartGeneration}_{u(ST)}$$

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

$$\text{StartGeneration}_g = \sum_{u \in \text{UNITS}_g} \text{StartGeneration}_u$$

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 *generation 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* commences. In the event that no such *real-time dispatch schedule* is available, then the *EMC* shall use a value of zero for that StartGeneration_u for that *generation unit* in the calculations of this section D.8.3.

D.8.4 In the case where the *dispatch period* is involved in the calculation of a *pre-dispatch schedule scenario* and is the first *dispatch period* of the multiple *dispatch periods* involved in the calculation of the *pre-dispatch schedule 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 *real-time*

dispatch schedule for the *dispatch period* current at the time when the calculation of the *pre-dispatch schedule scenario* commences.

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 scenario* with a *nodal load scenario* corresponding to the *market outlook scenario* being calculated, and shall be taken from the *dispatch period* in such *pre-dispatch schedule scenario* immediately preceding the first *dispatch period* required in the calculation of the *market outlook scenario*, provided that such *pre-dispatch schedule scenario* contains the appropriate *dispatch period*. If such *pre-dispatch schedule scenario* 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 scenario* 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 scenario* 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 scenario* 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 in accordance with the following table:

For *multi-unit facilities g* comprising one gas turbine and one steam turbine:	
Where the gas turbine and steam turbine are both represented as *synchronised* or connected to the dispatch network in accordance with section D.6.5	Constraint *s*: $\frac{1}{\text{Proportion}_{u(GT)}} \times \text{LineFlow}_{k(GT,g)}$ $-\frac{1}{\text{Proportion}_{u(ST)}} \times \text{LineFlow}_{k(ST,g)}$ $+\text{DeficitMulti}_s - \text{ExcessMulti}_s = 0$

<table>
<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 both gas turbines and the steam turbine are each represented as either synchronised or connected to the dispatch network in accordance with section D.6.5</td><td>Constraint s:
$\frac{1}{\text{Proportion}_{u(GT1)}} \times \text{LineFlow}_{k(GT1,g)}$
$+ \frac{1}{\text{Proportion}_{u(GT2)}} \times \text{LineFlow}_{k(GT2,g)}$
$- \frac{2}{\text{Proportion}_{u(ST)}} \times \text{LineFlow}_{k(ST,g)}$
$+ \text{DeficitMulti}_{s} - \text{ExcessMulti}_{s} = 0$</td></tr>
<tr><td>Where the first gas turbine and steam turbine are each represented as synchronised or connected to the dispatch network in accordance with section D.6.5, and the second gas turbine is represented as not synchronised and not connected to the dispatch network in accordance with section D.6.5</td><td>Constraint s:
$\frac{1}{\text{Proportion}_{u(GT1)}} \times \text{LineFlow}_{k(GT1,g)}$
$- \frac{1}{\text{Proportion}_{u(ST)}} \times \text{LineFlow}_{k(ST,g)}$
$+ \text{DeficitMulti}_{s} - \text{ExcessMulti}_{s} = 0$</td></tr>
<tr><td>Where the second gas turbine and steam turbine are each represented as synchronised or connected to the dispatch network in accordance with section D.6.5, and the first gas turbine is represented as not synchronised and not connected to the dispatch network in accordance with section D.6.5</td><td>Constraint s:
$\frac{1}{\text{Proportion}_{u(GT2)}} \times \text{LineFlow}_{k(GT2,g)}$
$- \frac{1}{\text{Proportion}_{u(ST)}} \times \text{LineFlow}_{k(ST,g)}$
$+ \text{DeficitMulti}_{s} - \text{ExcessMulti}_{s} = 0$</td></tr>
</table>

D.8.8 The variable $\mathrm{LineFlow}_k$ 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 $\mathrm{LineMaxForward}_k$ shall have a value calculated as follows for the *dispatch network lines* referred to in section D.8.2.

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

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

D.9 LINE ADMITTANCE AND LINE LOSS APPROXIMATION

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

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

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

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

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

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

$$\text{PhaseAngleShift}_k = 0$$

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

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

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

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

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

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

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

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.2 The set ENERGYBIDS shall comprise bids to purchase *energy* 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 *load* forecast quantity; 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 of the corresponding *intertie schedule*; and

D.9A.5.2 the price of the *energy* bid shall equal 10xVoLL 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 $\text{ReserveGenerationMax}_r$ associated with each *reserve offer* 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 $\text{OfferedCapacity}_{g(r)}$.

D.9A.8 The parameter $\text{RegulationMax}_{g(l)}$ associated with each *regulation offer* 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 $\text{OfferedCapacity}_{g(l)}$.

D.9B VALIDATION TEST EQUATIONS

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

D.9B.1 LowLoad must be greater than zero.

$$\text{LowLoad}_{g(r)} > 0$$

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

D.9B.2 LowLoad must be less than Medium Load

$$\text{LowLoad}_{g(r)} < \text{MediumLoad x StandingReserveGenerationMax}_{g(r)}$$

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

D.9B.3 The LowLoad Reserve Point must lie on or above the line joining the origin to the Medium Load Reserve Point.

$$\text{LowLoadReserve}_r \geq \text{Slope x LowLoad}_{g(r)}$$

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

where :

$$\text{Slope} = \text{MediumLoadReserve}_r \text{ / (MediumLoad x StandingReserveGenerationMax}_{g(r)})$$

D.9B.4 The Medium Load Reserve Point must lie on or above the line joining the Low Load Reserve Point to the High Load Reserve Point.

$$\text{MediumLoadReserve}_r \geq \text{LowLoadReserve}_r + \text{Slope x (MediumLoad x StandingReserveGenerationMax}_{g(r)} - \text{LowLoad}_{g(r)})$$

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

where :

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

D.9B.5 The High Load Reserve Point must lie on or above the line joining the Medium Load Reserve Point to the Standing Reserve Generation Max Point.

$$\text{HighLoadReserve}_r \geq \text{MediumLoadReserve}_r + \text{Slope x (HighLoad x StandingReserveGenerationMax}_{g(r)} - \text{MediumLoad x StandingReserveGenerationMax}_{g(r)})$$

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

where :

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

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

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

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

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

D.11 ESTIMATED RESERVE EFFECTIVENESS

D.11.1 $\text{EstReserveEffectiveness}_{r(g,c)} = \text{Effectiveness}_{x(g,c),1}$

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

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 the *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 Appendix 6G section G.3.1.

D.12.1.1 In the event that a value of StartGeneration_g for any *generation 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 the *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* commences. In the event that no such *real-time 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 scenario*, 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 *real-time dispatch schedule* for the *dispatch period* current at the time when the calculation of the *pre-dispatch schedule scenario* commences, or, if this *real-time dispatch schedule* is not available, the *real-time dispatch schedule* for the *dispatch period* immediately preceding that which is current at the time when the calculation of the *pre-dispatch schedule scenario* commences.

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 scenario* with a *nodal load scenario* corresponding to the *market outlook scenario* being calculated, and shall be taken from the *dispatch period* in such *pre-dispatch schedule scenario* immediately preceding the first *dispatch period* required in the calculation of the *market outlook scenario*, provided that such *pre-dispatch schedule scenario* contains the appropriate *dispatch period*. If such *pre-dispatch schedule scenario* 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 scenario* 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 scenario* 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 scenario* or *market outlook scenario* respectively.

D.12.5

$$\text{GenerationEndMax}_g = \text{StartGeneration}_g + \left(\text{UpRampRate}_g / 60 \times \text{RemainingTime}\right)$$

$$\{g \in \text{ENERGYOFFERS}, g \notin \text{INTERTIEENERGYOFFERS}\}$$

D.12.6

$$\text{GenerationEndMin}_g = \text{StartGeneration}_g - \left(\text{DownRampRate}_g / 60 \times \text{RemainingTime}\right)$$

$$\{g \in \text{ENERGYOFFERS}, g \notin \text{INTERTIEENERGYOFFERS}\}$$

D.13 COMBINED RAMPING CONSTRAINTS

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

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

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

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

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

$\{l \in \text{REGULATIONOFFERS}\}$

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

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

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

D.13A REGULATION RANGE CONSTRAINTS

D.13A.1 A valid *regulation offer* shall only be used in the linear program if:

D.13A.1.1 a valid *energy offer* exists for the *generation registered facility* for that *dispatch period* and the sum of the quantities in that *energy offer* is greater than RegulationMin_g for the relevant *generation registered facility*;

D.13A.1.2 the StartGeneration_g of the relevant *generation registered facility* is greater than or equal to RegulationMin_g for the relevant *generation registered facility*; and

D.13A.1.3 the $StartGeneration_g$ of the relevant *generation registered facility* is less than or equal to $RegulationMax_g$ for the relevant *generation registered facility*.

Explanatory Note: Alternative tests could have been $StartGeneration_g$ + $UpRampRate_g$ x RemainingTime > $RegulationMin_g$, and $StartGeneration_g$ - $DownRampRate_g$ x RemainingTime < $RegulationMax_g$ which would ensure that the facility could provide the regulation at the end of the dispatch period. However, the current rules are more conservative, and are designed so that regulation can be provided throughout the dispatch period.

D.13B INTERTIE STATUS

D.13B.1 Assign a value to EstIntertieContribution based on the status of the *intertie* lines advised by the *PSO* in accordance with Appendix 6G section G.4.6:

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 Appendix 6G section G.5.7.

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

D.13B.2 Assign a value to $AcceptableFreqDeviation_c$, for each *reserve class c*, based on the status of the *intertie* lines advised by the *PSO* in accordance with section G.4.6:

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

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

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 schedule, pre-dispatch schedule scenarios* and the *market outlook scenarios* unless advised otherwise by the *PSO* from time to time.