Approximate NEMDE Formulation

Aleksis Xenophon

October 4, 2020

1 Overview

Australia's National Electricity Market (NEM) is dispatched via the National Electricity Market Dispatch Engine (NEMDE). The precise formulation of the NEMDE is not made publicly available, however the inputs to the model are. Using these input files along with publicly available information it is possible to infer the NEMDE's structure and construct an approximate representation of the algorithm. As the output of the NEMDE are also made available it is possible to assess the validity of these inferences by comparing output from the inferred model with observed output from the NEMDE. The following sections outline an approximate formulation of the NEMDE.

2 Notation

3 Model

3.1 Parameters

3.2 Expressions

3.2.1 Units

Unit bid cost:

$$UnitCost = \sum_{(i,j,k) \in TraderQuantityBands} K_{ij} PriceBand_{ijk} QuantityBand_{ijk} \tag{1}$$

where:

$$K_{ij} = \begin{cases} -1 & \text{if } j = \text{LDOF} \\ 1 & \text{otherwise} \end{cases}$$

MNSP bid cost:

$$MNSPCost = \sum_{(i,j,k) \in MNSPQuantityBands} PriceBand_{ijk} QuantityBand_{ijk} \tag{2}$$

3.2.2 Regions

Dispatched generation at end of dispatch interval:

$$DispatchedGeneration_r = \sum_{i,j \in O_r^{ENOF}} TraderTotalOffer_{ij} \quad \forall r \in R \tag{3}$$

Dispatched load at end of dispatch interval:

$$DispatchedLoad_r = \sum_{i,j \in O_r^{LDOF}} TraderTotalOffer_{ij} \quad \forall r \in R \tag{4}$$

Dispatched load at start of dispatch interval:

$$InitialScheduledLoad_r = \sum_{i,j \in O_r^{LDOF} \setminus O_r^{semi-dispatch}} TraderInitialMW_{ij} \quad \forall r \in R \tag{5}$$

Loss allocated to region at start of dispatch interval:

$$RegionInitialAllocatedLoss_r = \sum_{i \in Interconnectors} InitialLoss_i LossShareFactor_{ri} + \sum_{i \in MNSPs} InitialLoss_i LossFactor_{ri} \tag{6}$$

Loss allocated to region at end of dispatch interval:

$$RegionAllocatedLoss_r = \sum_{i \in Interconnectors} Loss_i LossShareFactor_{ri} + \sum_{i \in MNSPs} Loss_i MNSPLossFactor_{ri} \tag{7}$$

where:

$$LossShareFactor_{ri} = \begin{cases} LossShare_i & \text{if } r \text{ is } i\text{'s 'from' region} \\ 1 - LossShare_i & \text{if } r \text{ is } i\text{'s 'to' region} \\ 0 & \text{otherwise} \end{cases}$$

and

$$MNSPLossFactor_{ri} = \begin{cases} 1 & \text{if } r \text{ is } i\text{'s 'from' region and } InitialMW_i \geq 0 \\ 0 & \text{otherwise} \end{cases}$$

MSNP initial allocated loss:

$$RegionLossFactor_{ri} = \begin{cases} (FromLFExport_i - 1) & \text{if } r \text{ is } i\text{'s 'from' region and } InitialMW_i \geq 0 \\ (ToLFImport_i - 1) & \text{if } r \text{ is } i\text{'s 'to' region and } InitialMW_i \geq 0 \\ (FromLFImport_i - 1) & \text{if } r \text{ is } i\text{'s 'from' region and } InitialMW_i < 0 \\ (ToLFExport_i - 1) & \text{if } r \text{ is } i\text{'s 'to' region and } InitialMW_i < 0 \\ 0 & \text{otherwise} \end{cases}$$

$$MNSPLossShare_{ri} = \begin{cases} MNSPLossFactor_{ri} & \text{if } r \text{ is } i\text{'s 'from' region} \\ -(1 - MNSPLossFactor_{ri}) & \text{if } r \text{ is } i\text{'s 'to' region} \\ 0 & \text{otherwise} \end{cases}$$

$$FlowDirectionFactor_{ri} = \begin{cases} 1 & \text{if } r \text{ is } i\text{'s 'from' region} \\ -1 & \text{if } r \text{ is } i\text{'s 'to' region} \\ 0 & \text{otherwise} \end{cases}$$

Initial MNSP loss allocated to region:

$$MNSPInitialLoss_r = \sum_{i \in MNSPs} RegionLossFactor_{ri}(InitialMW_i + MNSPLossShare_{ri} InitialLoss_i) FlowDirectionFactor_{ri} \tag{8}$$

MNSP loss allocated to region:

$$MNSPLoss_r = \sum_{i \in MNSPs} RegionLossFactor_{ri}(Flow_i + MNSPLossShare_{ri} Loss_i) FlowDirectionFactor_{ri} \tag{9}$$

Region fixed demand:

$$\begin{aligned} FixedDemand_r =& RegionInitialDemand_r + RegionADE_r + RegionDF_r - RegionInitialScheduledLoad_r \\ & - RegionInitialAllocatedLoss_r - RegionInitialMNSPLoss_r \end{aligned} \tag{10}$$

Region cleared demand:

$$\begin{aligned} ClearedDemand_r =& RegionFixedDemand_r + RegionaAllocatedLoss_r + RegionDispatchedLoad_r \\ & + RegionMNSPLoss_r \end{aligned} \tag{11}$$

Interconnector export:

$$RegionInterconnectorExport_r = \sum_{i \in Interconnectors} FlowDirectionFactor_{ri} Flow_i \tag{12}$$

Net export:

$$RegionNetExport_r = RegionInterconnectorExport_r + RegionAllocatedLoss_r + RegionMNSPLoss_r \tag{13}$$

3.3 Constraints

3.3.1 Units

Trader total offer:

$$TraderTotalOffer_{ij} = \sum_{i=1}^{10} QuantityBand_{ijk} \quad \forall i,j \in TraderOffers \tag{14}$$

Trader quantity band limit:

$$QuantityBand_{ijk} \leq \overline{QuantityBand}_{ijk} + QuantityBandDeficit_{ijk} \quad \forall i,j,k \in QuantityBandOffers \tag{15}$$

Total offer constrained by MaxAvail:

$$TraderTotalOffer_{ij} \leq UIGF_{ij} + MaxAvailDeficit_{ij} \quad \forall i,j \in SemiScheduledOffers \cap ENOFOffers \tag{16}$$

$$\begin{aligned} TraderTotalOffer_{ij} \leq& MaxAvail_{ij} + MaxAvailDeficit_{ij} \\ & \forall i,j \in TraderOffers \setminus SemiScheduledOffers \cap ENOFOffers \end{aligned} \tag{17}$$

Trader ramp-up constraint:

$$\begin{aligned} TraderTotalOffer_{ij} - TraderInitialMW_i \leq& (OfferRampUpRate_{ij}/12) + RampUpDeficit_{ij} \\ & \forall i,j \in TraderEnergyOffers \end{aligned} \tag{18}$$

Trader ramp-down constraint:

$$\begin{aligned} TraderTotalOffer_{ij} - TraderInitialMW_i + RampDownDeficit_{ij} \geq& -(OfferRampDownRate_{ij}/12) \\ & \forall i,j \in TraderEnergyOffers \end{aligned} \tag{19}$$

MNSP total offer:

$$MNSPTotalOffer_{ij} = \sum_{i=1}^{10} MNSPBandAvail_{ijk} \tag{20}$$

MNSP band offer:

$$\begin{aligned} MNSPQuantityBand_{ijk} \leq & \overline{MNSPQuantityBand}_{ijk} + MNSPQuantityBandDeficit_{ijk} \\ & \forall i, j \in MNSPQuantityBands \end{aligned} \tag{21}$$

MNSP constrained by MaxAvail:

$$MNSPTotalOffer_{ij} \leq MaxAvail_{ij} + MNSPTotalOfferDeficit_{ij} \quad \forall i, j \in MNSPOffers \tag{22}$$

3.3.2 Generic constraints

$$f_i(\boldsymbol{a}, \boldsymbol{b}, \boldsymbol{c}) \leq RHS_i \quad \forall i \in LEQConstraints \tag{23}$$

$$g_i(\boldsymbol{a}, \boldsymbol{b}, \boldsymbol{c}) = RHS_i \quad \forall i \in EQConstraints \tag{24}$$

$$h_i(\boldsymbol{a}, \boldsymbol{b}, \boldsymbol{c}) \geq RHS_i \quad \forall i \in GEQConstraints \tag{25}$$

Power balance constraint:

$$\begin{aligned} RegionDispatchGeneration_r = & RegionFixedDemand_r + RegionDispatchedLoad_r + RegionNetExport_r \\ & \forall r \in Regions \end{aligned} \tag{26}$$

3.3.3 Interconnector

Forward flow:

$$Flow_i \leq \overline{Flow}_i + ForwardFlowDeficit_i \quad \forall i \in Interconnectors \tag{27}$$

Reverse flow:

$$Flow_i + ReverseFlowDeficit_i \geq -\underline{Flow}_i \quad \forall i \in Interconnectors \tag{28}$$

(add ramp rate constraint)

3.3.4 FCAS

Generator joint ramping raise regulation:

$$\begin{aligned} TraderTotalOffer_{i,ENOF} + TraderTotalOffer_{i,R5RE} \leq & TraderInitialMW_i + (SCADARampUpRate_i/12) \\ & + GeneratorJointRampingUpDeficit_{ij} \\ & \forall i, j \in FCASR5REOffers \cap FCASAvailableOffers \\ & \cap SCADARampUpRateDefined \\ & \cap EnergyOfferDefined \cap GeneratorOffers \end{aligned} \tag{29}$$

Generator joint ramping lower regulation:

$$\begin{aligned}TraderTotalOffer_{i,ENOF} - TraderTotalOffer_{i,L5RE} + GeneratorJointRampingDownDeficit_{ij} \\ \geq TraderInitialMW_i - (SCADARampDownRate_i/12) \\ \forall i,j \in FCASR5REOffers \cap FCASAvailableOffers \\ \cap SCADARampUpRateDefined \cap EnergyOfferDefined \\ \cap GeneratorOffers\end{aligned} \tag{30}$$

Generator joint capacity constraint (RHS):

$$\begin{aligned}&TraderTotalOffer_{i,ENOF} + UpperSlopeCoefficient_{ij}TraderTotalOffer_{ij} + TraderTotalOffer_{i,R5RE} \\ &\leq EffectiveEnablementMax_{ij} + GeneratorJointCapacityConstraintRHSDeficit_{ij} \\ &\forall i,j \in GeneratorOffers \cap ContingencyFCASOffers \\ &\cap HasCorrespondingEnergyOffer \cap FCASAvailable \cap HasR5REOffer\end{aligned} \tag{31}$$

$$\begin{aligned}&TraderTotalOffer_{i,ENOF} + UpperSlopeCoefficient_{ij}TraderTotalOffer_{ij} \\ &\leq EffectiveEnablementMax_{ij} + GeneratorJointCapacityConstraintRHSDeficit_{ij} \\ &\forall i,j \in GeneratorOffers \cap ContingencyFCASOffers \\ &\cap HasCorrespondingEnergyOffer \cap FCASAvailable \cap NoR5REOffer\end{aligned} \tag{32}$$

Generator joint capacity constraint (LHS):

$$\begin{aligned}&TraderTotalOffer_{i,ENOF} - LowerSlopeCoefficient_{ij}TraderTotalOffer_{ij} - TraderTotalOffer_{i,L5RE} \\ &+ GeneratorJointCapacityConstraintLHSDeficit_{ij} \geq EffectiveEnablementMin_{ij} \\ &\forall i,j \in GeneratorOffers \cap ContingencyFCASOffers \\ &\cap HasCorrespondingEnergyOffer \cap FCASAvailable \cap HasL5REOffer\end{aligned} \tag{33}$$

$$\begin{aligned}&TraderTotalOffer_{i,ENOF} - LowerSlopeCoefficient_{ij}TraderTotalOffer_{ij} \\ &+ GeneratorJointCapacityConstraintLHSDeficit_{ij} \geq EffectiveEnablementMin_{ij} \\ &\forall i,j \in GeneratorOffers \cap ContingencyFCASOffers \\ &\cap HasCorrespondingEnergyOffer \cap FCASAvailable \cap NoL5REOffer\end{aligned} \tag{34}$$

Joint energy and regulating FCAS constraint (RHS):

$$\begin{aligned}&TraderTotalOffer_{i,ENOF} + UpperSlopeCoefficient_{ij}TraderTotalOffer_{ij} \\ &\leq EffectiveEnablementMax_{ij} + GeneratorJointEnergyRegulatingRHSFCASDeficit_{ij} \\ &\forall i,j \in GeneratorOffers \cap RegulatingFCASOffers \cap HasEnergyOffer \\ &\cap FCASAvailable\end{aligned} \tag{35}$$

Joint energy and regulating FCAS constraint (LHS):

$$\begin{aligned}&TraderTotalOffer_{i,ENOF} - LowerSlopeCoefficient_{ij}TraderTotalOffer_{ij} \\ &+ GeneratorJointEnergyRegulatingLHSFCASDeficit_{ij} \geq EffectiveEnablementMin_{ij} \\ &\forall i,j \in GeneratorOffers \cap RegulatingFCASOffers \cap HasEnergyOffer \\ &\cap FCASAvailable\end{aligned} \tag{36}$$

Generator max FCAS available:

$$TraderTotalOffer_{ij} \leq EffectiveMaxAvailable_{ij} + MaxAvailDeficit_{ij} \quad \forall i,j \in GeneratorOffers \cap FCASOffers \tag{37}$$

Load joint ramping raise regulation:

$$\begin{aligned} TraderTotalOffer_{ij} - TraderTotalOffer_{i,R5RE} + LoadJointRampingRaiseDeficit_{ij} \\ \geq TraderInitialMW_{ij} - (TraderSCADARampDownRate_i/12) \\ \forall i,j \in LoadOffers \cap R5REOffers \cap FCASAvailable \\ \cap HasSCADARampDownRate \cap HasEnergyOffer \end{aligned} \tag{38}$$

Load joint ramping lower regulation:

$$\begin{aligned} TraderTotalOffer_{i,LDOF} + TraderTotalOffer_{i,L5RE} \leq TraderInitialMW_i \\ + (TraderSCADARampUpRate_i/12) + LoadJointRampingLowerDeficit_{ij} \\ \forall i,j \in LoadOffers \cap L5REOffers \cap FCASAvailable \\ \cap HasSCADARampUpRate \cap HasEnergyOffer \end{aligned} \tag{39}$$

Load joint capacity (RHS):

$$\begin{aligned} TraderTotalOffer_{i,LDOF} + UpperSlopeCoefficient_{ij} TraderTotalOffer_{ij} + TraderTotalOffer_{i,L5RE} \\ \leq EffectiveEnablementMax_{ij} + LoadJointCapacityConstraintRHSDeficit_{ij} \\ \forall i,j \in LoadOffers \cap ContingencyFCASOffers \cap FCASAvailable \\ \cap HasEnergyOffer \cap HasL5REOffer \end{aligned} \tag{40}$$

$$\begin{aligned} TraderTotalOffer_{i,LDOF} + UpperSlopeCoefficient_{ij} TraderTotalOffer_{ij} \\ \leq EffectiveEnablementMax_{ij} + LoadJointCapacityConstraintRHSDeficit_{ij} \\ \forall i,j \in LoadOffers \cap ContingencyFCASOffers \cap FCASAvailable \\ \cap HasEnergyOffer \cap NoL5REOffer \end{aligned} \tag{41}$$

Load joint capacity (LHS):

$$\begin{aligned} TraderTotalOffer_{i,LDOF} - LowerSlopeCoefficient_{ij} TraderTotalOffer_{ij} - TraderTotalOffer_{i,R5RE} \\ + LoadJointCapacityConstraintLHSDeficit_{ij} \geq EnablementMin_{ij} \\ \forall i,j \in LoadOffers \cap ContingencyFCASOffers \cap FCASAvailable \\ \cap HasEnergyOffer \cap HasR5REOffer \end{aligned} \tag{42}$$

$$\begin{aligned} TraderTotalOffer_{i,LDOF} - LowerSlopeCoefficient_{ij} TraderTotalOffer_{ij} \\ + LoadJointCapacityConstraintLHSDeficit_{ij} \geq EnablementMin_{ij} \\ \forall i,j \in LoadOffers \cap ContingencyFCASOffers \cap FCASAvailable \\ \cap HasEnergyOffer \cap NoR5REOffer \end{aligned} \tag{43}$$

Load joint energy regulating FCAS constraint (RHS):

$$\begin{aligned} TraderTotalOffer_{i,LDOF} + UpperSlopeCoefficient_{ij} TraderTotalOffer_{ij} \\ \leq EffectiveEnablementMax_{ij} + LoadJointRegulatingEnergyRHSDeficit_{ij} \\ \forall i,j \in LoadOffers \cap RegulatingFCASOffers \cap HasEnergyOffer \\ \cap FCASAvailable \end{aligned} \tag{44}$$

Load joint energy regulating FCAS constraint (LHS):

$$\begin{aligned}TraderTotalOffer_{i,LDOF} &- LowerSlopeCoefficient_{ij}TraderTotalOffer_{ij}\\ &+ LoadJointRegulatingEnergyLHSDeficit_{ij} \geq EffectiveEnablementMin_{ij}\\ &\forall i,j \in LoadOffers \cap RegulatingFCASOffers \cap HasEnergyOffer\\ &\cap FCASAvailable\end{aligned} \tag{45}$$

Load max FCAS available:

$$TraderTotalOffer_{ij} \leq EffectiveMaxAvail_{ij} + MaxAvailDeficit_{ij} \quad \forall i,j \in LoadOffers \cap FCASOffers \tag{46}$$

3.3.5 Loss model

Approximated loss:

$$Loss_i = \sum_k BreakPointY_{ik}\lambda_{ik} \quad \forall i \tag{47}$$

SOS2 condition 1:

$$Flow_i = \sum_k BreakPointX_{ik}\lambda_{ik} \quad \forall i \tag{48}$$

SOS2 condition 2:

$$\sum_k \lambda_{ik} = 1 \quad \forall i \tag{49}$$

SOS2 condition 3:

$$\sum_k LossY_{ik} = 1 \quad \forall i \tag{50}$$

SOS2 condition 4:

$$\sum_{z=l+1}^{k-1} LossY_{iz} \leq \sum_{z=l+1}^{k} \lambda_{iz} \quad \forall l = 2, \ldots, k-1 \quad \forall i \tag{51}$$

SOS2 condition 5:

$$\sum_{z=l+1}^{k} \lambda_{iz} \leq \sum_{z=l}^{k-1} LossY_{iz} \quad \forall l = 2, \ldots, k-1 \quad \forall i \tag{52}$$

SOS2 condition 6:

$$\lambda_{i,1} \leq LossY_{i,1} \tag{53}$$

SOS2 condition 7:

$$\lambda_{i,k} \leq LossY_{i,k-1} \tag{54}$$

3.3.6 Fast-start inflexibility constraints

Output fixed to 0 when unit unavailable / synchronising:

$$\begin{aligned}TraderTotalOffer_{i,EnergyOffer} + InflexibilityProfileLHSDeficit_{ij} = 0 + InflexibilityProfileRHSDeficit_{ij}\\ \forall i,j \in EnergyOffers \cap TraderCurrentMode0 \cup TraderCurrentMode1\end{aligned} \tag{55}$$

Output fixed to startup profile when ramping to min-loading:

$$\begin{aligned} TraderTotalOffer_{i,EnergyOffer} + InflexibilityProfileLHSDeficit_{ij} &= StartupProfile \\ &+ InflexibilityProfileRHSDeficit_{ij} \\ &\forall i,j \in EnergyOffers \cap TraderCurrentMode2 \end{aligned} \tag{56}$$

Output lower bound is min loading when in mode 3:

$$\begin{aligned} TraderTotalOffer_{i,EnergyOffer} + InflexibilityProfileDeficit_{ij} \geq MinLoading_i \\ \forall i,j \in EnergyOffers \cap TraderCurrentMode3 \end{aligned} \tag{57}$$

Output lower bound is inflexibility profile when in mode 4:

$$\begin{aligned} TraderTotalOffer_{i,EnergyOffer} + InflexibilityProfileDeficit_{ij} \geq InflexibilityProfile_i \\ \forall i,j \in EnergyOffers \cap TraderCurrentMode4 \cap InModel4 \end{aligned} \tag{58}$$

3.3.7 Tie-breaking constraints

$$(q_{ijk}/\overline{q}_{ijk}) - (q_{qrs}/\overline{q}_{qrs}) = Slack1_{ijkqrs} - Slack2_{ijkqrs} \quad \forall i,j,k,q,r,s \in PriceTied \tag{59}$$

$$TieBreakCost = \sum_{i,j,k,q,r,s \in PriceTied} TieBreakPrice(Slack1_{ijkqrs} + Slack2_{ijkqrs}) \tag{60}$$

3.4 Objective Function

$$\text{minimise} \quad UnitCost + MNSPCost + ConstraintViolationPenalty + TieBreakCost \tag{61}$$