# SPD: the current implementation.

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# The SPD model formulation(1)

- Bids and offers ( Objective)
- AC Transmission.
- HVDC transmission
- Security constraints.
- Mixed constraints.
- Instantaneous reserve model

# Bids and offers ( Objective)

4.1.1.1 $$NetBenefit = \sum_{p \in BIDS} \sum_{j=1}^{PurchaseBidBlocks_p} Purchase_{p,j} \times PurchaseBidPrice_{p,j}$$

$$- \sum_{g \in OFFERS} \sum_{j=1}^{GenerationOfferBlocks_g} Generation_{g,j} \times GenerationOfferPrice_{g,j}$$

$$- \sum_{r \in RESERVEOFFERS} \sum_{j=1}^{ReserveOfferBlocks_r} Reserve_{r,j} \times ReserveOfferPrice_{r,j}$$

# Bid and Offer (constraints)

3.1.1.1 $Generation_{g,j} \le GeneratorOfferMW_{g,j}$

$j = 1, \ldots GenerationOfferBlocks_g \quad \forall g \in OFFERS$ .

3.1.1.2 $Generation_g = \sum_{j=1}^{GenerationOfferBlocks_g} Generation_{g,j} \quad \forall g \in OFFERS$ .

3.1.1.3 $Purchase_{p,j} \le PurchaseBidMW_{p,j} \quad j = 1, \ldots, PurchaseBidBlocks_p$

$\forall p \in BIDS$ .

3.1.1.4 $Purchase_p = \sum_{j=1}^{PurchaseBidBlocks_p} Purchase_{p,j} \quad \forall p \in BIDS$ .

# AC Transmission (1).

3.3.1.1 $$ACNodeNetInjection_n = \sum_{q \in S_{AC}(n)} ACLineFlow_q^{Directed} - \sum_{q \in R_{AC}(n)} ACLineFlow_q^{Directed} \quad \forall\, n \in ACNODES\ .$$

3.3.1.2
$$\begin{aligned} ACNodeNetInjection_n = & \sum_{g \in OFFERS_n} Generation_g - \sum_{p \in BIDS_n} Purchase_p \\ & - \sum_{l \in S_{HVDC}(n)} HVDCLinkFlow_l \\ & + \sum_{l \in R_{HVDC}(n)} \left( HVDCLinkFlow_l - HVDCLinkLosses_l \right) \\ & - \sum_{l \in HVDCLINKS_n} \tfrac{1}{2} \times HVDCLinkFixedLosses_l \\ & - \sum_{q \in R_{AC}(n)} ACLineLosses_q^{Directed} \\ & - \sum_{k \in ACLINES_n} \tfrac{1}{2} \times ACLineFixedLosses_k \quad \forall\, n \in ACNODES \end{aligned}$$

Energy prices - shadow prices of equation (3.3.1.1)

# AC Transmission (2).

3.3.1.3 $ACLineFlow_q^{Directed} \le ACLineCapacity_{k(q)}$

$\forall q \in DIRECTEDACLINES$ .

3.3.1.4 $ACLineFlow_k = ACLineFlow_{F(k)}^{Directed} - ACLineFlow_{B(k)}^{Directed} \quad \forall k \in ACLINES$ .

3.3.1.5 $ACLineFlow_k = ACLineAdmittance_k \times \left(ACNodeAngle_{b(k)} - ACNodeAngle_{e(k)}\right)$

$\forall k \in ACLINES$ .

3.3.1.6 $ACLineFlowBlock_{q.j}^{Directed} \le ACLineLossMW_{k(q)} \quad j = 1, \ldots, ACLineLossBlocks_{k(q)}$

$\forall q \in DIRECTEDACLINES$ .

3.3.1.7 $ACLineFlow_q^{Directed} = \sum_{j=1}^{ACLineLossBlocks_{k(q)}} ACLineFlowBlock_{q,j}^{Directed}$

$\forall q \in DIRECTEDACLINES$ .

3.3.1.8 $ACLineLossesBlock_{q,j}^{Directed} = ACLineFlowBlock_{q,j}^{Directed} \times ACLineLossFactor_{k(q),j}$

$j = 1, \ldots, ACLineLossBlocks_{k(q)} \quad \forall q \in DIRECTEDACLINES$ .

3.3.1.9 $ACLineLosses_q^{Directed} = \sum_{j=1}^{ACLineLossBlocks_{k(q)}} ACLineLossesBlock_{q,j}^{Directed}$

$j = 1, \ldots, ACLineLossBlocks_{k(q)} \quad \forall q \in DIRECTEDACLINES$ .

3.3.1.10 $ACNodeAngle_n = 0 \quad \forall n \in REFERENCENODES$.

# HVDC Transmission (1).

3.2.1.1 $HVDCLinkFlow_{l} \leq HVDCLinkCapacity_{l} \quad \forall l \in HVDCLINKS$ .

3.2.1.2 $HVDCLinkLosses_{l} = \sum_{bp=1}^{HVDCBreakpo\,int\,s_{l}} HVDCBreakpointMWLosses_{l,bp} \times Lambda_{l,bp}$

3.2.1.3 $HVDCLinkFlow_{l} = \sum_{bp=1}^{HVDCBreakpo\,int\,s_{l}} HVDCBreakpointMWFlow_{l,bp} \times Lambda_{l,bp}$

3.2.1.4 $\sum_{bp=1}^{HVDCBreakpo\,int\,s_{l}} Lambda_{l,bp} = 1$

3.2.1.5 $DCNodeNetInjection_{h\_n} = 0 \qquad \forall h\_n \in HVDCNODES$ .

3.2.1.6
$$DCNodeNetInjection_{h\_n} = -\sum_{l \in S_{HVDC}(h\_n)} HVDCLinkFlow_{l} + \sum_{l \in R_{HVDC}(h\_n)} \left(HVDCLinkFlow_{l} - HVDCLinkLosses_{l}\right) - \sum_{l \in HVDCLINKS_{h\_n}} \tfrac{1}{2} \times HVDCLinkFixedLosses_{l}$$

$\forall h\_n \in HVDCNODES$

# Constraints (1)

3.5.1.1 $Generation_{g(v)} \leq SecurityGenerationMaximum_{v} \quad \forall\, v \in SECURITY_{GenerationMaximum}.$

3.5.1.2 $Generation_{g(v)} \geq SecurityGenerationMinimum_{v} \quad \forall\, v \in SECURITY_{GenerationMinimum}.$

3.5.1.3 $ACLineFlow_{q(v)}^{Directed} \leq SecurityACLineCapacity_{v} \quad \forall\, v \in SECURITY_{ACLineCapa}$

3.5.1.4 $HVDCLinkFlow_{l(v)} \leq SecurityHVDCLinkCapacity_{v} \quad \forall\, v \in SECURITY_{HVDCLinkCapacity}.$

3.5.1.5 $$\sum_{q \in SECURITYACLINESGROUP_{v}} ACLineFlow_{q}^{Directed} \times SecurityGroupACLineWeight_{q}$$

$$\leq SecurityGroupACLinesFlow_{v} \quad \forall\, v \in SECURITY_{GroupACLinesFlow}.$$

# Constraints (2)

3.5.1.6 $$\sum_{n \in SECURITYACNODESGROUP_v} ACNodeNetInjection_n \times SecurityGroupACNodeWeight_n \le SecurityGroupACNodesNetInjection_v$$

$$\forall\ v \in SECURITY_{GroupACNodesNetInjection}.$$

3.5.1.7 $$\sum_{p \in SECURITYMARKETPURNODEGROUP_v} Purchase_p \times MarketNodePurWeight_p$$

$$+ \sum_{g \in SECURITYMARKETGENNODEGROUP_v} Generation_g \times MarketNodeGenWeight_g$$

$$+ \sum_{r \in SECURITYMARKETRESNODEGROUP_v} \mathrm{Re}\,serve_r \times MarketNodeResWeight_r$$

$$=\le\ge MarketNodeSecurityLimit_v$$

$$\forall\ v \in SECURITY_{GroupMarketNodes}$$

# Mixed Constraints (3)

3.6.1.1.

$$
\begin{aligned}
& MixedConstraintVariable_m \times MixedConstVarWeight1_m \\
+ & \sum_{p \in MIXEDPURNODEGROUP_m} Purchase_p \times MixedConstPurWeight_{p,m} \\
+ & \sum_{g \in MIXEDGENNODEGROUP_m} Generation_g \times MixedConstGenWeight_{g,m} \\
+ & \sum_{r \in MIXEDRESNODEGROUP_m} Reserve_r \times MixedConstResWeight_{r,m} \\
+ & \sum_{q \in MIXEDDIRACLINEGROUP_m} ACLineFlow_q^{Directed} \times MixedConstACLineWeight_{q,m} \\
+ & \sum_{q \in MIXEDDIRACLINEGROUP_m} ACLineLosses_q^{Directed} \times MixedConstACLineLossWeight_{q,m} \\
+ & \sum_{k \in MIXEDACLINEGROUP_m} ACLineFixedLosses_k \times MixedConstACLineFixedLossWeight_{k,m} \\
+ & \sum_{l \in MIXEDDCLINEGROUP_m} HVDCLinkFlow_l \times MixedConstDCLineWeight_{l,m} \\
+ & \sum_{l \in MIXEDDCLINEGROUP_m} HVDCLinkLosses_l \times MixedConstDCLineLossWeight_{l,m} \\
+ & \sum_{l \in MIXEDDCLINEGROUP_m} HVDCLinkFixedLosses_l \times MixedConstDCLineFixedLossWeight_{l,m} \\
= \leq \geq & \; MixedConstraintLimit1_m
\end{aligned}
$$

$$\forall \; m \in MIXEDCONSTRAINTS_{Type1}$$

3.6.1.2

$$\sum_{m \in MIXEDVARGROUP_b} MixedConstraintVariable_m \times MixedConstVarWeight2_{m,b}$$

$$= \leq \geq \; MixedConstraintLimit2_b$$

# Instantaneous reserve (1)

3.4.1.1 $$IslandRisk_{i,c,rc} = IslandRiskAdjustmentFactor_{i,c,rc} \times \left(HVDCRec_i - RiskOffset_{i,c,rc}\right)$$

$$\forall\ c \in RESERVECLASSES \quad \forall\ i \in ISLANDS \quad \forall\ rc \in \left\{DCCE_i, DCECE_i\right\}$$

3.4.1.2 $$HVDCRec_i = \sum_{n(i)} \left( \begin{array}{l} -\sum_{l \in S_{HVDC}(n)} HVDCLinkFlow_l \\ +\sum_{l \in R_{HVDC}(n)} \left(HVDCLinkFlow_l - HVDCLinkLosses_l\right) \\ -\sum_{l \in HVDCLINKS_n} \frac{1}{2} \times HVDCLinkFixedLosses_l \end{array} \right)$$

$$\forall\ i \in ISLANDS$$

# Instantaneous reserve (2)

3.4.1.3

$$IslandRisk_{i,c,rc} = IslandRiskAdjustmentFactor_{i,c,rc} \times \left(Generation_g - RiskOffset_{i,c,rc}\right) + \sum_{r \in RESERVEOFFERS_{g,c}} Reserve_r$$

$$\forall\, g \in ISLANDRISKGENERATORS_i \quad \forall\, c \in RESERVECLASSES$$

$$\forall\, i \in ISLANDS \quad \text{for} \quad rc = g$$

3.4.1.4

$$IslandRisk_{i,c,rc} = IslandRiskAdjustmentFactor_{i,c,rc} \times \left(IslandMinimumRisk_i - RiskOffset_{i,c,rc}\right)$$

$$\forall\, c \in RESERVECLASSES \quad \forall\, i \in ISLANDS \quad \text{for } rc = Manual_i$$

3.4.1.5

$$RiskOffset_{i,c,rc} = MixedConstraintVariable_{m(i,c,rc)}$$

$$\forall\, c \in RESERVECLASSES \quad \forall\, i \in ISLANDS \quad \forall\, rc \in RISKCLASSES_i$$

# Instantaneous reserve (3)

3.4.2.1 $Reserve_{r,j} \le ReserveOfferProportion_{r,j} \times Generation_{g(r)}$

$j = 1,\ldots, ReserveOfferBlocks_r \quad \forall\, r = RESERVEOFFERS_{PLSR}.$

3.4.2.2

$Reserve_{r,j} \le ReserveOfferMaximum_{r,j} \quad j = 1,\ldots, ReserveOfferBlocks_r$

$\forall\, r = RESERVEOFFERS.$

3.4.2.3 $Reserve_r = \sum_{j=1}^{ReserveOfferBlocks_r} Reserve_{r,j} \quad \forall\, r \in RESERVEOFFERS.$

3.4.2.4 $Generation_g + ReserveMaximumFactor_{g,c} \times \sum_{r \in RESERVEOFFERS_{g,c}} Reserve_r$

$\le ReserveGenerationMaximum_g$

$\forall\, g \in OFFERS \quad \forall\, c \in RESERVECLASSES.$

3.4.2.5 $Reserve_r \le Purchase_{p(r)} \quad \forall\, r \in RESERVEOFFERS_{IL}.$

# Instantaneous reserve (4)

3.4.3.1 $IslandRisk_{i,c,rc} \leq MaxIslandRisk_{i,c} \quad \forall\, rc \in RISKCLASSES$

3.4.3.2

$$MaxIslandRisk_{i,c} \leq \sum_{r \in RESERVEOFFERS_{i,c}} Reserve_r \quad \forall\, c \in RESERVECLASSES$$

$\forall\, i \in ISLANDS$

Reserve prices - shadow prices of equation (3.4.3.2)

# SPD size, modelling language, solver,

- 700 Branches
- 500 Buses
- Two AC system connected by HVDC link(Pole 1 and Pole2)
- The model is written using AIMMS2 modelling language.
- CPLEX6.5(LP) solves  problem very quickly (few seconds).

# SPD inputs

- Line’s limits, network configuration and outage information are provided by Grid owner.
- Security constraints are prepared by System Operator.
- RiskOffset coefficients are prepared by Reserve Management Tool (RMT).

# SPD outputs (inputs)

Seven different outputs using SPD with different initial inputs:

- PDS – Pre-dispatch Schedule (Offers and Bids)
- SDS – Security Dispatch Schedule (Load forecast)
- SPDQ – Schedule of Prices and Dispatch Quantities (Load forecast))
- RTD – Real Time Dispatch (Load forecast base on SCADA generation data)
- RTP – Real Time Pricing (SCADA load data)
- Final Pricing (Metered load data)

# MIP algorithms.

- AC branch integer constraints.
- Integer constraints to prevent circulating flow between HVDC links.
- Piece-wise linear approximation of HVDC losses (Lambda formulation).
- Integer Constraints for non-continuous limits

# Infeasibility in the SPD.

- Infeasibilities are detected by appearance a non-zero explicit slack variable values (Deficit or Surplus) with very big, around 100,000+ ($/MW) penalty factors in the objective function.
- Penalty factors are a method to solve the LP and to clearly identify issues within the solution.
- Price Infeasibilities always resolved for the final pricing process.