California ISO

# Day-Ahead Market Enhancements
# Draft Technical Description

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DAME Stakeholder Call

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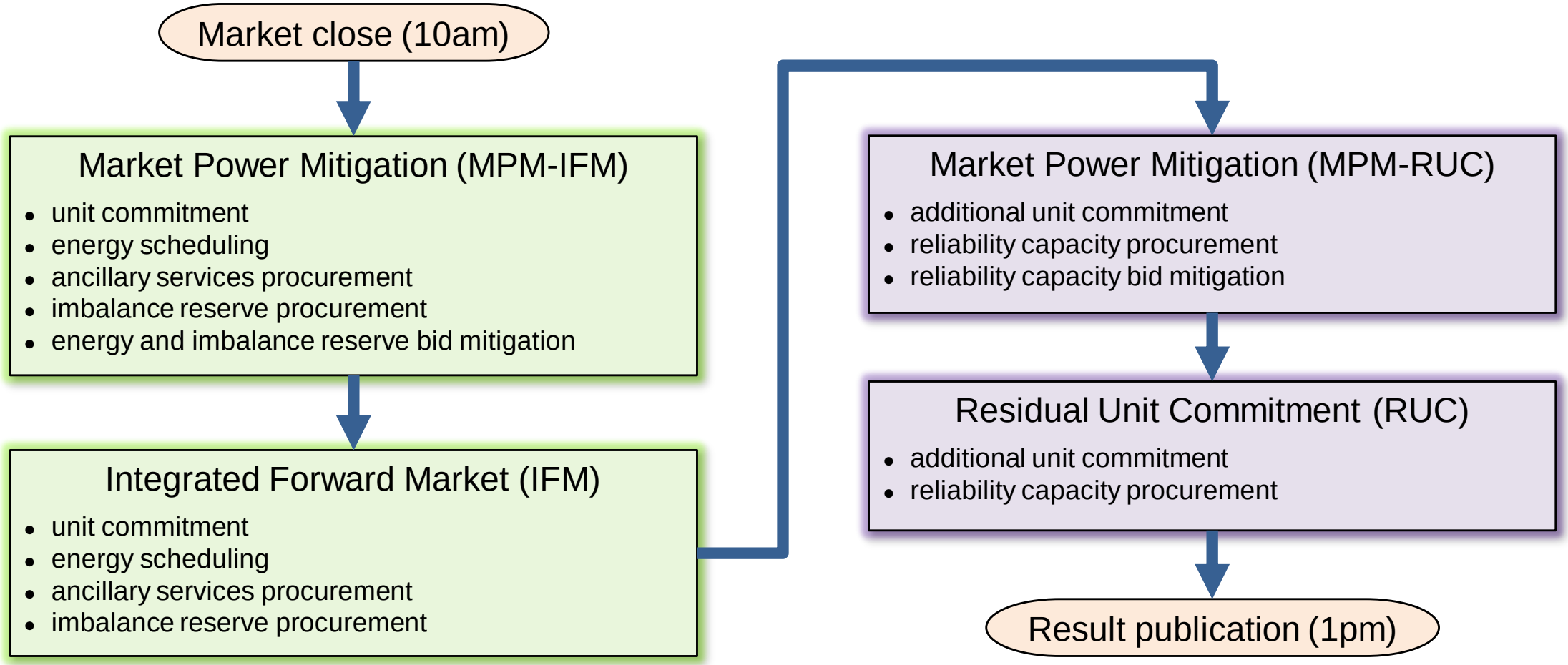
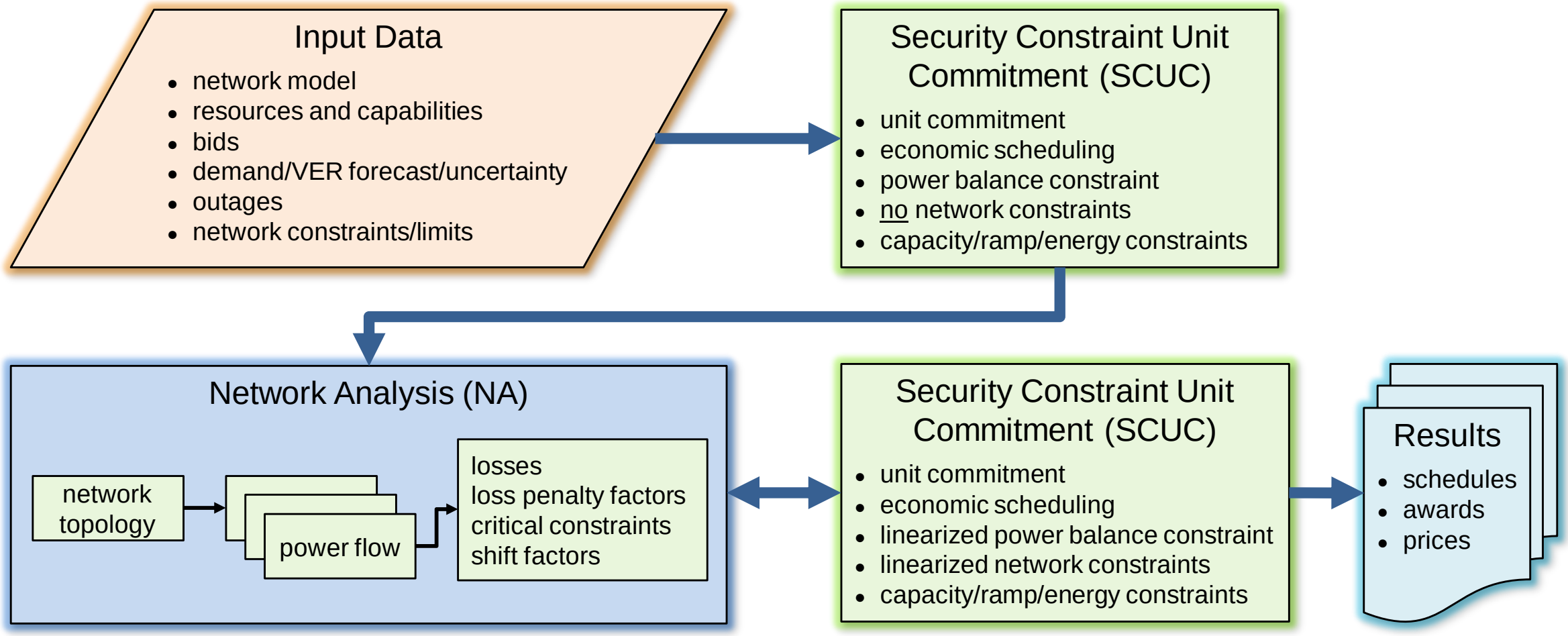
# Overview

- Market application sequence
- Mixed Integer Linear Programming optimization
- Imbalance reserve procurement in IFM
- Reliability capacity procurement in RUC
- Power balance constraints
- Network constraints
- State of Charge constraints
- Resource Supply Index in Market Power Mitigation
- Price formation

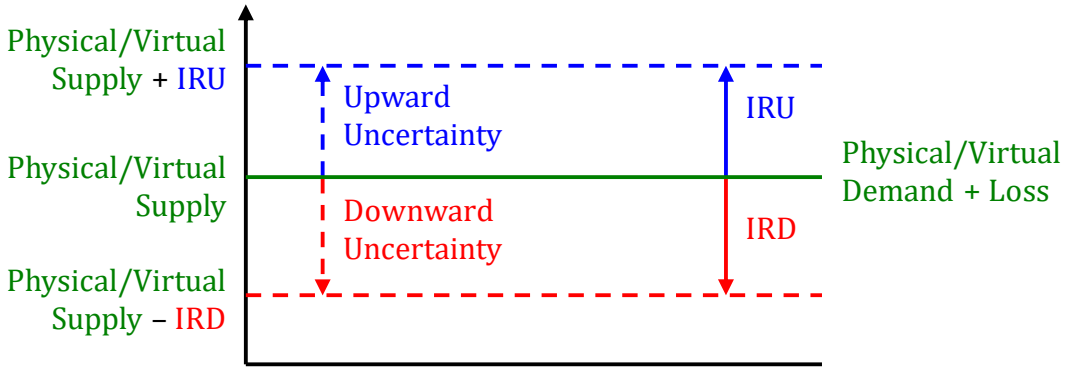
# Market Application Sequence

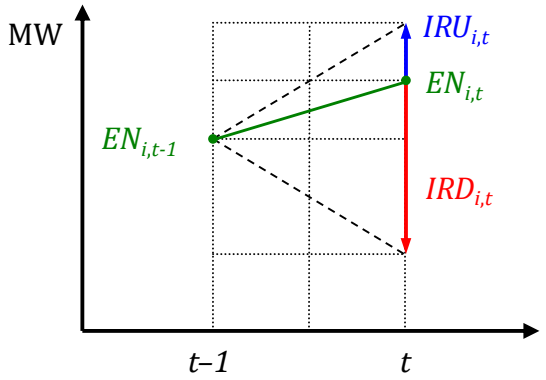


# Mixed Integer Linear Programming Optimization



# Imbalance Reserve Procurement in IFM




$$\sum_i EN_{i,t} + \sum_i VS_{i,t} = \sum_i L_{i,t} + \sum_i VD_{i,t} + Loss_t$$

$$\sum_i IRU_{i,t} \geq IRUR_t$$

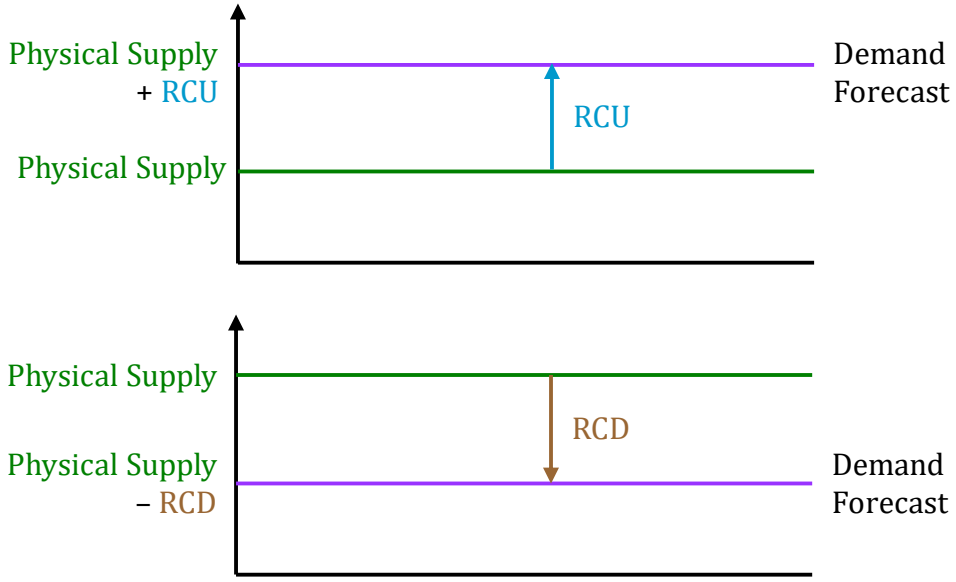
$$\sum_i IRD_{i,t} \geq IRDR_t$$

$$LEL_{i,t} + IRD_{i,t} \leq EN_{i,t} \leq UEL_{i,t} - IRU_{i,t}$$

$$EN_{i,t} - EN_{i,t-1} \leq RRU_i\left(EN_{i,t-1}, T_{60}\right) - 4\,\delta\, IRU_{i,t}$$

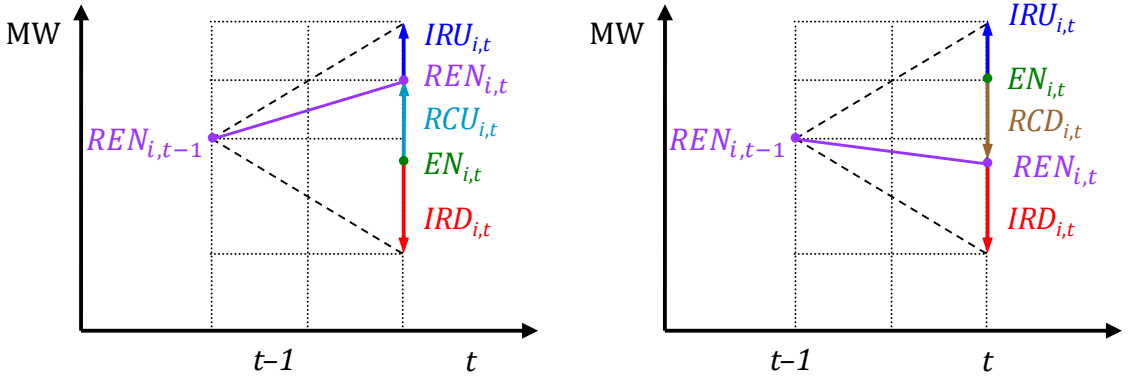
$$EN_{i,t} - EN_{i,t-1} \geq -RRD_i\left(EN_{i,t-1}, T_{60}\right) + 4\,\delta\, IRD_{i,t}$$

# Reliability Capacity Procurement in RUC




$$\{EN_{i,t}, IRU_{i,t}, IRD_{i,t}\} \text{ fixed}$$

$$\sum_i REN_{i,t} \equiv \sum_i \left(EN_{i,t} + RCU_{i,t} - RCD_{i,t}\right) = D_t$$




$$LEL_{i,t} + IRD_{i,t} \le REN_{i,t} \le UEL_{i,t} - IRU_{i,t}$$

$$REN_{i,t} - REN_{i,t-1} \le RRU_i\left(REN_{i,t-1}, T_{60}\right) - 4\,\delta\, IRU_{i,t}$$

$$REN_{i,t} - REN_{i,t-1} \ge -RRD_i\left(REN_{i,t-1}, T_{60}\right) + 4\,\delta\, IRD_{i,t}$$

# Power Balance Constraints

- IFM

$$\sum_i EN_{i,t} + \sum_i VS_{i,t} = \sum_i L_{i,t} + \sum_i VD_{i,t} + Loss_t \Rightarrow \sum_i \frac{\Delta EN_{i,t}}{LPF_{i,t}} + \sum_i \frac{\Delta VS_{i,t}}{LPF_{i,t}} - \sum_i \frac{\Delta L_{i,t}}{LPF_{i,t}} - \sum_i \frac{\Delta VD_{i,t}}{LPF_{i,t}} = 0$$

- RUC

$$\sum_i \left(EN_{i,t} + RCU_{i,t} - RCD_{i,t}\right) = D_t \Rightarrow \sum_i \frac{\Delta RCU_{i,t}}{LPF_{i,t}^{(r)}} - \sum_i \frac{\Delta RCD_{i,t}}{LPF_{i,t}^{(r)}} = 0$$

# Network Constraints

- IFM

$$LFL_{m,t} \le F_{m,t} \le UFL_{m,t} \Rightarrow \widetilde{LFL}_{m,t} \le \tilde{F}_{m,t} + \sum_i \left(\Delta EN_{i,t} + \Delta VS_{i,t} - \Delta VD_{i,t} - \Delta L_{i,t}\right) SF_{i,m,t} \le \widetilde{UFL}_{m,t}$$

$$LFL_{m,t} \le F^{(u)}_{m,t} \le UFL_{m,t} \Rightarrow \widetilde{LFL}^{(u)}_{m,t} \le \tilde{F}^{(u)}_{m,t} + \sum_i \left(\Delta EN_{i,t} + \Delta IRU_{i,t} + \Delta VS_{i,t} - \Delta VD_{i,t} - \Delta L_{i,t}\right) SF_{i,m,t} \le \widetilde{UFL}^{(u)}_{m,t} \Rightarrow$$

$$\widetilde{LFL}_{m,t} \le \tilde{F}_{m,t} + \sum_i \left(\Delta EN_{i,t} + IRU_{i,t} + \Delta VS_{i,t} - \Delta VD_{i,t} - \Delta L_{i,t} + DF^{(u)}_{i,t}\, IRUR_t\right) SF_{i,m,t} \le \widetilde{UFL}_{m,t}$$

$$LFL_{m,t} \le F^{(u)}_{m,t} \le UFL_{m,t} \Rightarrow \tilde{F}^{(d)}_{m,t} + \sum_i \left(\Delta EN_{i,t} - \Delta IRD_{i,t} + \Delta VS_{i,t} - \Delta VD_{i,t} - \Delta L_{i,t}\right) SF_{i,m,t} \le \widetilde{UFL}^{(d)}_{m,t} \Rightarrow$$

$$\widetilde{LFL}_{m,t} \le \tilde{F}_{m,t} + \sum_i \left(\Delta EN_{i,t} - IRD_{i,t} + \Delta VS_{i,t} - \Delta VD_{i,t} - \Delta L_{i,t} - DF^{(d)}_{i,t}\, IRDR_t\right) SF_{i,m,t} \le \widetilde{UFL}_{m,t}$$

- RUC

$$LFL_{m,t} \le F^{(r)}_{m,t} \le UFL_{m,t} \Rightarrow \widetilde{LFL}^{(r)}_{m,t} \le \tilde{F}^{(r)}_{m,t} + \sum_i \left(\Delta RCU_{i,t} - \Delta RCD_{i,t}\right) SF_{i,m,t} \le \widetilde{UFL}^{(r)}_{m,t}$$

# State of Charge Constraints

- IFM

$$SOC_{i,t} = SOC_{i,t-1} - \left(EN_{i,t}^{(+)} + \eta_i \, EN_{i,t}^{(-)}\right)$$
$$0 \le EN_{i,t}^{(+)} \le u_{i,t} \, UEL'_{i,t}$$
$$\left(1 - u_{i,t}\right) LEL'_{i,t} \le EN_{i,t}^{(-)} \le 0$$
$$EN_{i,t} = EN_{i,t}^{(+)} + EN_{i,t}^{(-)}$$

$$SOC_{i,t-1} - RU_{i,t} - SR_{i,t} - NR_{i,t} - IRU_{i,t} \ge \underline{SOC}_{i,t}$$
$$SOC_{i,t-1} + \eta_i \left(RD_{i,t} + IRD_{i,t}\right) \le \overline{SOC}_{i,t}$$

$$SOC_{i,t}^{(u)} = SOC_{i,t-1}^{(u)} - EN_{i,t}^{(+)} - \eta_i \, EN_{i,t}^{(-)} - ARU_t \, RU_{i,t} \ge \underline{SOC}_{i,t}$$
$$SOC_{i,t}^{(d)} = SOC_{i,t-1}^{(d)} - EN_{i,t}^{(+)} - \eta_i \, EN_{i,t}^{(-)} + \eta_i \, ARD_t \, RD_{i,t} \le \overline{SOC}_{i,t}$$

$$CF \, RU_{i,t} \le -LCL_{i,t} - RD_{i,t}$$
$$CF \, RU_{i,t} \le \max\left(0, -LEL_{i,t}\right)$$
$$CF \, RD_{i,t} \le UCL_{i,t} - RU_{i,t}$$
$$CF \, RD_{i,t} \le \min\left(0, UEL_{i,t}\right)$$

- RUC

$$SOC_{i,t-1} - RU_{i,t} - SR_{i,t} - NR_{i,t} - IRU_{i,t} - RCU_{i,t} \ge \underline{SOC}_{i,t}$$
$$SOC_{i,t-1} + \eta_i \left(RD_{i,t} + IRD_{i,t} + RCD_{i,t}\right) \le \overline{SOC}_{i,t}$$

# Resource Supply Index in Market Power Mitigation

- IFM

$$\overline{SCF}_{i,\mathrm{m},t} = -\min\left(0, SF_{i,m,t}\right)\ \min\left(UCL_{i,t} - RU_{i,t} - SR_{i,t} - NR_{i,t}, UEL_{i,t}\right)$$

$$\underline{SCF}_{i,m,t} = -w_{i,t}\ \min\left(0, SF_{i,m,t}\right)\ \max\left(LCL_{i,t} + RD_{i,t}, LEL_{i,t}\right)$$

$$WC_{i,m,t} = \overline{SCF}_{i,m,t} - \underline{SCF}_{i,m,t}$$

$$DCF_{i,m,t} = -\min\left(0, SF_{i,m,t}\right)\ EN_{i,t}$$

$$RSI_{m,t} = \left(\sum_{i \in FCS_{m,t}} \overline{SCF}_{i,m,t} + \sum_{i \in PPS_{m,t}} \underline{SCF}_{i,m,t}\right) \Big/ \sum_{i} DCF_{i,m,t}$$

$$DCF^{(u)}_{i,m,t} = -\min\left(0, SF_{i,m,t}\right)\ \left(EN_{i,t} + IRU_{i,t}\right)$$

$$RSI^{(u)}_{m,t} = \left(\sum_{i \in FCS_{m,t}} \overline{SCF}_{i,m,t} + \sum_{i \in PPS_{m,t}} \underline{SCF}_{i,m,t}\right) \Big/ \sum_{i} DCF^{(u)}_{i,m,t}$$

$$DCF^{(d)}_{i,m,t} = -\min\left(0, SF_{i,m,t}\right)\ \left(EN_{i,t} - IRD_{i,t}\right)$$

$$RSI^{(d)}_{m,t} = \left(\sum_{i \in FCS_{m,t}} \overline{SCF}_{i,m,t} + \sum_{i \in PPS_{m,t}} \underline{SCF}_{i,m,t}\right) \Big/ \sum_{i} DCF^{(d)}_{i,m,t}$$

- RUC

$$\overline{SCF}_{i,\mathrm{m},t} = -\min\left(0, SF_{i,m,t}\right)\ \min\left(UCL_{i,t} - RU_{i,t} - SR_{i,t} - NR_{i,t} - IRU_{i,t}, UEL_{i,t} - IRU_{i,t}\right)$$

$$\underline{SCF}_{i,m,t} = -w_{i,t}\ \min\left(0, SF_{i,m,t}\right)\ \max\left(LCL_{i,t} + RD_{i,t} + IRD_{i,t}, LEL_{i,t} + IRD_{i,t}\right)$$

$$WC_{i,m,t} = \overline{SCF}_{i,m,t} - \underline{SCF}_{i,m,t}$$

$$DCF_{i,m,t} = -\min\left(0, SF_{i,m,t}\right)\left(EN_{i,t} + RCU_{i,t} - RCD_{i,t}\right)$$

$$RSI_{m,t} = \left(\sum_{i \in FCS_{m,t}} \overline{SCF}_{i,m,t} + \sum_{i \in PPS_{m,t}} \underline{SCF}_{i,m,t}\right) \Big/ \sum_{i} DCF_{i,m,t}$$

# Price Formation

$$
\begin{aligned}
\sum_i \frac{\Delta EN_{i,t}}{LPF_{i,t}} + \sum_i \frac{\Delta VS_{i,t}}{LPF_{i,t}} - \sum_i \frac{\Delta L_{i,t}}{LPF_{i,t}} - \sum_i \frac{\Delta VD_{i,t}}{LPF_{i,t}} = 0 \quad & \lambda_t \\
\sum_i IRU_{i,t} \geq IRUR_t \quad & \rho_t \\
\sum_i IRD_{i,t} \geq IRDR_t \quad & \sigma_t \\
\sum_i \frac{\Delta RCU_{i,t}}{LPF_{i,t}^{(r)}} - \sum_i \frac{\Delta RCD_{i,t}}{LPF_{i,t}^{(r)}} = 0 \quad & \xi_t \\
\sum_i \left(\Delta EN_{i,t} + \Delta VS_{i,t} - \Delta VD_{i,t} - \Delta L_{i,t}\right) SF_{i,m,t} \leq b_{m,t} \quad & \mu_t \\
\sum_i \left(\Delta EN_{i,t} + IRU_{i,t} + \Delta VS_{i,t} - \Delta VD_{i,t} - \Delta L_{i,t}\right) SF_{i,m,t} \leq b_{m,t}^{(u)} \quad & \mu_t^{(u)} \\
\sum_i \left(\Delta EN_{i,t} - IRD_{i,t} + \Delta VS_{i,t} - \Delta VD_{i,t} - \Delta L_{i,t}\right) SF_{i,m,t} \leq b_{m,t}^{(d)} \quad & \mu_t^{(d)} \\
\sum_i \left(\Delta RCU_{i,t} - \Delta RCD_{i,t}\right) SF_{i,m,t} \leq b_{m,t}^{(r)} \quad & \mu_t^{(r)}
\end{aligned}
\Rightarrow
\begin{cases}
LMP_{i,t} = \dfrac{\lambda_t}{LPF_{i,t}} - \sum_m SF_{i,m,t}\,\mu_{m,t} - \sum_m SF_{i,m,t}\,\mu_{m,t}^{(u)} - \sum_m SF_{i,m,t}\,\mu_{m,t}^{(d)} \\
IRUMP_{i,t} = \rho_t - \sum_m SF_{i,m,t}\,\mu_{m,t}^{(u)} \\
IRDMP_{i,t} = \sigma_t + \sum_m SF_{i,m,t}\,\mu_{m,t}^{(d)} \\
RCUMP_{i,t} = \dfrac{\xi_t}{LPF_{i,t}^{(r)}} - \sum_m SF_{i,m,t}\,\mu_{m,t}^{(r)} \\
RCDMP_{i,t} = -\dfrac{\xi_t}{LPF_{i,t}^{(r)}} + \sum_m SF_{i,m,t}\,\mu_{m,t}^{(r)}
\end{cases}
$$