Preventive-Corrective Control for Contingency Modeling in AC PF Based SCUC

Petar Ristanovic, CAISO
Jim Frame, Siemens

June 24, 2013

CAISO Market Software Design Principles

- Stochastic influences modeled in **forecasting** of load, ancillary services, renewables production and special services such as flexible ramping
- Representation of the physical characteristic of the system to the maximum extent possible
- Multi interval **time-coupled** co-optimization of energy and AS
- **Minimum possible out-of-market interventions**
- Longest possible time horizons with smallest possible **uniform** time steps
- Minimize impact of different time increments across hierarchical markets
- SCUC/SCDD market optimization with built-in successive relaxed Linear Programming based **AC OPF**

Market software functional requirements and solution approaches

	Functionality	Economic Dispatch (ED)	Dynamic Dispatch (DD)	Security Constrained ED (SCED)	Security Constrained DD (SCDD)	Unit Commitment (UC)	Security Constrained UC (SCUC)	Optimal Outage Coordination (OOC)	
Single interval optimization	Single part bids for energy and AS								non-MIP problems
	Virtual bids for production and consumption								
	Up to congestion transactions								
	Preventive enforcement of transmission constraints								
	Preventive/corrective enforecement of transmission constraints								
	Cascading of AS								
	Co-optimization of energy and AS								MIP problems
Multi interval time coupled optimization	Dynamic ramp rate constraints								
	Dynamic AS ramp rate constraints								
	Resource no-load costs								
	Resource multi-segment startup costs								
	Interruptable load bids								
	Constrained output generation (COG) dispatch and pricing								
	Limited time of use resources								
	Special resource status change constraints								
	Special resource grouping constraints								
	Forbidden regions of operation								
	Resource startup/shutdown MW profiles								
	Multi stage generation								
	Multi-interval block transactions								
	Minimum on-line commitment constraints								
	Generation and transmission outage requests								
	Special grouping constraints for outage requests								

California ISO
Shaping a Renewed Future

Relevant NERC/WECC reliability standards

- **NERC BAL-002-1a R4.1**: A Balancing Authority shall return its ACE to zero if its ACE just prior to the Reportable Disturbance was positive or equal to zero. For negative initial ACE values just prior to the Disturbance, the Balancing Authority shall return ACE to its pre-Disturbance value.

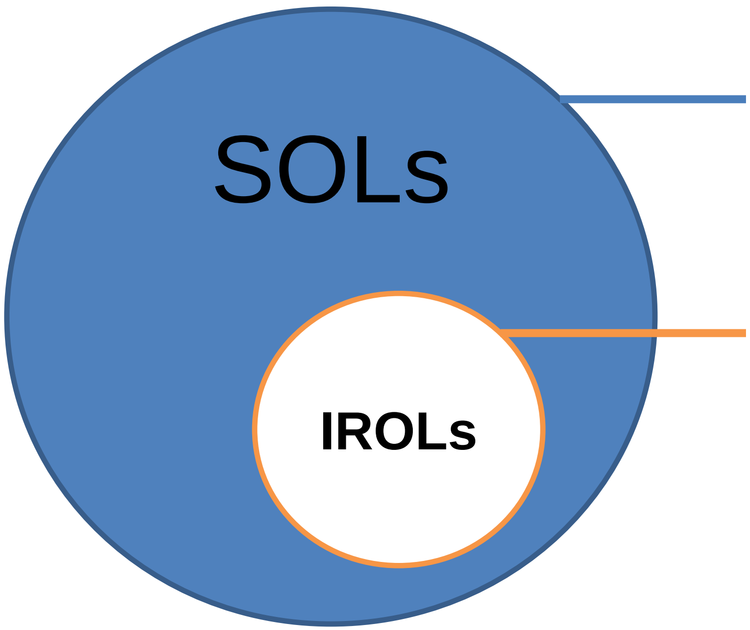
- **NERC BAL-002-1a R4.2**: The default Disturbance Recovery Period is **15 minutes** after the start of a Reportable Disturbance.

- **WECC TOP-007-WECC-1 R1**: When the actual power flow exceeds an SOL for a Transmission path, the Transmission Operators shall take immediate action to reduce the actual power flow across the path such that at no time shall the power flow for the Transmission path exceed the SOL for more than **30 minutes**

SOLs versus IROLs

If there is a violation:

Types of limits



Definition	NERC standard	WECC standard
Broad term for operating limit	Report violation	30 min for corrective action, no load shed
Subset of SOLs that if violated, could expose a widespread area of the bulk electric system to instability, uncontrolled separation(s) or cascading outages	30 min for corrective action, can use load shed	Not applicable

Current practice at CAISO to mitigate potential generator outages and SOL violations

- Generator outages
  - Special nomogram constraints added to market model based on off-line engineering studies
  - Exceptional dispatches
- SOL violations (8 WECC paths within CAISO)
  - 10 minutes reserves
  - Minimum on line capacity constraints
  - Exceptional dispatches to position resources at higher ramp rate operating range

Reliability challenges

Mechanism	Addresses:	Amount of capacity procured determined by:	Locational definition:	Ensures accurate amt of capacity procured at right location?
10 min contingency reserves	NERC/WECC operating reserve requirements	WECC operating reserve requirements	System-wide	Partially – deliverability issues because not flow-based and granularity
Exceptional dispatch	As specified in ISO tariff	Operator judgment	Location specific based on operator judgment	Partially – potential deliverability issues and imprecise procurement
MOC constraint	WECC standard TOP-007-WECC-1 R1 and non-flow based constraints	Predefined static region and requirement	Predefined static region	Partially – predefined static regions and only commits units to Pmin
Preventive-corrective constraint	WECC standard TOP-007-WECC-1 R1	Optimized solution	Nodal	Fully

Efficiency challenges

Mechanism	Optimized procurement?	Efficiently dispatched post-contingency?	Bid cost	Fast response valued in market?
10 min contingency reserves	Yes, for system-wide need co-optimized with energy	May have deliverability issues	Reflected in LMP	Yes
Exceptional dispatch	No, manual process	Very likely	Not reflected in LMP	No
MOC constraint	No, constraint is pre-defined and not dynamic	Likely	Not reflected in LMP	No, ramping speed not considered
Preventive-corrective constraint	Yes, at nodal level	Yes	Reflected in LMP and potential LMCP payment	Yes

Generation outages preventive-corrective mitigation assuming participation of resources with AS awards

- **Post AGC state:**

$$\sum_{k \in Ru, k \neq l} \Delta p_{k,t}^{l,C1} \leq min(Req_t^{Ru}, p_{l,t}^{En}) \quad , \qquad 0 \leq \Delta p_{k,t}^{l,C1} \leq p_{k,t}^{Ru}$$

$$\sum_{i \neq l} SF_{i,t}^{m} \cdot p_{i,t}^{En} + \sum_{k \in Ru, k \neq l} SF_{k,t}^{m} \cdot \Delta p_{k,t}^{l,C1} \leq P_{t,EL}^{m}$$

- **Post contingency reserves deployment state:**

$$\sum_{k \in Sr \cup Nr, k \neq l} \Delta p_{k,t}^{l,C2} = p_{l,t}^{En} \quad , \qquad 0 \leq \Delta p_{k,t}^{l,C2} \leq p_{k,t}^{Sr} + p_{k,t}^{Nr}$$

$$p_{k,t}^{Sr} \leq min[p_{k,t}^{max} - p_{k,t}^{En} - p_{k,t}^{Ru}, p_{k,t}^{Sr,max}, RU_{k,t}(p_{k,t}^{En}, p_{k,t+1}^{En}, 10)]$$

$$\sum_{i \neq l} SF_{i,t}^{m} \cdot p_{i,t}^{En} + \sum_{k \in Sr \cup Nr, k \neq l} SF_{k,t}^{m} \cdot \Delta p_{k,t}^{l,C2} \leq P_{t,NL}^{m}$$

Generation outages preventive-corrective mitigation assuming participation of all available resources

- **Post AGC state:**

$$\sum_{k\in Ru,k\neq l} \Delta p_{k,t}^{l,C1} \leq min(Req_t^{Ru}, p_{l,t}^{En}) \quad , \qquad 0 \leq \Delta p_{k,t}^{l,C1} \leq p_{k,t}^{Ru}$$

$$\sum_{i\neq l} SF_{i,t}^{m} \cdot p_{i,t}^{En} + \sum_{k\in Ru,k\neq l} SF_{k,t}^{m} \cdot \Delta p_{k,t}^{l,C1} \leq P_{t,EL}^{m}$$

- **Post contingency reserves deployment state:**

$$\sum_{k\neq l} \Delta p_{k,t}^{l,C2} = p_{l,t}^{En} \quad , \qquad 0 \leq \Delta p_{k,t}^{l,C2} \leq \min\left[p_{k,t}^{max} - p_{k,t}^{En} - p_{k,t}^{Ru}, RU_{k,t}\left(p_{k,t}^{En}, p_{k,t+1}^{En}, 10\right)\right]$$

$$\sum_{i\neq l} SF_{i,t}^{m} \cdot p_{i,t}^{En} + \sum_{k\neq l} SF_{k,t}^{m} \cdot \Delta p_{k,t}^{l,C2} \leq P_{t,NL}^{m}$$

$p_{k,t}^{En}, p_{k,t}^{AS}$ **- Energy and ancillary services – *AS* (*Ru, Sr, Nr*), awards for resource *k* at interval *t***

$\Delta p_{k,t}^{l,C}$ **- Post contingency *l* adjustments of resource *k* at interval *t***

$RU_{k,t}$ **- Maximum ramp up for unit *k* at interval *t* assuming 10 minutes ramping time**

$P_{t,NL}^{m}, P_{t,EL}^{m}$ **- Constraint *m* normal (*NL*) and emergency (*EL*) limits at interval *t***

Preventive-corrective SOL contingency violation relief

$$\sum_{k} SF_{k,t}^{m,l}\left(p_{k,t}^{En} + \Delta p_{k,t}^{l,C}\right) \le P_{t,NNL}^{m,l}$$

$$\Delta p_{k,t}^{l,C} = \Delta p_{k,t}^{l+} - \Delta p_{k,t}^{l-}$$

$$\Delta p_{k,t}^{l+} \le \min\left[p_{k,t}^{max} - p_{k,t}^{En}, RU_{k,t}\left(p_{k,t}^{En}, p_{k,t+1}^{En}, 30\right)\right]$$

$$\Delta p_{k,t}^{l-} \le \min\left[p_{k,t}^{En} - p_{k,t}^{min}, RD_{k,t}\left(p_{k,t}^{En}, p_{k,t+1}^{En}, 30\right)\right]$$

$p_{k,t}^{min}, p_{k,t}^{max}$ - Resource k minimum and maximum operating limits at interval t

$RU_{k,t}$ - Maximum ramp up for unit k at interval t assuming 30 minutes ramping

$RD_{k,t}$ - Maximum ramp dn for unit k at interval t assuming 30 minutes ramping

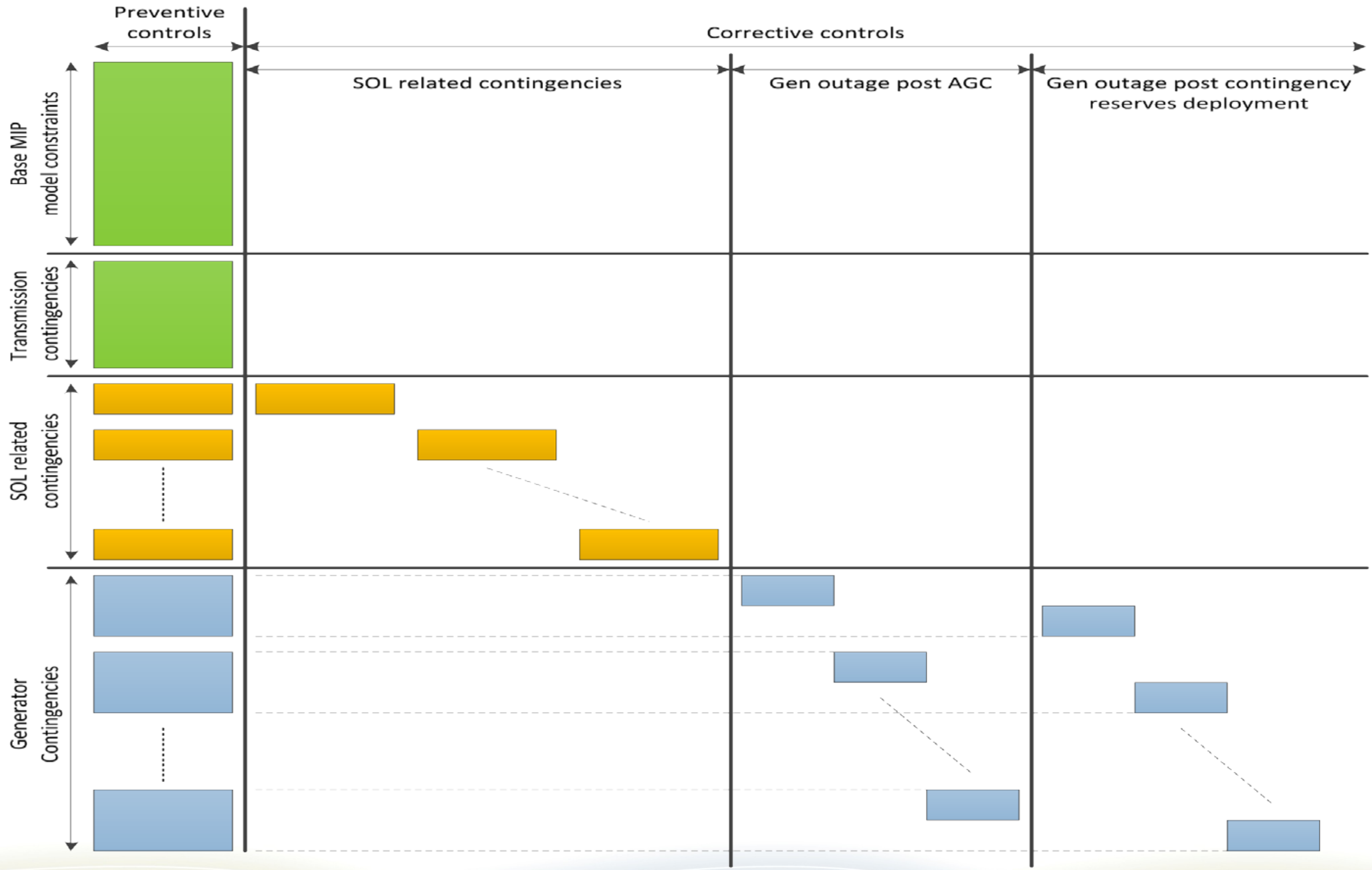
l - Contingency index

$P_{t,EL}^{m,l}$ - Constraint (SOL) m emergency limit for contingency l at interval t

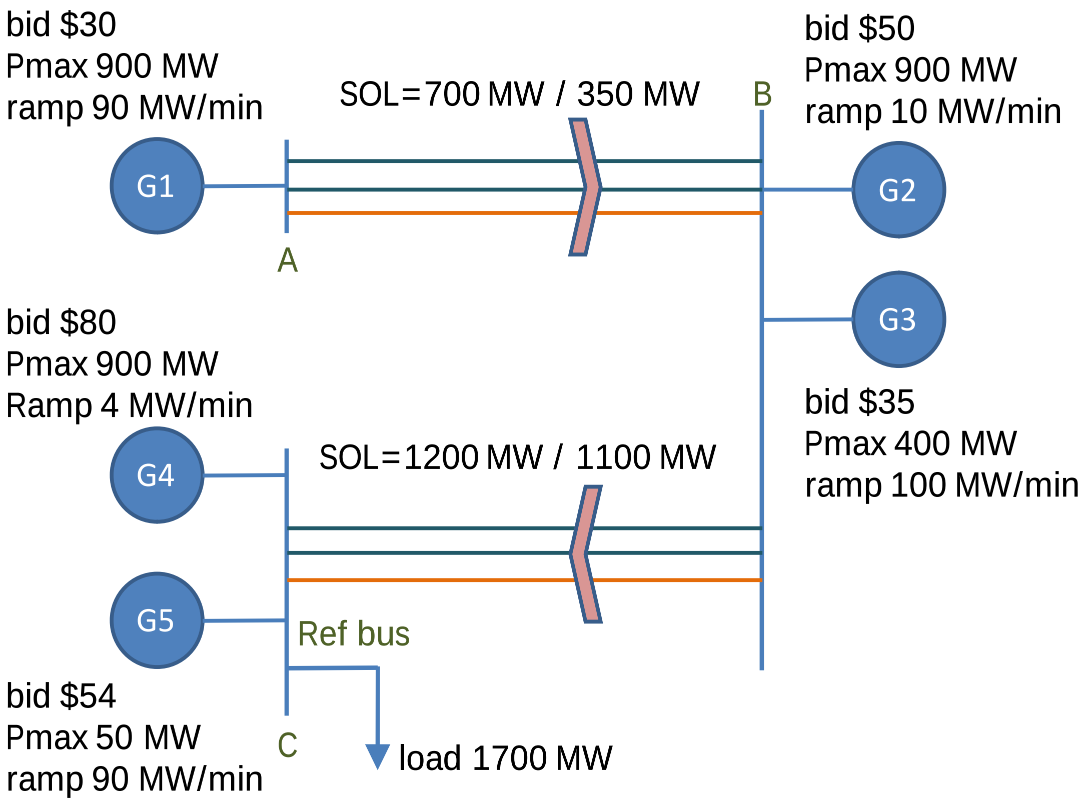
Impact on CAISO operation and market software

- Positives
  - Improvement in system reliability as a result of improved accuracy in modeling operating constraints
  - Ensures accurate amount of contingency reserves procured at right locations
  - Reduction in out of market operator interventions
  - Reduction in total system operating costs since resources are positioned in the most economic way to manage pre-contingency and post-contingency flows
  - Marginal value of corrective capacity correctly reflects opportunity costs, congestion cost savings, and/or instruction deviation penalties
  - Required changes to market software are not complex
- Negatives
  - Significant increase in optimization problem size due to the introduction of corrective variables

Impact on SCUC model size



Example



	Energy in base case				
Gen	P^0	LMP	λ^0	μ^0_{AB}	μ^0_{BC}
G1	700	$30	$80	–$5	–$19
G2	150	$50	$80	–$5	–$19
G3	350	$50	$80	–$5	–$19
G4	470	$80	$80	–$5	–$19
G5	30	$80	$80	–$5	–$19
	Corrective Capacity in contingency kc=1				
Gen	ΔP^{kc}	LMCP	λ^1	μ^1_{AB}	μ^1_{BC}
G1	–350	$0	$15	–$15	$0
G2	200	$15	$15	–$15	$0
G3	50	$15	$15	–$15	$0
G4	80	$15	$15	–$15	$0
G5	20	$15	$15	–$15	$0
	Corrective Capacity in contingency kc=2				
Gen	ΔP^{kc}	LMCP	λ^2	μ^2_{AB}	μ^2_{BC}
G1	0	$0	$11	$0	–$11
G2	–150	$0	$11	$0	–$11
G3	50	$0	$11	$0	–$11
G4	80	$11	$11	$0	–$11
G5	20	$11	$11	$0	–$11

Thank you

Petar Ristanovic
pristanovic@caiso.com

Jim Frame
jim.frame@siemens.com