External Network Model Expansion at CAISO

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Background

- CAISO launched a stakeholder initiative on Full Network Model (FNM) Expansion
- Responding to FERC and NERC joint staff findings/recommendations following the September 8, 2011 power outage event that affected Arizona and South California
  - Finding 2: Lack of updated external networks in the next-day study models
  - Finding 11: Lack of real-time external visibility
  - Source: http://www.ferc.gov/legal/staff-reports/04-27-2012-ferc-nerc-report.pdf

Primary Objectives

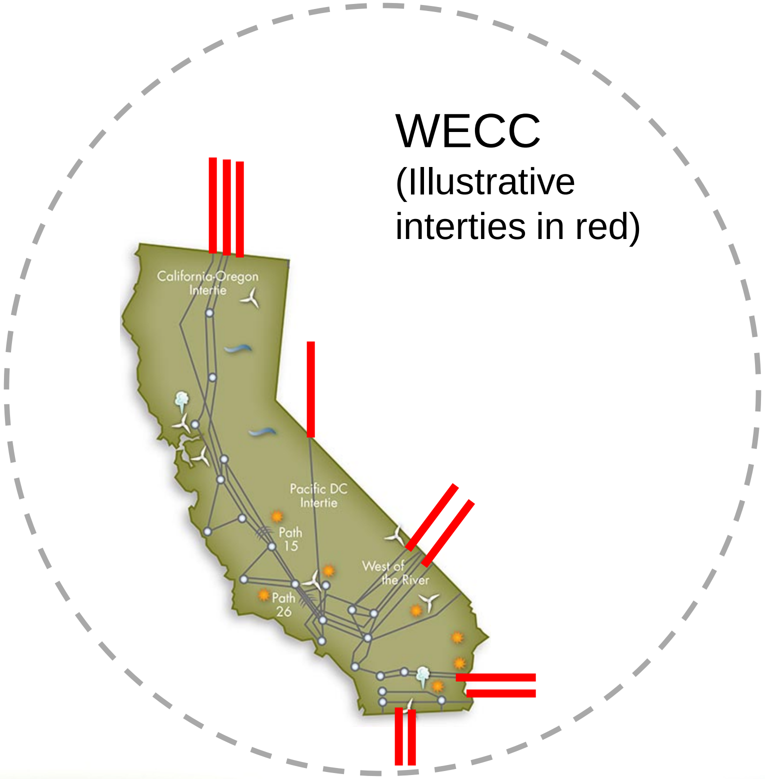
- Improve reliability and market solution accuracy
  - Accurate loop flow modeling
  - Enhanced security analysis
  - Better outage coordination
  - Accurate High Voltage Direct Current (HVDC) model

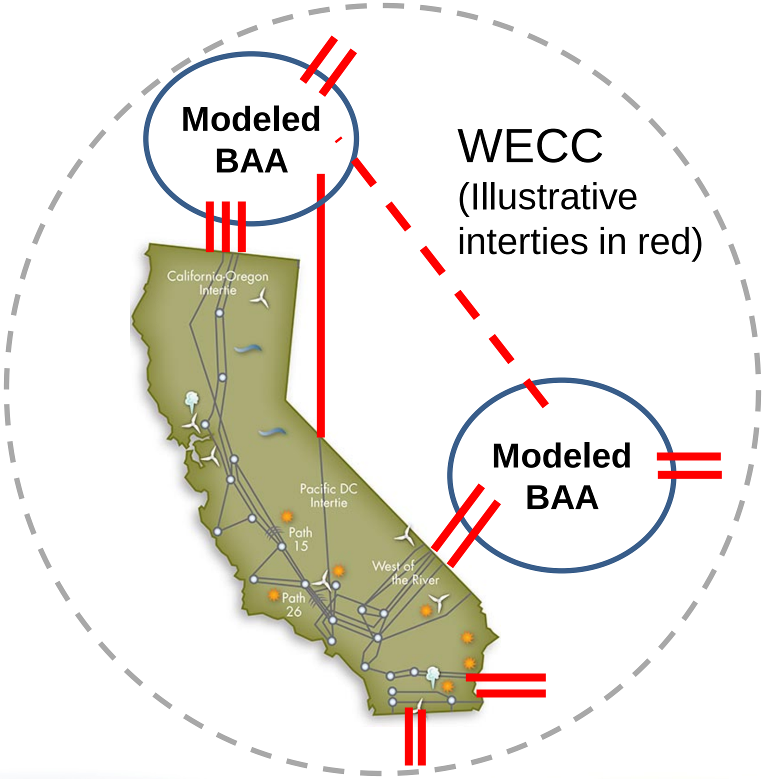
Scope of the FNM Expansion

- Surrounding Balancing Authority Areas (BAAs) with sufficient modeling detail to account for loop flows
  - Data source: WECC Reliability Coordinator
- Phased expansion conditional on:
  - Available telemetry and outage information
  - Good quality of State Estimator solution
- Ultimate goal: model the entire WECC
  - All of WECC is currently in the EMS model

Current and Proposed FNM

- Import/export scheduling points are currently at interties, but can be relocated within modeled BAAs

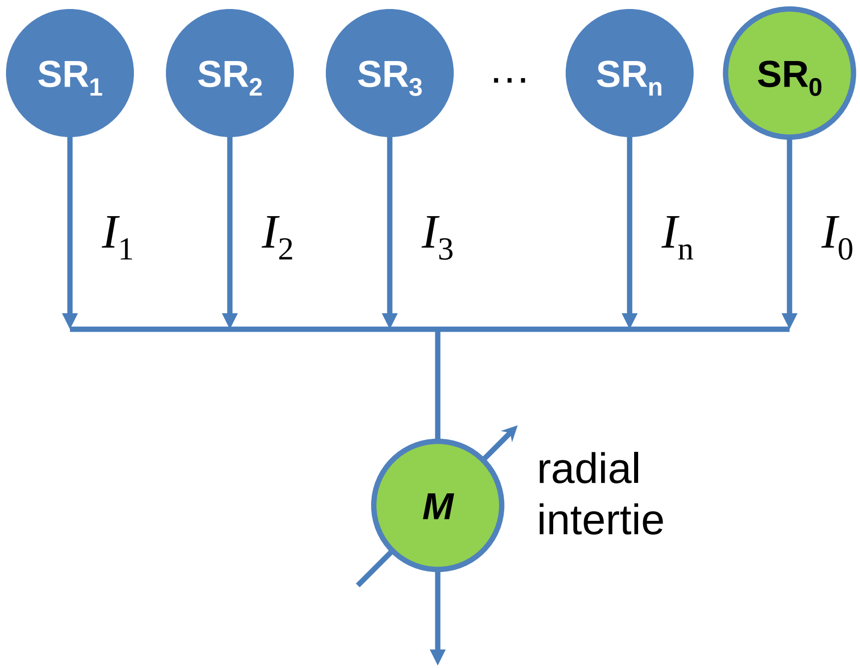




Issues with Current FNM

- The impact of external contingencies cannot be analyzed
  - Conservative intertie limits and computationally expensive nomograms
- Day-Ahead schedules ignore loop flow from external transactions
  - External network outside the CAISO footprint is not in the FNM
  - Next day operating conditions of external systems, including generation schedules and transmission outages, are not in the FNM
- Loop flow impact must be mitigated in real time
  - Transmission limit reduction on power flow constraints
  - Compensating injections to model loop flow in the real time market
  - Exceptional dispatch instructions (out-of-market)
- High cost market solution, reliability risk, loss of transparency
- Revenue neutrality loss by cutting day-ahead schedules

Real-Time Compensating Injections



SR: System resource (import/export)
I: Import schedule (algebraic)
M: Telemetry (meter)
SR_0: Compensating injection (algebraic)
α: Attenuation factor

- Import/export schedules are modeled as algebraic injections from system resources at the FNM boundary
- Loop flow is modeled as a fixed intertie schedule for the difference between metered and scheduled flow:

$$I_0 = \alpha \left(M - \sum_{k=1}^{n} I_k \right)$$

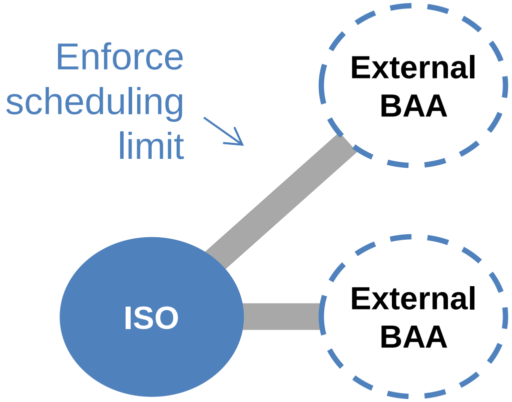
Market Enhancement with FNM Expansion

- New generation aggregation point (GAP) and load aggregation point (LAP) definitions for external BAAs
  - Used for base generation and load schedule calculation
    - LAP is used to distribute demand forecast through load distribution factors
    - GAP is used to distribute demand forecast net of scheduled interchange through generation distribution factors (normalized for outages)
  - GAP is used as scheduling point (SP) for import/export bids
    - Import/export schedules are superimposed on base generation

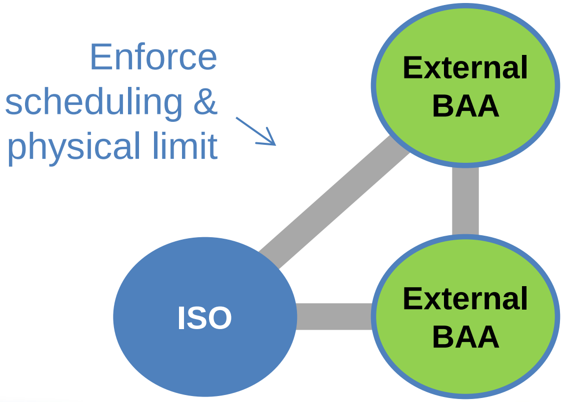
Intertie Constraints with FNM Expansion

- Two constraint groups for each intertie:
  - Scheduling limit (contract path)
    - Physical intertie schedules for energy and ancillary services associated with specific intertie
  - Physical limit
    - All physical/virtual schedules for energy based on power flow contributions using shift factors

Current FNM



With FNM expansion

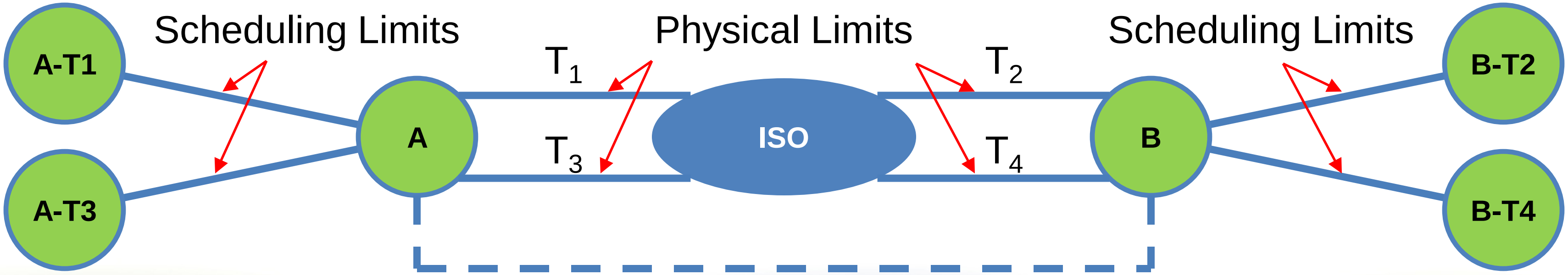


Intertie Pricing with FNM Expansion

- Aggregate LMP at a SP includes impact from binding physical limits
- Aggregate LMP at a SP for physical intertie schedules includes impact from binding scheduling limit at associated intertie
- Potentially different LMPs at a SP for
  - Virtual intertie schedules
  - Physical intertie schedules associated with different interties

Congestion Revenue Rights with FNM Expansion

- SPs can be used as CRR sources and sinks
- Scheduling limits can be enforced for CRR bids/nominations at a SP on associated interties
- Point-to-point CRR from A to B
  - CRR pays for physical congestion cost from A to B
  - If A is a SP and the CRR source is associated with intertie T_1, CRR also pays scheduling congestion on T_1
  - If B is a SP and the CRR sink is associated with intertie T_2, CRR also pays scheduling congestion on T_2

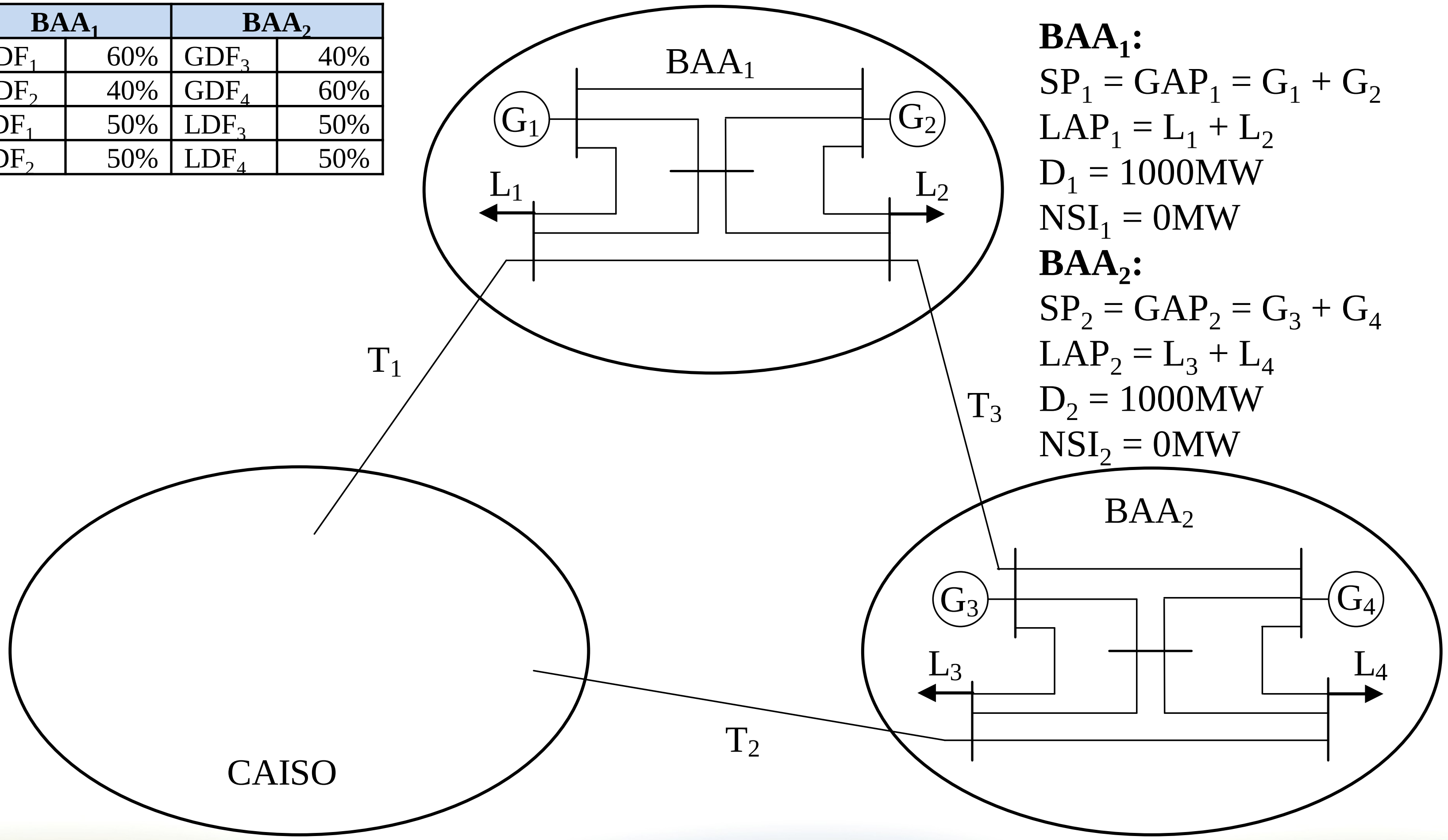


HVDC Link Model with FNM Expansion

- Replace HVDC link with algebraic power injections at converter stations
  - Free variables (no cost in the objective function)
  - Balanced by constraint approximating DC losses
  - Allow bidirectional power flow
  - Rectifier injection limited by HVDC power flow capability
- Internal HVDC link (Trans Bay Cable)
- HVDC intertie (PDCI, InterMountain-Adelanto)
  - Injection limited by associated import/export schedules
  - Point-to-point financial right between converter stations

Day-Ahead Market Example: Setup

BAA_1		BAA_2	
GDF_1	60%	GDF_3	40%
GDF_2	40%	GDF_4	60%
LDF_1	50%	LDF_3	50%
LDF_2	50%	LDF_4	50%



BAA_1:

$SP_1 = GAP_1 = G_1 + G_2$

$LAP_1 = L_1 + L_2$

$D_1 = 1000MW$

$NSI_1 = 0MW$

BAA_2:

$SP_2 = GAP_2 = G_3 + G_4$

$LAP_2 = L_3 + L_4$

$D_2 = 1000MW$

$NSI_2 = 0MW$

Day-Ahead Market Example: Base Schedules and Intertie Bids

- Distribute demand to LAP
- Distribute demand net of NI to GAP
- AC power flow with NSI control and distributed load slack
  - BAA_1 loss: 30MW
  - BAA_2 loss: 30MW

BAA_1		**BAA_2**	
G_1	600MW	G_3	400MW
G_2	400MW	G_4	600MW
L_1	485MW	L_3	485MW
L_2	485MW	L_4	485MW
Loss	30MW	Loss	30MW
NSI_1	0MW	NSI_2	0MW

Bid	**SC**	**Scheduling Point**	**Type**	**Intertie**	Quantity	**Price**
B_1	SC_1	SP_1	I	T_1	100MW	$20
B_2	SC_2	SP_1	I	T_2	100MW	$25
B_3	SC_3	SP_2	I	T_1	100MW	$30
B_4	SC_4	SP_2	E	T_2	100MW	$50

Day-Ahead Market Example: Market Clearing Results and Settlement

- Bids B_1, B_2, and B_4 clear and determine NSI
- AC power flow with NSI control and distributed generation slack
  - BAA_1 loss: 35MW
  - BAA_2 loss: 25MW

BAA_1		BAA_2	
G_1	723MW	G_3	358MW
G_2	482MW	G_4	537MW
L_1	485MW	L_3	485MW
L_2	485MW	L_4	485MW
Loss	35MW	Loss	25MW
NSI_1	200MW	NSI_2	–100MW

Bid	SC	Scheduling Point	Type	Intertie	Schedule (MW)	LMP ($/MWh)	Charge ($)
B_1	SC_1	SP_1	I	T_1	100	26	–2,600
B_2	SC_2	SP_1	I	T_2	100	26	–2,600
B_3	SC_3	SP_2	I	T_1	0	28	0
B_4	SC_4	SP_2	E	T_2	100	28	2,800

Day-Ahead Market Example: Intertie Constraints

BAA$_1$				BAA$_2$			
Resource	**GDF**	**SF on T$_1$**	**SF on T$_2$**	**Resource**	**GDF**	**SF on T$_1$**	**SF on T$_2$**
G$_1$	60%	80%	20%	G$_3$	40%	20%	80%
G$_2$	40%	60%	40%	G$_4$	60%	40%	60%
SP$_1$		72%	28%	SP$_2$		32%	68%

- Scheduling limit constraints
  - Based on associated intertie
    - T$_1$: $OTC_{1,\text{min}} \leq B_1 + B_3 \leq OTC_{1,\text{max}}$
    - T$_2$: $OTC_{2,\text{min}} \leq B_2 - B_4 \leq OTC_{2,\text{max}}$
- Physical limit constraints
  - Based on shift factors with reference the CAISO distributed load slack
    - T$_1$: $OTC_{1,\text{min}} \leq 0.72\ B_1 + 0.72\ B_2 + 0.32\ B_3 - 0.32\ B_4 + \cdots \leq OTC_{1,\text{max}}$
    - T$_2$: $OTC_{2,\text{min}} \leq 0.28\ B_1 + 0.28\ B_2 + 0.68\ B_3 - 0.68\ B_4 + \cdots \leq OTC_{2,\text{max}}$

References

- http://www.caiso.com/Documents/StrawProposal-FullNetworkModelExpansion.pdf
- http://www.caiso.com/Documents/RevisedStrawProposal-EnergyImbalanceMarket-053013.pdf