Generator Contingency & RAS Modeling

Revised Issue Paper & Straw Proposal

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Background & Objectives

Background

N-1 security including loss of generation

A secure transmission system must be able to withstand credible transmission contingencies as well as credible generation contingencies.

1. **Transmission security for loss of transmission element**
    a. Transmission line or transformer loss

2. **Transmission security for loss of generation**
    a. Generator loss
    b. Generator loss due to RAS operation (includes loss of transmission element)

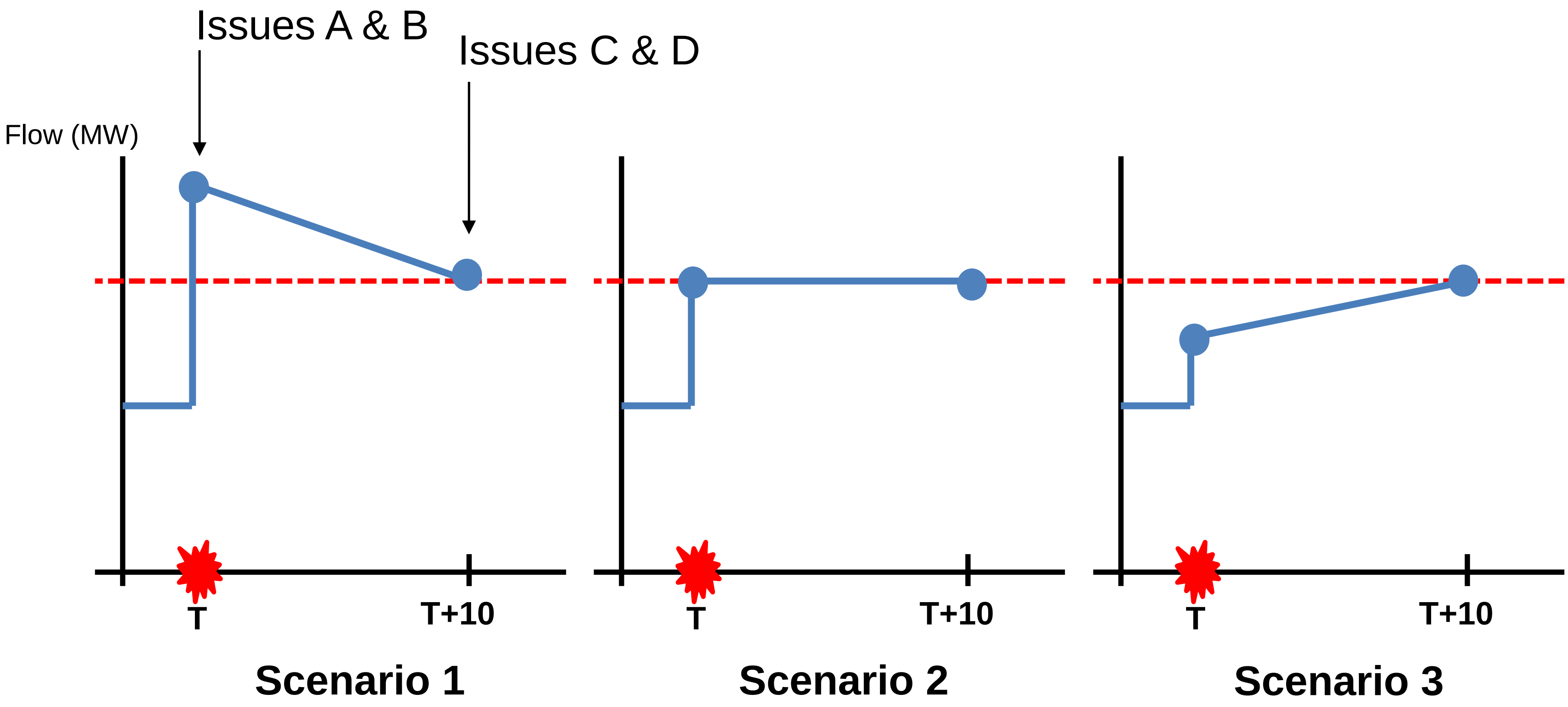
Issues

Four core transmission system issues related to loss of generation

Issue	Description	Timing	Operations Priority
A	**Gen loss only** • Flow <= emergency ratings	T	2
B	**Gen + Tx loss (RAS)** • Flow <= emergency ratings	T	1
C	**Gen loss only** • Achieve power balance in 10 minutes • Flow <= emergency ratings in 10 minutes	T+10	3
D	**Gen + Tx loss (RAS)** • Achieve power balance in 10 minutes • Flow <= emergency ratings in 10 minutes	T+10	4

Issues

Illustrate the difference between the T issues and T+10 issues



Why are we here?

- Conducted cross-functional internal meetings to discover, properly segment, and prioritize root issues in the generator contingency space
- Pivot the initiative to solve ISO operations' and ISO regional transmission planning's highest priority issues from a reliability standpoint
- Generation-loss remedial action schemes can arm large portions of generation within the ISO and have the potential to drop large amounts of generation
- Transmission system security for these types of events is currently managed out-of-market
  - Potential for production cost savings
  - Potential to accurately reflect cost of supply in energy prices

Initiative Objectives

Generator Contingency & RAS Modeling

Focusing on **Issue A** and **Issue B** as they are fundamentally related:

1. Allow for the benefits of increased transmission capability while protecting the transmission system for generation loss (including RAS events)

2. Appropriately pre-dispatch generation such that all transmission lines will be below emergency ratings if generation loss events (including RAS events) were to occur

3. Accurately price the contribution to congestion

Proposal

Methodology

Preventive constraint

- Add a preventive constraint to the security constrained economic dispatch

- The new contingency removes generation from service and distributes the lost generation to all other nodes on the system pro-rata based on pmax

- Monitor initial flows on transmission lines plus the flows placed on transmission lines from the pro-rata distribution to be less than emergency ratings

Methodology

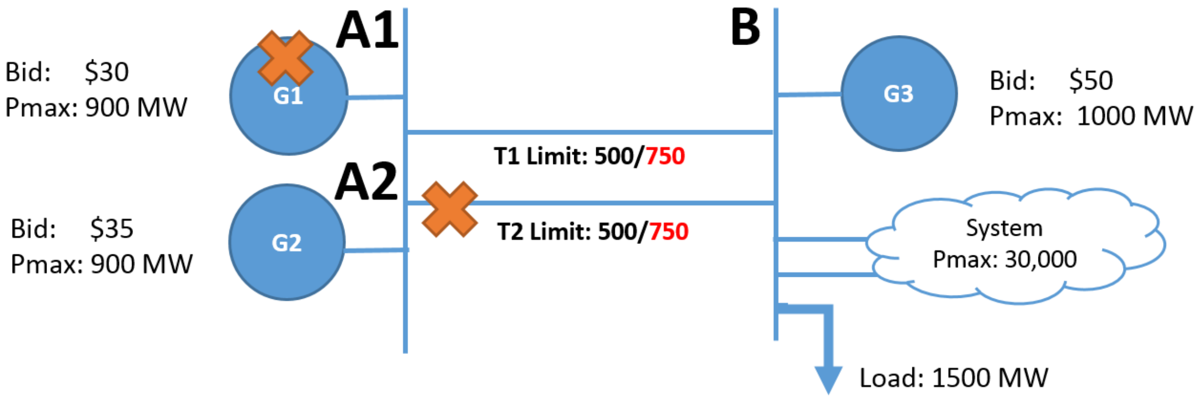
Generation loss distribution

- The pmax of each node divided by the sum of the total pmax on the system is each node’s generation distribution factor.
- Every node picks up a small portion of the contingency generator’s output
- The resulting flows on the system are compared to transmission emergency ratings
- The marginal congestion contribution from a binding transmission constraint in a generator contingency to the LMP at the node of the generator outage includes the impact of the assumed generation loss distribution
- LMP’s congestion component includes the impact of the generator contingency congestion

Examples

RAS modeled, normal limit binds, increased transfer capability

- Normal limit binds
- lower production cost solution by allowing 1,000 MW to flow pre-contingency.



Generator	Energy Bid	Energy Award	LMP
G1	$30	900	$35
G2	$35	100	$35
G3	$50	500	$50

$$GFF^{g}_{i,m} = \overset{N}{\underset{\substack{i=1\\ i\neq o_g}}{SF^{g}_{i,m}}} \qquad \forall i \neq o_g$$

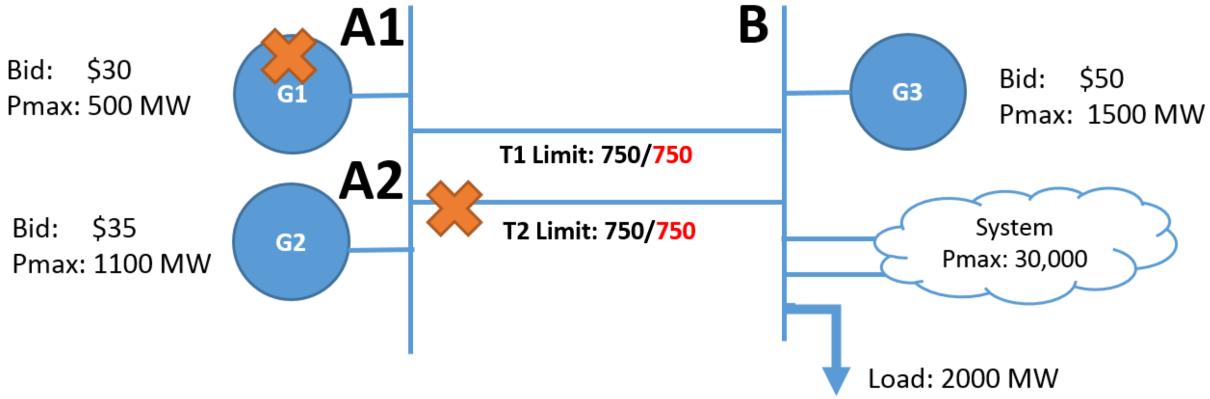
$$= (1)\cdot\frac{900}{31,900} + (0)\cdot\frac{1,000}{31,900} + (0)\cdot\frac{30,000}{31,900} = 0.028213$$

		Normal		Loss of G1+T2		
Generator (i)	**λ^0**	**$SF^0_{i,AB}$**	**μ^0_{AB}**	**$GFF^{RAS}_{i,AB}$**	**μ^{RAS}_{AB}**	**LMP**
G1	$50	1	$15	0.028213	$0	$35
G2	$50	1	$15	1	$0	$35
G3	$50	0	$15	0	$0	$50

Examples

RAS modeled, only emergency limit binds, accurate prices

- Emergency limit binds
- RAS generator does not contribute to binding constraint, receives higher LMP



Generator	Energy Bid	Energy Award	LMP
G1	$30	500	$49.49
G2	$35	733	$35
G3	$50	767	$50

$$GFF^{g}_{i,m} = \overset{N}{\underset{\substack{\iota=1\\ i\neq o_g}}{SF^{g}_{i,m}}} \qquad \forall i \neq o_g$$

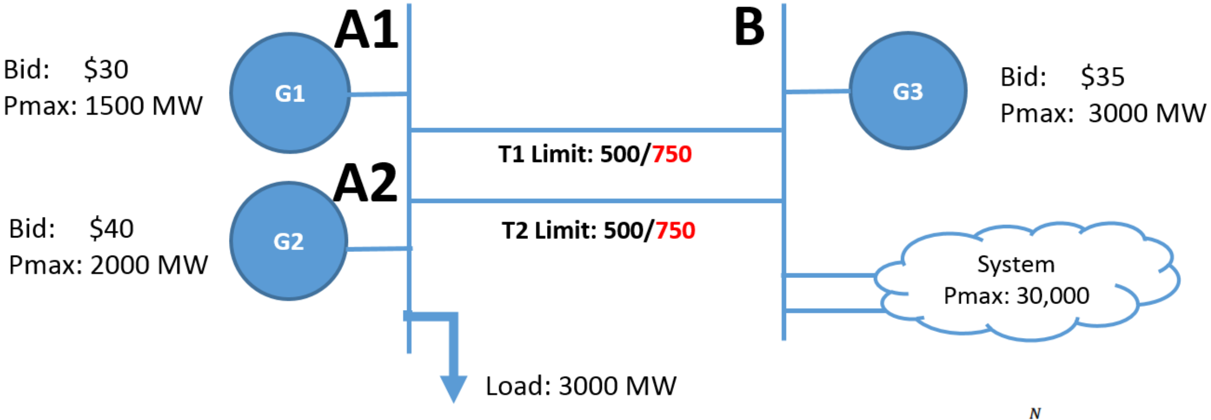
$$= (1)\cdot\frac{1{,}100}{32{,}600} + (0)\cdot\frac{1{,}500}{32{,}600} + (0)\cdot\frac{30{,}000}{32{,}600} = 0.033742$$

		Normal		**Loss of G1+T2**		
Generator (i)	**λ^0**	**$SF^0_{i,AB}$**	**μ^0_{AB}**	**$GFF^{RAS}_{i,AB}$**	**μ^{RAS}_{AB}**	**LMP**
G1	$50	1	$0	0.033742	$15	$49.49
G2	$50	1	$0	1	$15	$35
G3	$50	0	$0	0	$15	$50

Examples

Generator Contingency, emergency limit binds, accurate prices

- Emergency limit binds
- Generator contributes to binding constraint, receives lower LMP



Generator	Energy Bid	Energy Award	LMP
G1	$30	1500	$35.29
G2	$40	1414	$40
G3	$35	86	$35

$$GFF_{A1,AB}^{RAS} = \sum_{\substack{i=1 \\ i\neq o_g}}^{N} SF_{i,m}^{g}\, GDF_{o_g,i}$$

$$= (0)\cdot\frac{2000}{35{,}000} + (1)\cdot\frac{3{,}000}{35{,}000} + (1)\cdot\frac{30{,}000}{35{,}000} = 0.942857$$

		Normal		Loss of T1		Loss of G1		Loss of G2		Loss of G3		
Generator (i)	**λ^0**	**$SF^0_{i,BA}$**	**μ^0_{BA}**	**$SF^{T1}_{i,BA}$**	**μ^{T1}_{BA}**	**$GFF^{G1}_{i,BA}$**	**μ^{G1}_{BA}**	**$GFF^{G2}_{i,BA}$**	**μ^{G2}_{BA}**	**$GFF^{G3}_{i,BA}$**	**μ^{G3}_{BA}**	**LMP**
G1	$40	0	$0	0	$0	0.942857	$5	0	$0	0	$0	$35.29
G2	$40	0	$0	0	$0	0	$5	0.956522	$0	0	$0	$40
G3	$40	1	$0	1	$0	1	$5	1	$0	0.895522	$0	$35

Appendix

Methodology

Preventive constraint

$$\min \sum_{i=1}^{N} C_i \left(G_i - G_{i,\min}\right) \qquad (a)$$

subject to:

$$g(\boldsymbol{G}) = 0 \qquad (b)$$

$$h_m(\boldsymbol{G}) \le F_m, \qquad m = 1,2,\ldots,M \qquad (c)$$

$$h_m^k(\boldsymbol{G}) \le F_m^k, \qquad \begin{cases} m = 1,2,\ldots,M \\ k = 1,2,\ldots,K \end{cases} \qquad (d)$$

$$G_i^g = G_i + GDF_{o_g,i} \cdot G_{o_g}, \qquad \begin{cases} i = 1,2,\ldots,N \\ g = 1,2,\ldots,K_g \end{cases} \qquad (e)$$

$$h_m^g(\boldsymbol{G}^g) \le F_m^g, \qquad \begin{cases} m = 1,2,\ldots,M \\ g = 1,2,\ldots,K_g \end{cases} \qquad (f)$$

$$G_{i,\min} \le G_i \le G_{i,\max}, \qquad i = 1,2,\ldots,N \qquad (g)$$

Distribute output to rest of system

Ensure flows below Emergency ratings

Methodology

Preventive constraint

(e) Is the generation loss distribution in the generation contingency state, which is assumed lossless and pro rata on the maximum generation capacity ignoring capacity and ramp rate limits:

$$GDF_{o_g,i} = \begin{cases} -1 & i = o_g \\ G_{i,\max} \Big/ \sum_{\substack{i=1 \\ i \neq o_g}}^{N} G_{i,\max} & i \neq o_g \end{cases}, \quad \begin{cases} i = 1,2,\ldots,N \\ g = 1,2,\ldots,K_g \end{cases}$$

Methodology

Preventive constraint

(f) is the set of transmission constraints in each generation contingency case, which can be linearized around the base case power flow solution as follows:

$$h_m^g(\boldsymbol{G}^g) \cong \tilde{h}_m(\tilde{\boldsymbol{G}}) + \sum_{i=1}^{N} SF_{i,m}^g \left(G_i^g - \tilde{G}_i\right) = \tilde{h}_m(\tilde{\boldsymbol{G}}) + \sum_{i=1}^{N} SF_{i,m}^g \left(G_i + GDF_{o_g,i}\, G_{o_g} - \tilde{G}_i\right)$$

$$\leq F_m^g, \qquad \begin{cases} m = 1,2, \dots, M \\ g = 1,2, \dots, K_g \end{cases}$$

Methodology

Locational Marginal Prices

The marginal congestion contribution from a binding transmission constraint in a generator contingency to the LMP at the node of the generator outage includes the impact of the assumed generation loss distribution:

$$LMP_i = \frac{\lambda}{LPF_i} - \sum_{m=1}^{M} SF_{i,m}\,\mu_m - \sum_{k=1}^{K}\sum_{m=1}^{M} SF_{i,m}^{k}\,\mu_m^{k} - \sum_{g=1}^{K_g}\sum_{m=1}^{M}\left(SF_{i,m}^{g} + \delta_{o_g,i}\sum_{i=1}^{N} SF_{i,m}^{g}\,GDF_{o_g,i}\right)\mu_m^{g}\,,$$

$$i = 1,2,\ldots,N$$

Where:

$$\delta_{o_g,i} = \begin{Bmatrix} 1 & i = o_g \\ 0 & i \neq o_g \end{Bmatrix},\ \begin{cases} i = 1,2,\ldots,N \\ g = 1,2,\ldots,K_g \end{cases}$$