Generator Contingency & RAS Modeling

Issue Paper

April 19, 2016

Table of Contents

Revision History

Date	Revision
04/19/2016	Initial Release
04/20/2016	Corrected MW flows in example 3.1.3. Corrected rounding errors in example 3.1.4. Corrected total bid cost calculation in example 3.1.5.

1. Introduction

The ISO intends to resolve two transmission system reliability issues using its advanced market software, rather than relying on out-of-market interventions. First, the ISO intends to enhance and ensure N-1 transmission security by modeling generation loss in the market and providing basic "remedial action scheme" modeling. Second, the ISO intends to address stranded contingency reserve procurement by ensuring that contingency reserves are transmission feasible.

2. Stakeholder Engagement

The schedule for stakeholder engagement is provided below and targets the October 2016 Board of Governors meeting for implementation in fall of 2017.

Date	Event
Wed 4/19/2016	Issue paper
Mon 4/25/2016	Stakeholder call
Fri 5/13/2016	Stakeholder comments due on issue paper
Thu 5/19/2016	Straw proposal posted
Thu 5/26/2016	Stakeholder meeting (straw proposal)
Thu 6/09/2016	Stakeholder comments due on straw proposal
Thu 6/23/2016	Revised straw proposal posted
Thu 6/30/2016	Stakeholder conference call (revised straw proposal)
Thu 7/14/2016	Stakeholder comments due (revised straw proposal)
Mon 8/8/2016	Draft final proposal posted
Mon 8/15/2016	Stakeholder meeting (draft final proposal)
Mon 8/29/2016	Stakeholder comments due (draft final proposal)
10/26-10/27	Board of Governors
Fall 2017	Implementation

3. Background & Issues

Overall, the ISO must ensure a transmission feasible dispatch. There are two aspects of transmission feasibility to consider: (1) the system must be secure after the loss of a transmission or generation element and (2) the system must be secure after the loss of a transmission or generation element and the subsequent deployment of contingency reserves.

This issue paper focuses on system performance after a contingency and subsequent deployment of contingency reserves.

3.1. Discussion

The ISO must ensure a transmission feasible dispatch that considers the system condition at a point in time after a single generator contingency and after the deployment of contingency reserves. This section discusses the appropriate system condition at a point in time after any single contingency that also considers the deployment of contingency reserves.

3.1.1. N-1 security including loss of generation

The ISO, as a transmission operator, must plan to meet unscheduled changes in system configuration and generation dispatch (at a minimum N-1 Contingency planning) in accordance with NERC, Regional Reliability Organization, sub-regional, and local reliability requirements. We accomplish this by establishing and operating within system operating limits.

Most system operating limits are straightforward and, once derived, can be directly modeled in the market system; the market uses these limits to produce a security constrained economic dispatch. Others are more complex and the ISO relies on operations engineering studies of near term system conditions to ensure that a reasonable mix of available generation and transmission in certain areas are sufficient to ensure N-1 security. For these complex system operating limits, operators additionally watch the real-time conditions and make generation dispatch adjustments out-of-market to ensure N-1 security through real-time.

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

Transmission security for transmission contingencies

Transmission loss has an immediate impact on the transmission system.

The ISO market system currently ensures that for the loss of a transmission element, all elements of the remaining system will be below emergency ratings.

With the addition of the Contingency Modeling Enhancements initiative, the ISO market system will ensure that for the loss of a transmission element, no element of the remaining system will be over its emergency rating and that there is enough ramping capability to return certain facilities below a dynamic post-contingency system operating limit within 30 minutes.

Transmission security for generator contingencies

Generation loss has an immediate impact on transmission system flows. While it does not change the network topology of the system, it could dramatically impact flows and even cause operating limit exceedances and violations. The ISO has not yet added the functionality to model generation loss within its security constrained economic dispatch. The loss of a generating unit in certain areas could result in the overload of transmission facilities above emergency ratings as the ISO dispatches contingency reserves to recover from a generator contingency event.

3.1.2. Current contingency reserve procurement

The ISO, as a transmission operator and balancing authority, must plan to meet capacity and energy reserve requirements, including the deliverability/capability for any single contingency.

The ISO procures 100% of its Ancillary Services (AS) needs, including contingency reserves, associated with the CAISO Forecast of CAISO Demand net of unconditionally qualified self-provided AS. AS bids are evaluated simultaneously with energy bids in the IFM to clear bid-in supply and demand. Thus, the IFM co-optimizes energy and contingency reserves; the capacity of a resource with energy and AS bids is optimally used for an energy schedule, or it is reserved for AS in the form of AS awards.

In the optimization of energy and contingency reserve clearing, limits on AS regions are enforced as constraints represented by penalty prices in the application software, while energy and contingency reserves are economically optimized subject to the AS region procurement constraint(s).

The ISO currently defines AS regional constraints to reflect transmission limitations between regions within the balancing authority area footprint. AS regional constraints restrict the contingency reserves procured in one AS region to cover for (1) outages in another AS region and (2) constraints between the regions. AS regional constraints secure a minimum contingency reserve procurement (to ensure reliability) and/or a maximum contingency reserve procurement target (that increases the probability of deliverability of contingency reserves to each region), such that the total contingency reserve procurement reflects the current system topology and deliverability needs.

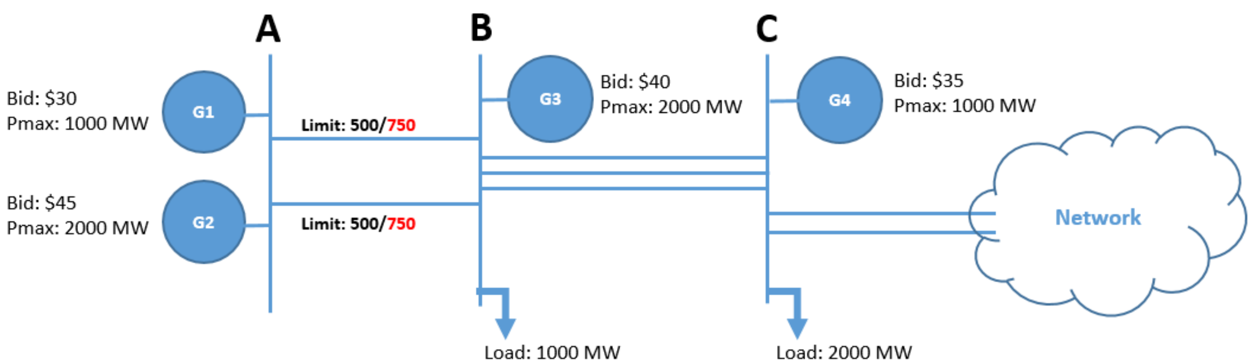
The ISO currently has eight sub-AS regions. As defined, the primary purpose of the eight sub-AS regions is to account for expected congestion on Path 15 and Path 26. Based on forecasts, the ISO uses one of several pre-defined system conditions related to Path 15 and Path 26 flows in order to determine the minimum/maximum contingency reserve procurement in each region and whether that procurement can include imports.

The AS regional constraints do not consider more localized limitations to ensure sufficient deliverable contingency reserve procurement. Given the loss of a generator and the subsequent deployment of contingency reserves all transmission elements should be below emergency ratings; however, the market does not explicitly ensure this response while also ensuring the system access to 100% of the contingency reserves.

3.1.3. Infeasible contingency reserve procurement

In this example, contingency reserves are procured behind a transmission path with an emergency rating that would prevent the eventual deployment of those reserves.

Observe the local transmission topology and current market dispatch below. Notice that the loss of generator G4 and subsequent deployment of contingency reserves would cause Path AB to be loaded above its emergency rating. Assume we award contingency reserves to G1 and G2 to meet an overall contingency reserve requirement of 1000 MW.



Base case dispatch							
Generator	P^0	AS	λ^0	SF_g^{AB}	μ^0_{AB}	μ^k_{AB}	LMP_g
G1	750	250	$40	1	$0	$10	$30
G2	0	750	$40	1	$0	$10	$30
G3	1250	0	$40	0	$0	$10	$40
G4	1000	0	$40	0	$0	$10	$40
Path Flows							
Pre-contingency					**After loss of G4 & full AS deployment**		
$Flow_{AB}$	750				$Flow_{AB}$	**1750** (Above rating of 1500)	

Assume the economic awards of contingency reserves can be provided from generators G1 and G2. G1 is awarded 250 MW of contingency reserves and G2 is awarded 750 MW of contingency reserves to meet a total contingency reserve requirement of 1000 MW.

As shown in the example above, given the loss of the generator G4 at Node C, Path AB would be loaded above its emergency rating of 1500 MW once the generation deficit is replenished by contingency reserves from generators G1 and G2. This would violate the emergency limit for Path AB. In practice, if the contingency would occur, 250 MW of the full 1000 MW contingency reserves procured by the ISO would be unusable. An appropriate contingency reserve procurement would ensure that Path AB is not loaded above its emergency rating due to a single generator contingency event and the subsequent deployment of contingency reserves. The dispatch that achieves this goal is shown below.

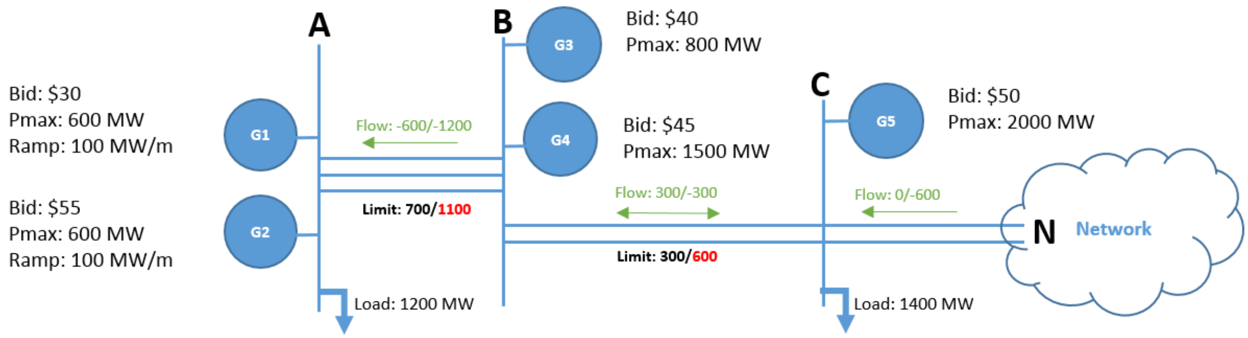
Base case dispatch							
Generator (g)	P^0	AS	λ^0	SF_g^{AB}	μ^0_{AB}	μ^k_{AB}	LMP_g
G1	750	250	$40	1	$0	$10	$30
G2	0	**500**	$40	1	$0	$10	$30
G3	1250	**250**	$40	0	$0	$10	$40
G4	1000	0	$40	0	$0	$10	$40
Path Flows							
Pre-contingency					**After loss of G4 & AS Deployment**		
$Flow_{AB}$	750				$Flow_{AB}$	**1500** (Below rating)	

We achieve this today by operator intervention.

3.1.4. Insecure transmission given the potential loss of generation

In this example, a transmission path would be overloaded above its emergency rating after the loss of a generator and subsequent deployment of contingency reserves.

Observe the transmission topology and current market dispatch below. Notice that the loss of generator G1 and subsequent deployment of contingency reserves from generator GN (somewhere out in the network N) would cause Path AB to be loaded above its emergency rating. In this example, we assume that there are no contingency reserve eligible resources at buses A, B, and C.



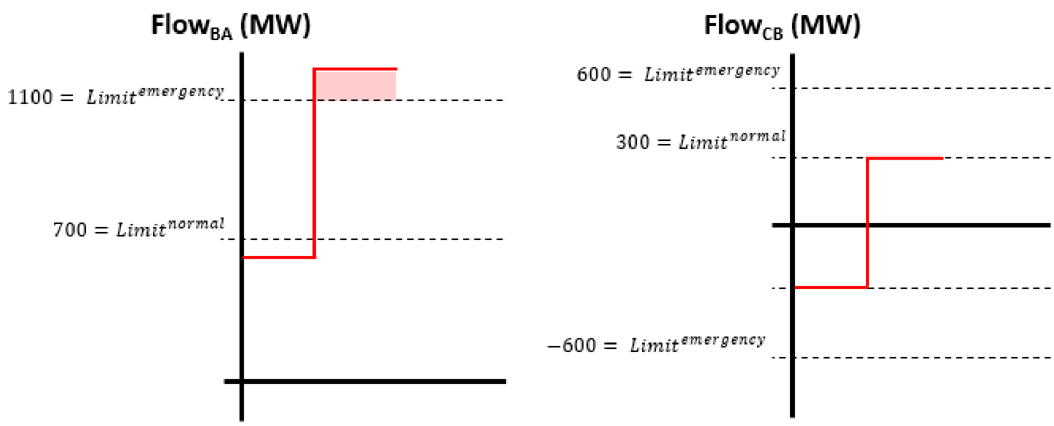
Base case dispatch										
Generator (g)	P^0	AS	λ^0	SF_g^{AB}	μ^0_{AB}	μ^k_{AB}	SF_g^{BC}	μ^0_{BC}	μ^k_{BC}	LMP_g
G1	600		$47.70	0.54	$0	*N/A*	0.54	$5	*N/A*	$45
G2	0		$47.70	0.54	$0	*N/A*	0.54	$5	*N/A*	$45
G3	800		$47.70	–0.46	$0	*N/A*	0.54	$5	*N/A*	$45
G4	100		$47.70	–0.46	$0	*N/A*	0.54	$5	*N/A*	$45
G5	1100		$47.70	–0.46	$0	*N/A*	–0.46	$5	*N/A*	$50
GN	0	600	$47.70	–0.46	$0	*N/A*	–1	$5	*N/A*	$50

Path Flows			
	Pre-contingency	**After loss of G1**	
$Flow_{AB}$	–600	$Flow_{AB}$	**–1200** (Above emergency rating)
$Flow_{BC}$	300	$Flow_{BC}$	–300
$Flow_{CN}$	0	$Flow_{CN}$	–600

The current market dispatch places generator G2 at 0 MW which does not ensure that post-contingency flows on Path AB remain below 1100 MW after the loss of generator G1. This dispatch pattern violates the emergency rating on Path AB. The shadow prices that would be associated with the generator contingency (μ^k_{AB} & μ^k_{BC}) are shown as "Not Applicable" because in this example, the generator contingency would be the only contingency in the set of contingencies (k), but it is not enforced. Notice how the normal rating on Path BC binds in the base case (non-zero μ^0_{BC}).

The LMP at the G1 location is calculated as $47.70 - 0.54×($0) - 0.54×($5) = $45.

The movement in flows from pre-contingency to post contingency are shown below.



As shown in the example above, given the loss of the generator G1 at Node A, Path AB would be loaded above its emergency rating of 1100 MW. This violates the emergency limit for Path AB. An appropriate dispatch would ensure that Path AB does not load above its emergency rating given a single contingency event. The dispatch that achieves this goal is shown below. We now add the generator contingency as the only contingency into the set of contingencies (k). In this example, we assume that there are no contingency reserve eligible resources at buses A, B, and C.

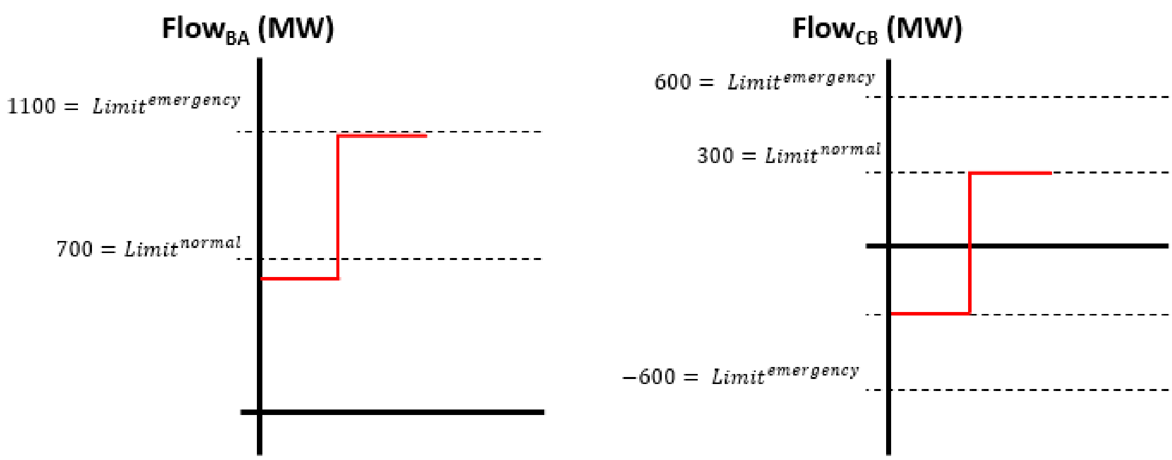
Desirable base case dispatch (G-1 Secure)										
Generator	P^0	AS	λ^0	SF_g^{AB}	μ^0_{AB}	μ^k_{AB}	SF_g^{BC}	μ^0_{BC}	μ^k_{BC}	LMP_g
G1	600		$52.30	0.54	$0	–$10	0.54	$5	$0	$55
G2	**100**		$52.30	0.54	$0	–$10	0.54	$5	$0	$55
G3	800		$52.30	–0.46	$0	–$10	0.54	$5	$0	$45
G4	**0**		$52.30	–0.46	$0	–$10	0.54	$5	$0	$45
G5	1100		$52.30	–0.46	$0	–$10	–0.46	$5	$0	$50
GN	0	600	$52.30	–0.46	$0	–$10	–1	$5	$0	$50

Path Flows			
	Pre-contingency	**After loss of G1**	
$Flow_{AB}$	**–500**	$Flow_{AB}$	**–1100** (Below rating)
$Flow_{BC}$	300	$Flow_{BC}$	–300
$Flow_{CN}$	0	$Flow_{CN}$	–600

The secure dispatch places generator G2 at 96 MW to ensure that post contingency flows on Path AB do not exceed 1100 MW after the loss of generator G1. The shadow prices associated with the generator contingency (μ^k_{AB} & μ^k_{BC}) are now shown because the generator contingency is enforced as the only contingency in the contingency set (k). Notice that the emergency rating on Path AB binds for generator contingency k (non-zero μ^k_{AB}). Also notice that the normal rating on Path BC still binds in the base case (non-zero μ^0_{BC}).

The LMP at the G1 location is calculated as \$52.30 - 0.54×(\$0) - 0.54×(-\$10) - 0.54×(\$5) - 0.54×(\$0) = \$55.

The movement in flows from pre-contingency to post contingency are shown below.

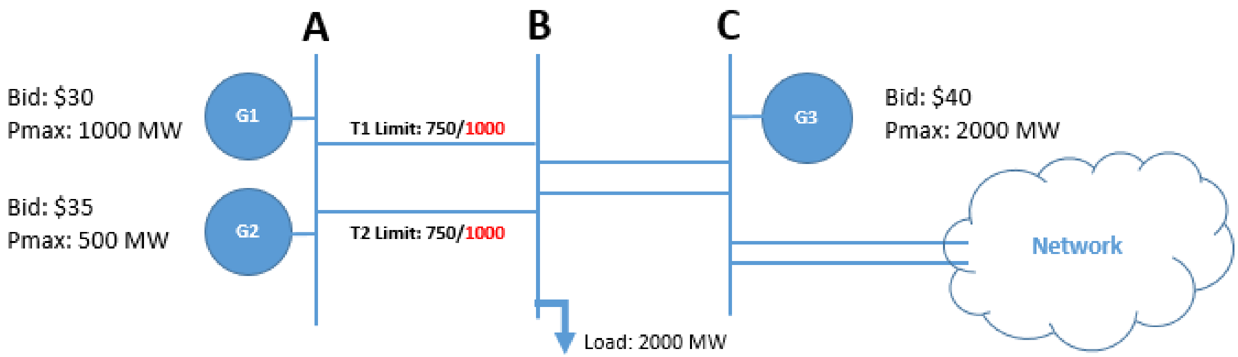


3.1.5. Uneconomic dispatch given RAS generation loss

Many of the Remedial Action Schemes (RAS) in the ISO involve the loss of a transmission element along with the subsequent loss of all or a portion of generation. If not explicitly modeled in the market, the ISO may be producing an uneconomic dispatch behind certain constraints. If the ISO gains the capability to model the loss of generation as discussed above, it could explicitly model these RAS in the market.

In this example, the market does not produce the lowest production cost dispatch without modeling the RAS.

Observe the transmission topology and current market dispatch below. In the field, a RAS is defined such that for the loss of transmission line T2, generator G1 will trip offline. Notice that the loss of transmission line T2 and subsequent RAS loss of generator G1 would result in transmission line T1 to be loaded under its emergency rating. However, the current dispatch that accomplishes this could have dispatched generator G2 higher in the base case if the RAS was modeled in the market. Below, a contingency in contingency set k is defined as simply the loss of T2. Note that G2 is not dispatched. In this example, we assume that there are no contingency reserve eligible resources at buses A, B, and C.



Base case dispatch							
Generator (g)	P^0	AS	λ^0	SF_g^{AB}	μ^0_{AB}	μ^k_{AB}	LMP_g
G1	1000		$40	1	$0	$5	$35
G2	0		$40	1	$0	$5	$35
G3	1000		$40	0	$0	$5	$40
GN	0	1000	$40	0	$0	$5	$40

Path Flows			
Pre-contingency		**After loss of T2**	
$Flow_{AB}$	1000	$Flow_{AB}$	1000
$Flow_{BC}$	–1000	$Flow_{BC}$	–1000
$Flow_{CN}$	0	$Flow_{CN}$	0

This example yields a total bid cost of 1000($30) + 1000($40) = $70,000.

As shown in the example above, given the loss of transmission line T2, transmission line T1 would actually be loaded below its emergency rating considering a RAS that trips generator G1. This would not violate the emergency limit for transmission line T1.

An appropriate dispatch would ensure that T1 does not load above its emergency rating given the contingency event and G2 is not held back from its economic dispatch. The dispatch that achieves this goal is shown below. The contingency k is defined as the loss of T2 and the loss of G1 together. Note that G2 is now dispatched.

Desirable base case dispatch (RAS Modeled)							
Generator (g)	P^0	AS	λ^0	SF_g^{AB}	μ^0_{AB}	μ^k_{AB}	LMP_g
G1	1000		$40	1	$5	$0	$35
G2	**500**		$40	1	$5	$0	$35
G3	500		$40	0	$5	$0	$40
GN	0	1000	$40	0	$5	$0	$40

Path Flows			
Pre-contingency		**After loss of T2 and G1**	
$Flow_{AB}$	1500	$Flow_{AB}$	500
$Flow_{BC}$	–500	$Flow_{BC}$	–1500
$Flow_{CN}$	0	$Flow_{CN}$	–1000

This example yields a total bid cost of 1000($30) + 500($35) + 500($40) = $67,500.

As shown in the example above, the limiting condition is no longer the emergency rating on T1 for the loss of T2, but rather the normal limit in the base case on Path AB. Now, a total of 1500 MW can flow on Path AB in the base case rather than only 1000 MW. We can now dispatch G2 for a total bid cost savings of $2,500.

3.2. Issues

The ISO achieves N-1 transmission security and procures appropriate amounts of deliverable contingency reserves today; however it achieves this through manual intervention.

ISO operators rely on real-time contingency analysis tools and custom displays to constantly monitor the potential for generator contingencies that may push the system outside of operating limits and take manual action if necessary to keep the system within applicable limits. Assessing and ensuring N-1 security for generation contingencies requires a mix of offline studies, manual review, analysis, and out-of-market intervention.

The ISO also evaluates the overall system topology to determine if there would likely be capacity procured behind some transmission constraints that may prevent it from being fully deployed and blocks specific MW quantities or entire resources from receiving AS awards.

Both of these methods suffer from the inefficiencies associated with manual review, analysis, and out-of-market intervention. The market will gain efficiency by securing deliverable contingency reserves while pricing the transmission feasible deployment of those reserves into the market and reducing inefficiencies associated with manual review, analysis, and out-of-market intervention.

As discussed above, the following are not modeled in the market leading to inefficiencies and uplift:

1. Given a generator loss plus the deployment of contingency reserves, all transmission facilities must be below emergency ratings.
    a. Contingency reserves could be located behind the constraint
    b. Contingency reserves could be located in another area of the system
2. Given a transmission line loss, plus a generator loss due to RAS action, plus the deployment of contingency reserves, all transmission facilities must be below emergency ratings.
    a. Contingency reserves could be located behind the constraint
    b. Contingency reserves could be located in another area of the system

4. Scope of Initiative

This initiative is focused on required enhancements to the day ahead and real time markets to support generator contingencies. The eventual proposal should result in an economic dispatch that would respect all emergency limits after the loss of a generating unit and deployment of the required quantity of contingency reserves without the need for out-of-market intervention.

This initiative will not focus on the system response and state immediately after the loss of a generating unit.

5. Next Steps

The ISO will discuss the issue paper with stakeholders during a teleconference to be held on April 25, 2016. Stakeholders should submit written comments by May 13, 2016 to InitiativeComments@caiso.com.