Reserve Enhancements for Constrained Areas (Dynamic Reserves)

A Report by the
New York Independent System Operator

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Background

Operating reserves are needed to protect the electric system against contingencies, such as sudden loss of generation or trip of network equipment. The system is operated such that even after suffering the largest contingency, it can still be operated reliably. This is known as securing the system to N-1, where the 1 represents the number of contingencies that are respected. The NYISO operates the system and sets reserve requirements based on New York State Reliability Council (NYSRC) , Northeast Power Coordinating Council (NPCC) , and North American Electric Reliability Corporation (NERC) standards, which require the NYISO to carry operating reserves for a state-wide source contingency. In addition, the NYISO has five reserve areas[1] (reserve zones) and sets locational reserve requirements to help procure reserves throughout the New York Control Area due to limitations on the transmission system.

The existing operating reserve requirements are essentially static.[2] This static modeling approach uses a pre-determined value to procure reserves, which potentially reduces the flexibility of the market model to affect current or projected grid conditions (*e.g.*, generation commitments and electrical flows on transmission) and to maintain system reliability with a least cost solution. The static modeling of reserves, specifically locational requirements, does not optimally account and adjust for the real-time transmission flows and available transmission capability that could be used to deliver reserves from a more cost-effective reserve area. Today and in the future, the largest source contingency could change based on the current commitment of generation.

Therefore, within this study, the NYISO is exploring a *Dynamic Reserves* approach that will consider more efficient scheduling of operating reserves based on system conditions and transmission system capability. This will allow for appropriate reserves to be procured to cover the largest contingency that could potentially occur under the current system conditions (*i.e.,* generator or import tie-line), while also allowing for more reserves to be scheduled in cost-effective areas to meet the reliability needs of the system. In a future with increased penetration of weather-dependent generation technologies, the real-time system conditions will evolve more rapidly. Thus, a more dynamic method for determining and scheduling responsive and flexible resources for reserves will be necessary to maintain reliability at the least cost dispatch.

The Market Monitoring Unit (MMU) has recommended that NYISO dynamically adjust operating reserve requirements that must be held on internal resources since the *2015 State of Market Report*

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1. Throughout this paper, the term reserve areas will be used to refer to current reserve areas (i.e., NYCA, EAST, SENY, NYC and LI) and potential future reserve areas (e.g., certain NYC load pockets)
2. 30-minute operating reserve requirements in the SENY and LI reserve areas have an hourly component to them. However, these hourly requirements are pre-determined and therefore essentially static

(SOM).[3] Further expanding on this recommendation in the *2020 SOM*,[4] the MMU noted that, '*the reserve requirement for an area can be met more efficiently by scheduling additional generation in the area (i.e., reducing flows into the area and treating the unused interface capability as reserves), rather than scheduling reserves on internal generation'.* Given the MMU's recommendations and the importance of attributes such as resource flexibility and responsiveness, the NYISO commenced an evaluation of a dynamic reserve procurement methodology.

This report provides an overview of the assessment conducted by the NYISO to test the feasibility of procuring operating reserves dynamically. The NYISO designed a theoretical mathematical formulation that aimed to translate the need for operating reserves into a set of useable constraints within the market optimization. Next, the NYISO modeled these constraints and built a prototype to test the practical feasibility and applicability of dynamic reserve procurement. Further, the report discusses some of the test cases that were run on the prototype to inform the impacts on market efficiencies. The NYISO also considered extension of the developed prototype to certain potential future reserve areas, such as New York City load pockets that would better represent the value of short-notice resources in desirable locations. The report identifies some of the key areas that would need to be further evaluated in future phases of this project, which include, but are not limited to, the interaction of the ancillary services demand curves and transmission demand curves with the developed prototype. The study concludes with key observations from dynamic reserves prototype in the NYISO markets and provides recommendations for areas of additional analysis and collaboration with stakeholders, as needed.

Current Operating Reserve Requirements

Operating reserves[5] include: (a) 10-Minute Spinning Reserves, which is capacity held in reserve and synchronized to the grid and able to respond within 10-minutes; (b) 10-minute total reserves, which includes 10-Minute Spinning Reserves and 10-minute Non-Synchronized Reserves. 10-minute Non-Synchronized Reserves is capacity that is not synchronized to the grid, but can be started, synchronized, and increase output to a level within 10-minutes; and (c) 30-minute Reserves, which include synchronized and non-synchronized capacity that is available to respond within 30-minutes. Collectively, these operating reserves help maintain a close balance between the supply and demand of electricity and ensure

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[3] See Recommendation 2015-16 in the 2015 State of the Market Report, located at the following link NYISO-2015-SOM-Report

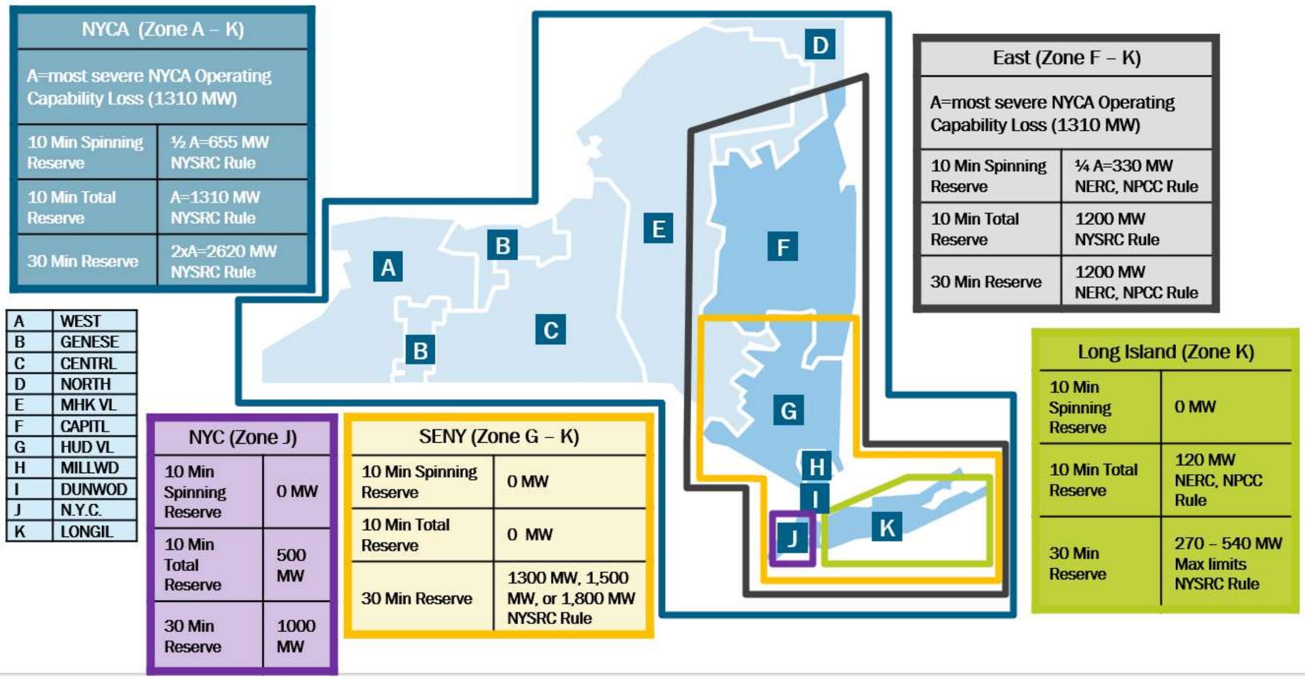
[4] See Recommendation 2015-16 in the *2020 State of the Market* Report, located at the following link: NYISO-2020-SOM Report

[5] Capitalized terms not otherwise defined herein shall have the meaning specified in the Market Administration and Control Area Services (Services Tariff) and Open Access Transmission Tariff (OATT).

continuous delivery of energy when unexpected events (*i.e.,* contingencies) arise that impact such service.

The NYISO procures fixed quantities of reserves in specific reserve areas across the state (Figure 1).

Figure 1: Current Operating Reserve Requirements



NYCA (Zone A – K)	
A=most severe NYCA Operating Capability Loss (1310 MW)	
10 Min Spinning Reserve	½ A=655 MW NYSRC Rule
10 Min Total Reserve	A=1310 MW NYSRC Rule
30 Min Reserve	2xA=2620 MW NYSRC Rule

A	WEST
B	GENESE
C	CENTRL
D	NORTH
E	MHK VL
F	CAPITL
G	HUD VL
H	MILLWD
I	DUNWOD
J	N.Y.C.
K	LONGIL

NYC (Zone J)	
10 Min Spinning Reserve	0 MW
10 Min Total Reserve	500 MW
30 Min Reserve	1000 MW

SENY (Zone G – K)	
10 Min Spinning Reserve	0 MW
10 Min Total Reserve	0 MW
30 Min Reserve	1300 MW, 1,500 MW, or 1,800 MW NYSRC Rule

East (Zone F – K)	
A=most severe NYCA Operating Capability Loss (1310 MW)	
10 Min Spinning Reserve	¼ A=330 MW NERC, NPCC Rule
10 Min Total Reserve	1200 MW NYSRC Rule
30 Min Reserve	1200 MW NERC, NPCC Rule

Long Island (Zone K)	
10 Min Spinning Reserve	0 MW
10 Min Total Reserve	120 MW NERC, NPCC Rule
30 Min Reserve	270 – 540 MW Max limits NYSRC Rule

10-Minute Total Reserve Requirements

For the NYCA reserve area, the current static 10-minute total reserve requirements are designed to replace the capability lost from a single largest source contingency in NYCA. For other applicable reserve areas such as EAST, SENY, and LI, the current 10-minute total reserve requirements are set to secure the transmission system to applicable ratings after the loss of the largest transmission contingency. The 10-minute total requirement is inclusive of any applicable 10-minute spinning reserve requirement.

10-Minute Spinning Reserve Requirements

Some of the reserve areas may require higher quality reserves, which are being offered by resources already synchronized with the grid and injecting or withdrawing energy. Therefore, in certain reserve areas a percentage of the 10-minute total reserve requirement must be procured as 10-minute spinning reserves. For example, the current NYCA and EAST 10-minute spinning reserve requirements are 50% and 25% of NYCA 10-minute total requirement, respectively.

30-Minute Total Reserve Requirements

30-minute total reserve requirements are needed to maintain enough reserves available to replenish the

10-minute total reserves state-wide (*i.e.*, in NYCA), and to prepare the system for the next possible contingency by bringing the transmission system back to normal operating criteria after suffering the first contingency. The 30-minute total requirement is inclusive of any applicable 10-minute total reserve requirement.

Need/Justification for Dynamic Reserve Requirements

The current static modeling of reserve requirements may not optimally reflect the varying needs of the grid to respond to changes in system conditions, such as:

1) Scheduling economic energy above 1,310 MW from individual suppliers when sufficient reserves are available: and/or
2) Shifting reserve procurements to lower-cost areas when sufficient transmission capability exists.

These static requirements do not consider the possibility of the largest source contingency changing based on current online generation or the current system topology. This may lead to overstating or understating the required operating reserves. The current static reserve requirements in areas such as SENY and EAST, which are determined by transmission limitations, are generally designed for the worst scenario which assumes the transmission system is fully scheduled and reserves are needed to be carried in a reserve area for the loss of a major transmission element. By accounting for the available transmission headroom based on current system topology, there is a potential to shift reserves to lower cost providers in other areas. This will accurately reflect the system's current needs. Accurately reflecting the system conditions with market products allows the market pricing to directly reflect the cost of maintaining system reliability under various scenarios, both normal and stressed operating conditions.

While there is a need for dynamic reserves under today's system conditions, this need only increases as the grid evolves in the coming years to include a resource mix with significantly more intermittent and energy limited resources. As both the net load and forecasted supply will tend to be more volatile and uncertain, adequate reserves will need to be scheduled in proper quantities to balance the grid and minimize the risks to reliability. Moreover, as intermittent generation grows in certain import constrained areas, it will be important to schedule adequate quantities of reserves in the proper locations to address the loss of supply.

Similarly, as part of the *More Granular Operating Reserves* effort, the NYISO is exploring the implementation of reserve requirements within certain constrained load pockets in New York City that would better represent the value of short-notice resources in desirable locations. The NYISO believes that an efficient and effective solution to implement load pocket reserves is dependent on *Dynamic Reserves*.

This is because static requirements in these load pockets can result in situations where holding reserves on supply is infeasible since all supply is providing economic energy and the reserves, or head room, have been shifted to the importing transmission lines. A dynamic determination of these requirements, which accounts for available transmission capability into a load pocket, could potentially reduce the quantity of reserves scheduled in these load pockets, improving market efficiency.

The endogenous, dynamic reserve procurement methodology considered in this study is a unique and novel approach to allocate reserves.

Dynamic Reserves Study Approach

As the NYISO has always operated with static reserve requirements, it was pertinent to first study the possibility of introducing the dynamic reserve scheduling construct. The NYISO addressed the study by splitting it into two phases.

The first phase was the 'Mathematical Formulation phase,' under which the NYISO designed a mathematical formulation of constraints by leaning on the fundamentals of why reserves are needed. This phase went through multiple iterations and the NYISO sought out external expertise to confirm the efficacy of the developed solution. The formulation is detailed in the Mathematical Formulation section below.

After confirming the theoretical accuracy of the formulation, it was important to test the practical applicability of the formulation through the development of a prototype. Thus, under the next phase, the 'Prototyping phase,' NYISO modeled the developed constraints into the market software and created a prototype for dynamically scheduling operating reserves. After successful execution of the prototype, the NYISO tested several scenarios using the prototype to confirm that results matched expectations. These cases are detailed in the Study prototype test results section of the paper.

Study Scope

As previously discussed, this study seeks to address two key components:

a) Exploring the feasibility of dynamically determining the minimum operating reserve requirements based on the single largest source contingency during market runs; and

b) Exploring dynamic allocation of reserves based on available transmission capability which will include a consideration of modeling local reserve requirements within certain NYC load pockets.

The objectives of the study (both the mathematical formulation and the prototype) were:

- To make the current static requirements dynamic, consistent with the system needs, by allowing the market software to solve for the operating reserve requirements endogenous to the market solution;
- Identify and solve for largest generation (source) contingency for every time step;
- Co-optimize generation and reserve schedules with available transmission headroom (interface flows);
- Secure the transmission system to pre-contingency and post-contingency interface limits with reserve requirements;
- Ensure compatibility with current SCUC and RTS systems including network topology modeling for effective implementation; and
- To closely model existing reserve areas with more generic modeling to allow for easy expansion to more granular reserve regions in the future.

Therefore, the formulation and feasibility of procuring the existing 10-minute spinning, 10-minute total, and 30-minute total requirements dynamically in the SCUC, RTC and RTD intervals was studied.[6] The ability to apply this methodology to potential future reserve areas (*e.g.*, certain NYC load pockets) was also explored.

Mathematical Formulation

The NYISO started with a theoretical approach by developing a generalized mathematical formulation to facilitate the determination of solving for the procurement of operating reserve requirements dynamically. The NYISO also sought feedback from external consultants on the feasibility of the formulation.

Key Concepts for Study

There are two primary concepts that drove the design of the formulation as described below.

Concept 1: Operating Reserves should be procured to account for the greater of the two contingencies in any reserve area:

- Loss of generation (source contingency): The reserve requirements should cover for the largest source contingency within a reserve area, less the available transmission headroom;

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[6] There may be a need for a 60-minute operating reserve requirement in certain reserve areas in the future. However, this study did not explicitly model any 60-minute reserve requirements. The formulation could potentially be extended to include a 60-minute operating reserve product, but the other market design, settlements and pricing details will require further analysis.

and

- Loss of transmission/import: The reserve requirement should account for the difference between the current flow and the applicable interface transfer limit, after the loss of largest transmission contingency.

Loss of Generation and Loss of Transmission equations should be modeled within the market software for each reserve area. The more restrictive of these constraints will drive the reserve requirement for each reserve area for every time step. This ensures sufficient reserves are procured to cover for the worst-case scenario and allows the optimization to trade-off between reserves, energy, and transmission costs.

Concept 2: There are two ways to secure reserves in any reserve area:

- Schedule reserves on resources inside the reserve area; and
- Schedule reserves outside the reserve area, while scheduling transmission flows to ensure there is sufficient import capability .

Determination of dynamic reserve requirements and associated schedules should strive to be endogenous to the optimization and considered by the objective function (*i.e.*, minimization of total production cost).

Development of the formulation considered the fundamental question of the need for operating reserves. Reserve requirements are designed to secure the system against contingency events such as the loss of generation and/or loss of transmission capability. Given this starting point, the NYISO developed equations to dynamically determine the single largest contingency, which could be either the loss of generation, loss of transmission, or a combination of the two depending on the 10-minute or 30-minute reserve requirement.[7] These equations are applied individually to all reserve areas, but since the dynamic reserves design does not change the current nesting of reserve areas, it doesn't lead to double accounting of reserves because the reserves secured in a nested reserve area count towards the requirement of the reserve areas that it is located within.

The formulation is designed to secure each reserve area such that if it suffers its largest single contingency,[8] there are enough reserves either inside the reserve area or enough headroom on the transmission system to import energy into the reserve area within the applicable timeframe (*i.e.*, 10 minutes or 30-minutes)

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[7] The dynamic reserves study didn't study the creation of a new reserve product (e.g., a 60-minute product). New constraints would need to be added for a 60-minute product. However, a similar approach as the 10-minute and 30-minute product can be used.

[8] The largest contingency is selected to protect the system against the worst-case scenario.

This was effectuated by creating a set of equations which would cover for ‘loss of largest source contingency’ and another set of equations that would cover for the ‘loss of largest transmission contingency’ within each reserve area. The more limiting of these two sets of equations would then set the dynamic reserve requirement for each reserve area for each timestep. By protecting for the more limiting of the two scenarios, the design schedules reserves to protect the system against the worst possible contingency.

Determination of the largest single contingency for non-NYCA reserve areas

When determining the 10-minute spinning reserve requirement and the 10-minute total reserve requirement for a non-NYCA reserve area, the largest single contingency is formulated as the generator with the largest energy plus 10-minute total reserve schedules. When determining the 30-minute total reserve requirement for a non-NYCA reserve area, the largest single contingency is formulated as the generator with the largest energy plus 30-minute total reserve schedules.

By accounting for the appropriate reserve product when determining the largest single contingency for each reserve requirement, the optimization accurately reflects the loss of the largest unit because if that unit were to trip offline, both the energy and reserves carried on that unit would be lost.

Determination of the largest single contingency in the NYCA reserve area

When determining the 10-minute spinning, 10-minute total and 30-minute total reserve requirements for the NYCA reserve area, the largest contingency is formulated as the generator with the largest combined energy, regulation, 10-minute spinning reserve schedule, 10-minute total reserve schedule and 30-minute total reserve schedule.

This difference in treatment of the NYCA and non-NYCA reserve areas is attributed to the NPCC and NYSRC rules, which require the NYISO to procure reserves in the NYCA to cover for the largest capability loss. Additionally, since regulation is only a product procured NYCA wide, it is included when determining the largest contingency NYCA wide.

Explanation of the Mathematical Formulation

With the foundational understanding of the concepts discussed in the above section, this section delves into the actual formulation while discussing each of the constraints in detail.

Loss of Generation Equations

As noted in Concept 1, the reserve requirements should cover for the largest source contingency within a reserve area, less the available transmission headroom. This design maintains sufficient reserves to protect each reserve area against the loss of the largest online generation. The additional security constraint for reserves allows the reserve requirement to be dynamic by either a) decreasing energy flows into the reserve area to create transmission headroom or b) decreasing scheduled energy production inside the reserve area to create reserve capability on resources.

Each of the 10-minute spinning, 10-minute total, and 30-minute total reserve requirements for each reserve area has their own security multiplier. These multipliers enable the procurement of the necessary quality of reserve product where needed by requiring the reserve requirements protect against the largest schedule of energy and reserves for that reserve product. This multiplier (security factor) could be any number greater than zero. For example, 10-minute total reserves may have a multiplier of 1 to replace the loss of the largest single source contingency within 10 minutes, and 2 for 30-minute total reserves to be able to replace the loss of largest single source contingency and to prepare the system for the next contingency in 30 minutes. Additionally, in certain reserve areas, the NYISO may need to procure a certain percentage of the 10-minute total reserves (*e.g.*, 25%) to be online, spinning and grid synchronized resources, so a 0.25 multiplier may be used there.

Subtracting the available transmission capability on the interface from the largest contingency lets the market software schedule reserves external to the reserve area. Therefore, the quantity of reserves needed to cover for the largest single contingency in a reserve area multiplied by the security factor would not necessarily have to be scheduled within the reserve area but could be imported, if that is the more economical solution.

Equations (1) to (3) below show the formulation of the 10-minute spinning, 10-minute total, and 30-minute total reserve requirements, which cover for the loss of largest online generation plus the applicable reserve product in any reserve area.[9] Since a portion of the 10-minute total requirement needs to be procured as 10-minute spinning requirements in certain reserve areas, the determination of the largest schedule for the 10-minute spinning requirement uses the applicable energy plus the 10-minute total reserve schedules in that reserve area.

$$Res_{RA_{a_i}}^{10Spin} \geq Mult_{RA_a}^{10Spin} * \{\max_{k \in Gen_{RA_a}} \{gen_{k_i} + res_{k_i}^{10Total}\}\} - RA_{aRes_{Capability_i}} \tag{1}$$

$$Res_{RA_{a_i}}^{10Total} \geq Mult_{RA_a}^{10Total} * \{\max_{k \in Gen_{RA_a}} \{gen_{k_i} + res_{k_i}^{10Total}\}\} - RA_{aRes_{Capabilit\ _i}} \tag{2}$$

$$Res_{RA_{a_i}}^{30Total} \geq Mult_{RA_a}^{30Total} * \{\max_{k \in Gen_{RA_a}} \{gen_{k_i} + res_{k_i}^{30Total}\}\} - RA_{aRes_{Capability_i}} \tag{3}$$

In these equations the available transmission capability on the interface into the reserve area from the

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[9] Refer to the appendix for detailed description of the terms in the formulation

outside area is the import that could be deducted from the largest generating contingency as shown in equation 4. [10]

$$RA_{aRes_{Capabilit_{\ i}}} = RA_{a_{Limit_i}} - RA_{a_{Flow_i}} \qquad (4)$$

The flow is defined as the forecasted load in the reserve area minus scheduled generation within the reserve area. The forecast load, rather than the bid load, was considered as the 'Load' value in equation (5) to effectively secure the system in the Day-Ahead market (DAM)[11] and account for any under-scheduling of energy to satisfy forecast load in a given area, as pointed out in the SOM report.[12] Another potential alternative could be to consider the maximum of a) bid load and b) forecast load to account for any scenario where the bid load is higher than the forecast load.

An important aspect of this design is it works for closed interfaces.[13] For the purposes of the study, all the interfaces are defined and modeled as closed interfaces because most of the current reserve areas, and anticipated future reserve areas (e.g., NYC load pockets), are either closed interfaces or can be closely approximated as closed interfaces.

$$RA_{a_{Flow_i}} = RA_{a_{Load_i}} - RA_{a_{Gen_i}} \qquad (5)$$

Loss of Transmission equations

The second facet of Concept 1 states that the reserve requirements should account for the difference between the current flow and the applicable interface transfer limit, after the loss of largest contingency (*e.g.*, import line(s), tower contingency, transformer) in the appropriate timeframe.

10-minute total requirements are needed to get the transmission system back under emergency limits should the system suffer a loss of a major transmission equipment as shown in equation (7). In certain reserve areas, a portion of the 10-minute total requirement may need to be held as spinning reserves to provide the system access to online synchronized generation if a contingency were to occur as shown in equation (6).

For all current reserve areas except NYC, the 30-minute requirements should account for securing the interface to normal transfer criteria after the loss of the largest transmission contingency, as shown in

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[10] Initially, the equations were set-up to account for the lesser of the a) available transmission capability on the interface and b) the reserve schedules outside of the reserve area. However, accounting for the reserve schedules outside of the reserve area could lead to potentially double accounting for any type of reserve shortages the reserve area is a part of. Thus, the reserve capability only accounts for the available transmission capability of the interface.

[11] The RTM only schedules energy, reserves and regulation to satisfy forecast load. There is no Bid load in the RTM

[12] Refer to Recommendation 2015-16 of the 2020 SOM Report

[13] Closed interfaces allow a reserve area to be modeled such that such that the power flows in and out of the reserve area equals (Load -Generation) of the reserve area

equation (8).

For NYC reserve area and potential future reserve areas (*i.e., NYC load pockets*), in addition to equation (8), another scenario should also be considered when determining 30-minute reserve requirements: securing the interface to appropriate normal ratings[14] after the loss of two largest transmission elements, as shown in equation (9). This requirement translates the physical operation of certain NYC load pocket interfaces (where they can be operated at higher-than-normal limits if the 30-minute requirements solve for the loss of two contingencies) to constraints within the market software which will provide a market mechanism to satisfy the reliability criteria.[15] Additionally, it ensures the 30-minute requirements cover for the possibility of two contingencies (largest source contingency and largest transmission contingency) occurring in 30-minutes.

Equations (6) to (9) below show the formulation of the 10-minute spinning, 10-minute total, and 30-minute total reserve requirements which cover for the loss of transmission based on the current system topology for the applicable reserve area interfaces.[16]

$$Res_{RA_{a_i}}^{10Spin} \geq Mult_{\mathrm{RA}_a}^{10Spin} * (10minute_{PostCon_{Import_{RA_{a_i}}}}) \tag{6}$$

$$Res_{RA_{a_i}}^{10Total} \geq (10minute_{PostCon_{Impor\ RA_{a_i}}}) \tag{7}$$

$$Res_{RA_{a_i}}^{30Total} \geq \left(30minute_{PostC\quad Import_{RA_{a_i}}}\right) \tag{8}$$

$$Res_{RA_{a_i}}^{30Total} \geq \left(30minute_{PostdualCo\ \ Impor\ RA_{a_i}}\right) \tag{9}$$

where,

$$10minute_{PostCon_{Import_{RA_{a_i}}}} = \max(0, RA_{Flow_{a_i}} - Limit_{Emer(N-1)_{RA_{a_i}}}) \tag{10}$$

$$30minute_{PostdualCon_{Import_{RA_{a_i}}}} = \max(0, RA_{Flow_{a_i}} - Limit_{Norm(N-1-1-0)_{RA_{a_i}}}) \tag{11}$$

$$30minute_{PostCon_{Impor\ RA_{a_i}}} = \max(0, RA_{Flow_{a_i}} - Limit_{Norm_{RA_{a_i}}}) \tag{12}$$

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[14] NYSRC local reliability requirements for NYC are more stringent requiring certain areas of the Con Edison system to be designed and operated for the occurrence of a second contingency. For details refer to (nysrc.org)

[15] For details refer to Recommendation 2017-1 of the '2020 SOM Report'

[16] Refer to the appendix for detailed description of the terms in the formulation

The difference between the applicable transfer limit[17] and the flow is the available import capability. When positive, this number represents a deficiency that needs to be held as reserves within the reserve area due to the lack of transmission headroom to import reserves as shown in equations (10) to (12).

Determining applicable reserve requirement in any reserve area

For each of the reserve products, the more limiting of the Loss of Generation or Loss of Transmission equations will set the reserve requirement. This design protects the reserve area against the worst-case scenario based on the current system topology.

The reserve requirements are therefore determined by simultaneously solving for the loss of generation and loss of transmission constraints. 10-minute spinning reserve requirements would be determined by the more restrictive of equation (1) and equation (6) and the 10-minute total reserve requirement would be determined by equation (2) and equation (7).

30-minute total reserve requirements would be determined by the more restrictive of equation (3), equation (8), and equation (13) in current reserve areas, whereas in NYC and potential future reserve areas (NYC load pockets) these requirements would be determined by the more restrictive of equation (3), equation (8), equation (13) and equation (9) as shown below:

- Securing for loss of source contingency with a security multiplier:

$$Res_{RA_{a_i}}^{30Total} \geq \mathrm{Mult}_{\mathrm{RA_a}}^{\mathrm{30Total}} * \{ \max_{\mathrm{k} \in \mathrm{Gen}_{RA_a}} \{\mathrm{gen}_{k_i} + res_{k_i}^{30Total}\}\} - RA_{aRes_{Capabilit\quad i}} \tag{3}$$

- Securing for one source contingency and N-1 transmission contingency:

$$Res_{RA_{a_i}}^{30Total} \geq \{ \max_{\mathrm{k} \in \mathrm{Gen}_{RA_a}} \{\mathrm{gen}_{k_i} + res_{k_i}^{30Total}\}\} - RA_{aRes_{Capabilit\quad i}} + \left(30minute_{PostC\quad Impo\quad RA_{a_i}} - 10minute_{PostC\quad Import_{RA_{a_i}}}\right) \tag{13}$$

- Securing transmission for N-1 to normal transfer capability:

$$Res_{RA_{a_i}}^{30Total} \geq \left(30minute_{PostCon_{Import_{RA_{a_i}}}}\right) \tag{8}$$

- Securing transmission for N-1-1-0 to normal transfer capability (applies to NYC and NYC load pockets):

$$Res_{RA_{a_i}}^{30Tot} \geq \left(30minute_{PostdualCon_{Import_{RA_{a_i}}}}\right) \tag{9}$$

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[17] All limits will be calculated via an offline study by NYISO Operations. For the study prototype, a set of illustrative but realistic limits were used.

Prototype

The prototype was created by adding the equations developed in the formulation phase to the current code for Day-Ahead Market (DAM) and the Real-Time Market (RTM) (*i.e.*, the SCUC, RTC and RTD software). However, within this analysis and the testing of results, the NYISO focused on the DAM (or SCUC software) because operating reserve bids are available in the DAM and it produces results over a 24-hour optimization period which helps inform the reasonableness of the solutions.

The prototyping of this mathematical formulation was vital to study the feasibility of the DAM solution with dynamic reserves constraints. The NYISO also stress tested the prototype under various scenarios to analyze the accuracy of the results, test the effectiveness of incorporating it into the market software, and its impacts on the market solution. The prototype that was developed was used to run a few SCUC scenarios to demonstrate the feasibility of dynamic scheduling of reserves and its impacts on market efficiency. The process of running these cases was to first establish a baseline by re-running a select number of DAM days, based on the current static reserve requirements. Next, the same DAM days were run using the dynamic reserves prototype. A comparison of the reruns (based on the dynamic reserve prototype) with the base case (based on static reserve requirements) was performed on several outputs, including total production cost changes, LBMP changes, operating reserve clearing price changes, and changes in consumer costs.

The NYISO tested the developed prototype for performance using various scenarios on about 15 DAM days from Summer 2021. For the purposes of the report, 4 cases are discussed. These cases were strategically selected to test if the prototype developed meets the goals set out in the study scope. The cases were then selected such that the dynamic reserves constraints were activated incrementally for the different reserve areas. This approach enables better examination of the prototype results by confirming they are consistent with expected results and the intent of the design.

- Case 1: Activated dynamic reserve constraints for only NYCA-wide reserve products (*i.e.*, 10-minute spin, 10-minute total, 30-minute total)
- Case 2: Activated dynamic reserve constraints for only the SENY 30-minute operating reserve product, with the NYCA requirements static
- Case 3: Activated dynamic reserve constraints for all NYCA-wide reserve products and the SENY 30-minute reserve product
- Case 4: Activated dynamic reserve constraints for all reserve areas (*i.e.*, NYCA, EAST, SENY, NYC and LI)

Study prototype test results

Figure 2: Summary of Results

Summary Table [Dynamic Reserves Case - Base Case]			
	Total production cost delta [$]	**Price cap load delta [MW]**	**LBMP delta (Ref bus) [$/MWh]**
NYCA only	-47554.00	1330.00	-0.97
SENY only	858.00	-8.00	0.01
NYCA and SENY	-47230.00	1375.00	-0.63
Full Dynamic	-48645.00	1502.00	-0.69

Note:

- Negative values in production cost delta and LBMP delta columns imply the base case costs, or LBMPs were higher than the respective dynamic reserves case
- Positive values in production cost delta and LBMP delta columns imply the base case costs, or LBMPs were lower than the respective dynamic reserves case

Figure 3: Change in Average Reserve Clearing Prices

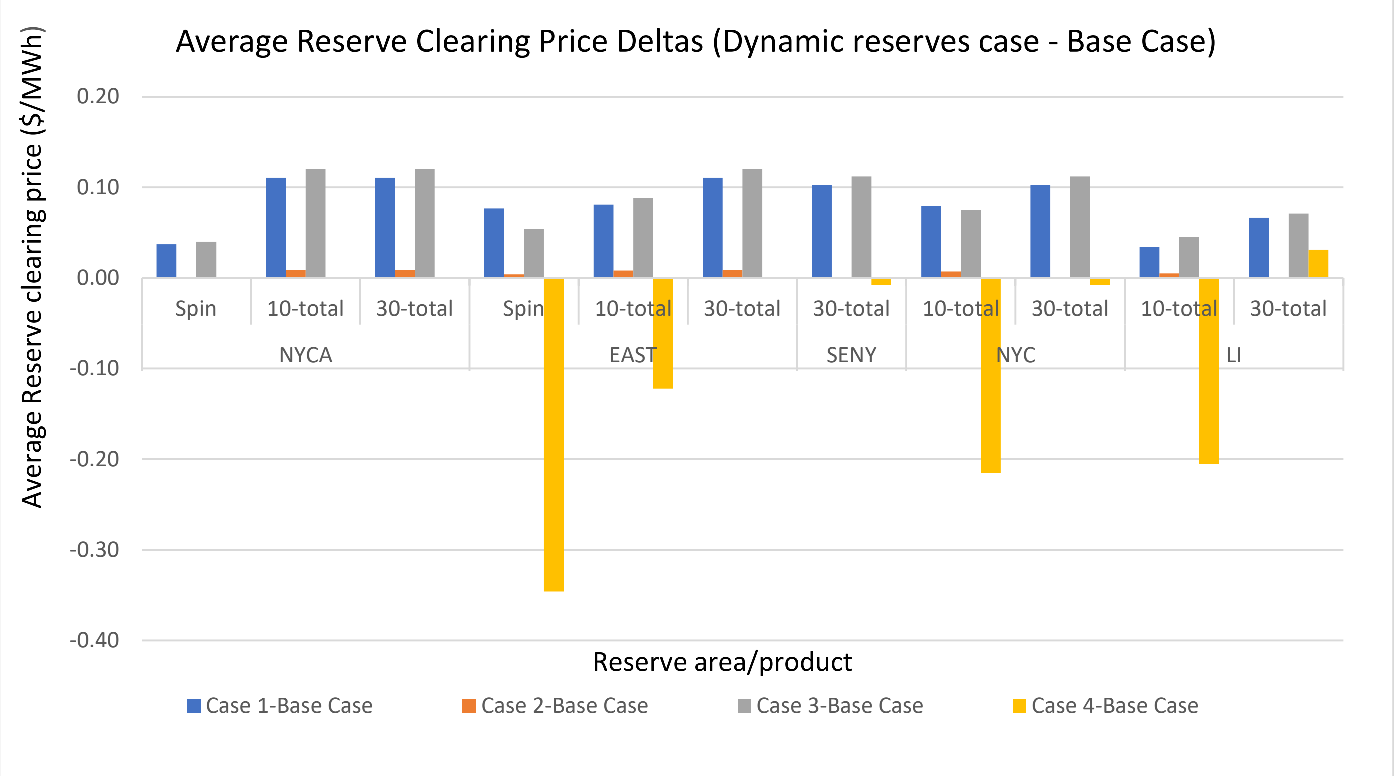
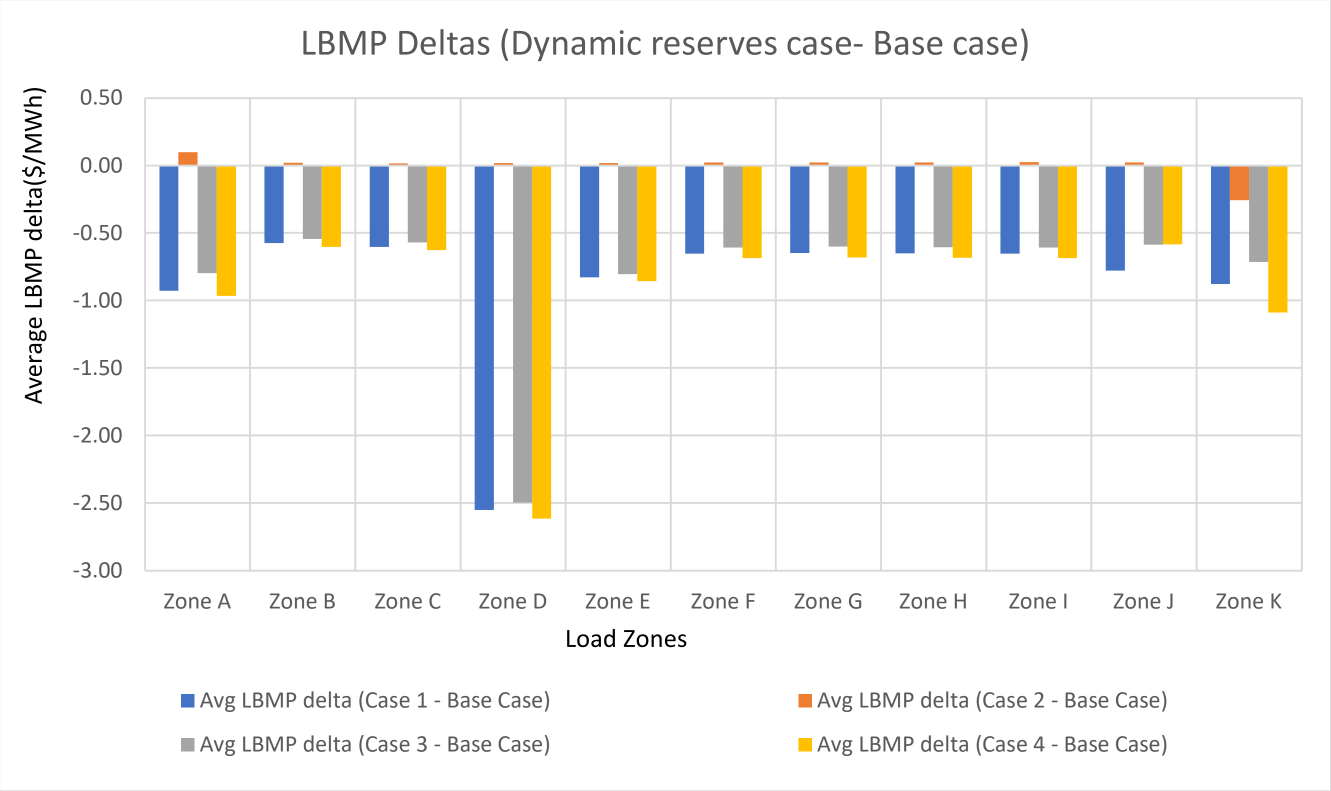


Figure 4: Change in LBMPs



Market day August 5, 2021, was used to re-run all the cases listed above. This day was selected because it was a hot summer day and incorporated the most recent changes that went into effect within the market software (*e.g.*, Ancillary Services Shortage Pricing, Reserves for Resource Flexibility). All four cases were run on this day for consistent comparison of results.

To establish a baseline or a benchmark, it is necessary to re-run a base case. The base case was run with static reserve requirements in all reserve areas and this same base case was used for all four scenarios. To simulate typical operating conditions, major transmission lines were put back in service if they were out of service on the actual market day (*i.e.*, Y-50 on Long Island). Further, the Upper Operating Limits (UOL) on three external transactions were increased to allow economic energy to flow into NYCA. By increasing the UOL on these transactions, the base case created more imports and, therefore, decreased the total system cost in the base case as compared to the previous production case.

Case 1: NYCA reserve requirements set dynamically

This case tested if the prototype would dynamically schedule energy above the current 1,310 MW from an individual resource when it is economic to do so, while also securing the reserves needed to cover for this contingency. This was accomplished by increasing interface limits on the HQ interface (SCH-HQ-Import-Export) to allow the optimization to import more energy over the HQ interface when it was economical to do so (*i.e.*, results in lower total production cost). In addition, the dynamic reserve constraints were activated only for the NYCA reserve area by setting the multipliers shown in equations (1) to (3) to 0.5, 1, and 2 for 10-minute spinning, 10-minute total and 30-minute total products, respectively. For all other reserve areas, static requirements were maintained. It is important to note that the Loss of Transmission equations do not apply to the NYCA reserve area because all external proxies are treated as internal generation in the market software.

As expected, energy was scheduled above 1,310 MW in the hours it was economic. To secure this increase, additional operating reserves were also scheduled. The savings from energy outweighed the additional cost of procuring reserves, thereby resulting in a lower total system cost as shown in Figure 2. On average, the LBMPs decreased between $0.60/MWh and $2.55/MWh in each load zone and reserve clearing prices increased by less than $0.10/MWh in every reserve area. Due to lower LBMPs, more price-capped load[18] was served.

Case 2: Southeastern New York (SENY) 30-minute reserve requirement set dynamically

This case tested if transmission constraints could be modeled dynamically. Specifically, if the prototype could make decisions to utilize the headroom of transmission interfaces to increase or decrease the reserve requirements in a reserve area. To test the effectiveness of the prototype on transmission constraints, it was important to select a reserve area that is currently modeled due to transmission limitations. Therefore, for this scenario dynamic reserve constraints were activated only in the SENY reserve area.19 Normal and Emergency limits of the transmission interface were used from an offline operations study for Summer 2021. For all other reserve areas, static requirements were maintained.

In this case, the prototype did not buy any additional reserves as the NYCA reserve requirements were maintained at their static value of 2,620 MW. However, an average of 200 additional MWs of 30-minute reserves were held in the SENY reserve area based on the economics of the offers and the transmission limitations. The changes in total production costs[20] were less than the tolerance utilized in the optimization and, therefore, the results for the production costs, LBMPs, and operating reserve clearing prices are insignificant (as shown in Figure 2 and 3 respectively).

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18. Load that does not want to pay more than a certain amount of price to be served

19. Currently, SENY only has 30-minute reserve requirements. Therefore, only these requirements were modeled dynamically as the prototype did not anticipate creation of new reserve requirements.

20. The total production costs increased slightly. However, this increase is insignificant because it is within the acceptable MIP gap of the software. This implies that the software stops iterating after it finds a good solution within a certain tolerance.

Case 3: NYCA and SENY 30-minute reserve requirements set dynamically

This case tested simultaneously solving of two reserve areas with the dynamic reserves prototype. Both the Loss of Generation Equations and Loss of Transmission equations were tested by activating dynamic reserves constraints in both these reserves areas. In NYCA, the reserve requirements are set by the loss of generation because all external proxies are treated as internal generation within the model. Consequently, in SENY, the reserve requirements are set by transmission limitations. This was accomplished by increasing interface limits for HQ interface (SCH-HQ-Import-Export) and setting appropriate emergency and normal interface limits on SENY in accordance with Case 2. In addition, the dynamic reserve constraints were activated for a) the NYCA reserve area by setting the multipliers shown in equations (1) to (3) to 0.5, 1 and 2 for 10-minute spinning, 10-minute total, and 30-minute total products respectively and b) the SENY reserve area by setting the 30-minute total multiplier shown in equation (3) to 2. In addition, the Loss of Transmission equation (11) was activated for the SENY reserve area. The Loss of Transmission equations do not apply to the NYCA reserve area because all external proxies are treated as internal generation within the market software. For all other reserve areas, static requirements were maintained.

The results were consistent with case 1. Specifically, in the hours it was economic, energy was scheduled above 1,310 MW. To secure this, additional operating reserves were also scheduled. The reduction in production cost was lower than in the case 1 because better modeling of transmission interface limits on SENY resulted in a more accurate solution. The savings from energy outweighed the additional cost of procuring reserves, thereby resulting in a lower total system production cost as shown in Figure 2. On average, the LBMPs decreased between $0.50/MWh and $2.50/MWh in every zone and reserve clearing prices increased by less than $0.10/MWh in every reserve area.

Case 4: Reserve requirements set dynamically for all reserve areas

This case tested applying the dynamic reserves prototype to all current reserve areas and reserve products. This was effectuated by increasing interface limits for the HQ interface (SCH-HQ-Import-Export) and activating dynamic constraints in all current reserve areas by setting the multipliers shown in equations (1) to (3) to:

a) 0.5, 1 and 2 for NYCA 10-minute spinning, NYCA 10-minute total and NYCA 30-minute total products respectively

b) 0.25, 1 and 2 for the EAST 10-minute spinning, EAST 10-minute total and EAST 30-minute total products respectively

c) 0, 0 and 2 for 2 for the SENY 10-minute spinning, SENY 10-minute total and SENY 30-minute total products respectively. The SENY reserve area only has a 30-minute requirement, therefore, the 10-minute spinning and 10-minute total multipliers are ‘0’.

d) 0, 1 and 2 for the NYC 10-minute spinning, NYC 10-minute total and NYC 30-minute total products respectively. The NYC reserve area only has a 10-minute total and 30-minute total requirement, therefore, the 10-minute spinning multiplier is ‘0’.

e) 0, 1 and 2 for the LI 10-minute spinning, LI 10-minute total and LI 30-minute total products respectively. The LI reserve area only has a 10-minute total and 30-minute total requirement, therefore, the 10-minute spinning multiplier is ‘0’.

All the interface limits were adjusted appropriately based on normal and emergency limits determined by an offline operations study.

The results of case 4 were comparable to cases 1 and 3, where, in the hours it was economic, energy was scheduled above 1,310 MW. To secure this, additional operating reserves were also scheduled. This case showed the largest decrease in total production cost. Most of the decrease can be attributed to better modeling of transmission capabilities on Long Island.[21] Allowing reserves scheduled on LI to count for reserve areas that LI is a part of based on current system topology allows the prototype to carry cheaper reserves on LI (*i.e.*, greater than the static reserve requirements) and, therefore, reduces the total system costs. The prototype dynamically scheduled reserves on LI to both secure LI and test against its exportability. The exportability was tested by limiting the portion of LI reserves that could count towards NYCA up to the current flow on the Y49 and Y50 lines. This change in modeling increased reserve schedules on LI and aided in securing the additional economic imports into NY from HQ.

On average, the LBMPs decreased between $0.60/MWh and $2.60/MWh in every zone and reserve clearing prices either decreased or changed insignificantly even though additional reserves were secured. This is attributed to the better modeling of LI, enabling a higher quantity of reserves to be scheduled on LI and deliverable to other reserve areas.

The prototype proves that on a typical day the static requirement can be modeled dynamically, while considering the greater of the loss of source contingency and the loss of transmission contingency. The dynamic modeling is more flexible as it can adapt to different topologies.

Shadow prices of operating reserves will be determined by the more binding equations (*i.e.*, loss or generation or loss of transmission) in a reserve area. Generally, in the DAM (SCUC) these costs are based

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[21] Because of transmission system limitations on LI where power can only flow in one direction, the maximum reserves from LI that can be counted towards other reserve areas are limited to backing imports into LI to ‘0 MW’.

on the offers and in real-time these costs are based on the lost opportunity of not providing energy.

Additional Considerations for Market Design Concept Proposed phase

The 2021 Dynamic Reserves study was focused on determining the feasibility and applicability of dynamically procuring reserve products, which are currently static, in the DAM and RTM. The prototype showed that this is feasible and should be explored further given the rapid transition of the grid necessitating added flexibility. However, prior to implementing the design, the following aspects should be considered and analyzed:

1) Interaction of the operating reserve demand curves (ORDCs) and transmission demand curves with dynamic reserve requirements: The current ORDCs, which are based on static requirements, are either a single step demand curve or multiple step demand curves that rely on defined requirements. Given the potential shift to dynamic reserve requirements, how should these demand curves now be modeled since there would be an interaction between transmission flows and reserves and, therefore, the interaction between the two needs to be understood better?
    a. Impacts that dynamic reserve requirements could have on Scarcity pricing: Current scarcity logic is complicated with the cascading of reserve areas and, therefore, will need further investigation.
2) Consideration of the implications of pricing outcomes on the market incentives and market power concerns. Specifically, since a resources' energy and reserves schedules could have a direct impact on the resulting reserve requirement, the pricing outcomes will need to avoid any perverse incentives for units to offer in a manner to increase reserve requirements more than would be economic.
3) Impacts on the RTM (RTC and RTD) solution with the dynamic reserves prototype: The prototype showed little impact on the DAM solution in SCUC with the limited amount tests run to date but will need stress testing of solution times on RTC and RTD to ensure performance is not diminished substantially.
4) Interaction of dynamic reserves model with new resource models such as CSR, and ESR: Are there compounding issues with dynamic reserves considering the current test did not include any of these resources?
5) Assessing interplay between dynamic reserves scheduling and additional reserve requirements (*e.g.,* supplemental reserves): While not accepted by FERC, how could new reserve

requirements/products work with this?

6) Disabling of the dynamic reserves requirements during Thunder Storm Alerts (TSAs).
    a. Currently, the static requirements are set to 0 MWs in SENY and, NYC. Further consideration in the handling of TSAs will be necessary.
7) Interaction of dynamic reserve modeling with the intermittent resource contingencies, whether loss of single resource or the correlated loss of energy across multiple resources: Currently the dynamic reserves prototype only contemplated reserve requirements based on the single largest source contingency or largest transmission contingency. However, given the rapidly evolving resource mix, the largest contingency in the future could potentially be correlated reduction in output by multiple generators (e.g., simultaneous reduction of offshore wind).

Given the transitioning grid and the expected increase in intermittent generation, to operate the future grid reliably, it will be vital to consider the effect of increased renewable generation not just from one single contingency but also the effect of multiple intermittent renewable resource contingencies (either partly/fully), especially since these resources do not currently have an obligation to offer into the DAM.

Conclusion

Dynamic scheduling of reserve requirements has the potential to support the Climate Leadership and Community Protection Act (CLCPA) by allowing more economic clean energy to be imported into the New York control area from external control areas (such as HQ). It also sets the stage to effectively account for and secure the potential increased offshore wind generation on LI by improving the modeling of LI transmission interface.

Based on testing the prototype under various scenarios, as detailed in the section of this report, the NYISO concludes that dynamically setting operating reserve requirements based on the single largest contingency system wide and using available transmission headroom is a feasible concept. This concept will need to be further developed and evaluated and its application to all reserve areas would need to be further tested. Further, the NYISO 's analysis was limited to a few DAM re-runs. While it is possible to extend the developed prototype to the RTM software, the implications on RTM solutions were not tested.

- Prototype showed that it is feasible to dynamically set reserve requirements based upon:
    - Largest scheduled unit(s) or proxy
    - Account for loss of scheduled reserves on the largest contingency
    - Transmission security

   - Available reserve import security

Recommendations

Recommendation 1: The NYISO should consider revising the approach for the determination of the single largest contingency from the current static requirement to a more dynamic methodology as demonstrated in the study formulation and prototype. This is especially relevant for the NYCA reserve area as all other reserve areas are cascaded within NYCA. This will result in scheduling of economic energy above 1,310 MW from individual suppliers when sufficient reserves are available.

Recommendation 2: As shown in Case 4 above, the highest production cost savings are realized when dynamic reserve constraints are activated simultaneously in all reserve areas. Therefore, the NYISO should consider applying the dynamic reserves approach that is developed in the prototype to all reserve areas.

Recommendation 3: The methodology to determine reserve requirements should be consistent between the Day-Ahead and Real-Time Markets to extent practical. This will allow for more accurately reflecting system topology, resource availability, and predicted flows across the transmission system.

Recommendation 4: Currently, reserve providers in the Long Island (LI) reserve region are paid based on the clearing prices for the larger Southeastern New York (SENY) reserve region due to market power concerns and operating constraints in Long Island. To meet NYS's renewable energy targets, large developments of offshore wind projects are being anticipated in the LI zone. It will be essential to have enough reserves within LI along with sufficient transmission capability to recover from the loss of intermittent output that is used to meet load on LI. To accomplish this, the wholesale markets should establish reserve prices for LI that properly reflect the value and associated cost of the reserves being procured within the LI zone. This is currently a State of the Market recommendation from Potomac Economics[22] and the NYISO has proposed this as a project, *Long Island Reserve Constraint Pricing*, to be pursued in future years. This project will evaluate whether revisions to current compensation rules are warranted to provide additional availability incentives for Long Island suppliers. This modeling enhancement is intended to better reflect the value of reserve capability on LI.

Recommendation 5: As stated in the study scope, the NYISO believes that the successful implementation of the More Granular Operating Reserves project is dependent on dynamic reserves (specifically, accounting for the transmission headroom so reserves can be held on lower cost resources

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[22] Refer to Recommendation 2019-1 from the 2020 SOM report

outside a reserve area when transmission headroom is available). The prototype developed a framework on implementing the dynamic reserves constraint in load pocket within NYC by considering the N-1-1-0 interface limits. Therefore, the NYISO may now consider pursuing the More Granular Operating Reserves project by extending the dynamic reserves concept to load pockets in NYC.

Recommendation 6: Consider expanding the methodology definition of source contingency to ensure it includes correlated source contingencies, such as simultaneous reduction of offshore wind, as the largest source contingency. There are challenges that exist with correlated source contingencies being accounted for as the largest contingency. Intermittent resources are not scheduled in the same manner as other resources and therefore additional information including intermittent forecasts and forecast confidence would need to be factored into determining the reserve requirement. Also, the loss of energy across multiple correlated intermittent units should also be accounted for in the determination of the reserve requirements. This is especially pertinent given the current goals for the development of offshore wind and other large intermittent resources within the state.

Appendix I: Mathematical Formulation Equations

Securing a Reserve Area for the Loss of Generation

Calculating the Actual Energy Flows in a Reserve Area:

$$RA_{a_{Flow_i}} = (RA_{a_{Load_i}} - RA_{a_{Gen_i}})$$

- RA_a is the applicable reserve area
- $RA_{a_{Flow_i}}$ is the actual energy flow into or out of reserve area a for time step i
    - $RA_{a_{Flow_i}}$ is positive into reserve area a
    - $RA_{a_{Flow_i}}$ is negative out of reserve area a
- Note: For the NYCA reserve area (Load Zones A-K), $RA_{a_{Flow_i}}$ value is equal to 0 MW because external proxies are evaluated as generators
- $RA_{a_{Load_i}}$ is the forecasted load[23] in reserve area a for time step i (Day-Ahead or real-time, as applicable)
- $RA_{a_{Gen_i}}$ is the sum of all energy schedules on resources inside reserve area a for time step i

Calculating the Available Transmission Headroom in a Reserve Area:

$$RA_{aRes_{Capability_i}} = RA_{a_{Limit_i}} - RA_{a_{Flow_i}}$$

- $RA_{aRes_{Capability_i}}$ is the capability to secure reserves external to reserve area *a* for time step *i*
- $RA_{a_{Limit_i}}$ is the pre-contingency normal limit for the reserve area *a* for time step *i*
    - Note: For the NYCA reserve area (Load Zones A-K), the RA_{Limit} value is equal to 0 MW because external proxies are evaluated as generators

Securing the Reserve Area for the Loss of a Generator

$$Res_{RA_{a_i}}^{10Spin} \geq Mult_{RA_a}^{10Spin} * \{\max_{k \in Gen_{RA_a}} \{gen_{k_i} + res_{k_i}^{10Total}\}\} - RA_{aRes_{Capability_i}}$$

$$Res_{RA_{a_i}}^{10Total} \geq Mult_{RA_a}^{10Total} * \{\max_{k \in Gen_{RA_a}} \{gen_{k_i} + res_{k_i}^{10Total}\}\} - RA_{aRes_{Capabilit}\ _i}$$

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[23] To effectively secure the system this value could potentially be the higher of a) bid load and b) forecast load

$$Res_{RA_{a_i}}^{30Total} \geq Mult_{RA_a}^{30Total} * \{\max_{k \in Gen_{RA_a}} \{gen_{k_i} + res_{k_i}^{30Total}\}\} - RA_{aRes_{Capability_i}}$$

Where;

- $\mathrm{Res}_{\mathrm{RA}_{a_i}}^{\mathrm{10Spin}}$ is the $10 - minute$ spinning reserve requirement in reserve area a for time step i
- $\mathrm{Res}_{\mathrm{RA}_{a_i}}^{\mathrm{10Total}}$ is the $10 - minute$ total reserve requirement in reserve area a for time step i
- $\mathrm{Res}_{\mathrm{RA}_{a_i}}^{\mathrm{30Total}}$ is the $30 - minute$ total reserve requirement in reserve area a for time step i
- $\max_{\mathrm{k \in Gen}_{RA_a}} \{gen_{k_i} + res_{k_i}^{10Total}\}$ is the resource in reserve area a for time step i with the largest energy plus 10-minute total reserve schedule; except NYCA, where it is the resource with the largest schedule (i.e., energy + reserves + regulation)
- $\max_{\mathrm{k \in Gen}_{RA_a}} \{gen_{k_i} + res_{k_i}^{30Total}\}$ is the resource in reserve area a for time step i with the largest energy plus 30-minute total reserve schedule; except NYCA, where it is the resource with the largest schedule (i.e., energy + reserves + regulation)
- $\mathrm{Mult}_{\mathrm{RA_a}}^{\mathrm{10Spin}}$ is the $10\ minute$ spin multiplier for reserve area a applied to the largest schedule where applicable
- $\mathrm{Mult}_{\mathrm{RA_a}}^{\mathrm{10Total}}$ is the $10\ minute$ total multiplier for reserve area a applied to the largest schedule where appicable
- $\mathrm{Mult}_{\mathrm{RA_a}}^{\mathrm{30Total}}$ is the $30\ minute$ total multiplier for reserve area a applied to the largest schedule where applicable

Securing a Reserve Area for the Loss of Transmission

Contingency Headroom on Interface

The difference between the applicable transfer limit[24] and the flow is the available import capability. When negative, this number represents a deficiency that needs to be held as reserves within the reserve area due to the lack of transmission headroom to import reserves.

$$10minute_{PostCon_{Import_{RA_{a_i}}}} = RA_{Flow_{a_i}} - Limit_{Emer(N-1)_{RA_{a_i}}}$$

$$30minute_{PostdualCo\ \ Import_{RA_{a_i}}} = RA_{Flow_{a_i}} - Limit_{Norm(N-1-1-0)_{RA_{a_i}}}$$

$$30minute_{PostCon_{Import_{RA_{a_i}}}} = RA_{Flow_{a_i}} - Limit_{Norm_{RA_{a_i}}}$$

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[24] 24. All limits will be calculated via an offline study by NYISO Operations

- $10\mathrm{minute}_{\mathrm{PostCon}_{\mathrm{Import}_{\mathrm{RA}_{a_i}}}}$ is the applicable post-contingency transfer limit of reserve area a for time step i that the flow should be under within 10 minutes
- $30\mathrm{minute}_{\mathrm{PostCon}_{\mathrm{Import}_{\mathrm{RA}_{a_i}}}}$ is the applicable post-contingency transfer limit of reserve area a for time step i that the flow should be under within 30 minutes
- $30minute_{PostdualCon_{Import_{RA_{a_i}}}}$ is the applicable post dual contingency transfer limit of reserve area a for time step i that the flow should be under within 30 minutes
- $\mathrm{Limit}_{\mathrm{Emer(N-1)}_{\mathrm{RA}_{a_i}}}$ is the emergency transfer limit for single contingency of reserve area a for time step i, depending on the applicable reliability rules to determine the need for 10 minute or 30-minutes reserves
- $\mathrm{Limit}_{\mathrm{Norm(N-1-1-0)}_{\mathrm{RA}_{a_i}}}$ is the normal transfer limit for dual contingency of reserve area a for time step i, depending on the applicable reliability rules to determine the need for 30-minutes reserves
- $\mathrm{Limit}_{\mathrm{Norm}_{\mathrm{RA}_{a_i}}}$ is the normal transfer limit of reserve area a for time step i, depending on the applicable reliability rules to determine the need for 30-minutes reserves

Securing the Reserve Area for the Loss of Transmission

$$Res_{RA_{a_i}}^{10Spin} \geq Mult_{\mathrm{RA}_a}^{10Spin} * (10minute_{PostCon_{Import_{RA_{a_i}}}})$$

$$Res_{RA_{a_i}}^{10Total} \geq (10minute_{PostCon_{Import_{RA_{a_i}}}})$$

$$Res_{RA_{a_i}}^{30Total} \geq \left(30minute_{PostCon_{Import_{RA_{a_i}}}}\right)$$

$$Res_{RA_{a_i}}^{30Total} \geq \left(30minute_{PostDualC\quad Im\quad RA_{a_i}}\right)$$

Tying Loss of Generation and Loss of Transmission Together

Simultaneous Constraints for 10-minute spinning reserves:

$$Res_{RA_{a_i}}^{10Spin} \geq Mult_{\mathrm{RA}_a}^{10Spin} * \{\max_{\mathrm{k}\in\mathrm{Gen}_{RA_a}} \{gen_{k_i} + res_{k_i}^{10SP}\}\} - RA_{aRes_{Capabilit}\ i}$$

$$Res_{RA_{a_i}}^{10Spin} \geq -\mathrm{Mult}_{\mathrm{RA_a}}^{\mathrm{10Spin}} * (10minute_{PostCon_{Impo}\ RA_{a_i}})$$

The more restrictive of the two equations will determine the applicable requirement for the reserve area.

Simultaneous Constraints for 10-minute total reserves:

$$Res_{RA_{a_i}}^{10Total} \geq Mult_{\mathrm{RA}_a}^{10Total} * \{\max_{\mathrm{k}\in\mathrm{Gen}_{RA_a}} \{gen_{k_i} + res_{k_i}^{10Total}\}\} - RA_{aRes_{Capability_i}}$$

$$Res_{RA_{a_i}}^{10Total} \geq -(10minute_{PostCon_{Impor}\ RA_{a_i}})$$

The more restrictive of the two equations will determine the applicable requirement for the reserve area.

Simultaneous Constraints for 30-minute total reserves:

- Securing for loss of source contingency with a security multiplier:
$$Res_{RA_{a_i}}^{30Total} \geq \mathrm{Mult}_{\mathrm{RA_a}}^{\mathrm{30Total}} * \{\max_{\mathrm{k}\in\mathrm{Gen}_{RA_a}} \{\mathrm{gen}_{k_i} + res_{k_i}^{30Total}\}\} - RA_{aRes_{Capabilit}\ i}$$
- Securing for one source contingency and N-1 transmission contingency:
$$Res_{RA_{a_i}}^{30Total} \geq \{\max_{\mathrm{k}\in\mathrm{Gen}_{RA_a}} \{\mathrm{gen}_{k_i} + res_{k_i}^{30Total}\}\} - RA_{aRes_{Capability_i}} + \left(30minute_{PostC\ \ Impor\ RA_{a_i}} - 10minute_{PostCon_{Import_{RA_{a_i}}}}\right)$$
- Secure transmission for N-1 to normal transfer capability:
$$Res_{RA_{a_i}}^{30Total} \geq -\left(30minute_{PostCon_{Imp}\ \ RA_{a_i}}\right)$$
- Secure transmission for N-1-1-0 to normal transfer capability (applies to NYC and NYC load pockets):
$$Res_{RA_{a_i}}^{30Total} \geq -\left(30minute_{PostdualCon_{Import_{RA_{a_i}}}}\right)$$

The more restrictive of the four equations will determine the applicable requirement for the reserve area.

Appendix II: Examples

Example 1: Securing Operating Reserves for Loss of Generation in a Reserve Area

Assumptions for Example:

- Three resources (G1, G2 and G3) exist within a reserve area
    - G1: Energy schedule = 100 MW; 10-minute total reserve schedule = 50 MW; 30-minute total reserve schedule = 25 MW; UOL = 200 MW
    - G2: Energy schedule = 50 MW; 10-minute total reserve schedule = 25 MW; 30-minute total reserve schedule = 30 MW; UOL = 150 MW
    - G3: Energy schedule = 150 MW; 10-minute total reserve schedule = 0 MW; 30-minute total reserve schedule = 0 MW; UOL = 150 MW
- Transmission line importing power into reserve area
    - Pre-contingency transfer limit[25] = 100 MW; Current flow = 50 MW
- The reserve area has the following security multipliers:
    - 10-minute spinning reserves: 0.25
    - 10-minute total reserves: 1
    - 30-minute total reserves: 2

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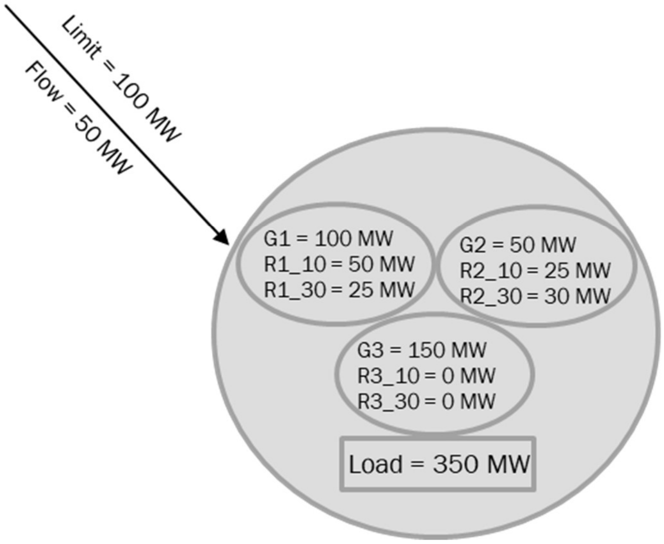
[25] For the purpose of these examples, the following definitions are used:

- Pre-contingency flow: Calculated interface flow before any contingency occurs and should remain the same immediately post-contingency as no redispatch is calculated in this, by design. Reserves are scheduled to allow for that redispatch.
- Pre-contingency normal limit: Current scheduled interface topology's normal transfer capability
- Post-contingency emergency limit: Interface transfer emergency limit reflecting the worst single contingency from the current scheduled interface topology
- Post-contingency normal limit: Interface transfer normal limit reflecting the worst single contingency from the current scheduled interface topology

Figure 5 Illustration for Example 1



Solution:

1) **G1:** Energy + 10-minute total reserve schedule = 100 MW + 50 MW = 150 MW; Energy + 10-minute total reserve schedule + 30-minute total reserve schedule = 100 MW + +50 MW + 25 MW = 175 MW

   G2: Energy + 10-minute total reserve schedule = 50 MW + 25 MW = 75 MW; Energy + 10-minute total reserve schedule + 30-minute total reserve schedule = 50 MW + 25 MW + 30 MW = 105 MW

   G3: Energy + 10-minute total reserve schedule = 150 MW+ 0 MW = 150 MW; Energy + 10-minute total reserve schedule + 30-minute total reserve schedule = 150 MW + 0 MW + 0 MW= 150 MW

2) Single largest source contingency for 10-minute total and 10-minute spinning reserves = max (150 MW, 75 MW, 150 MW) = 150 MW

3) Single largest source contingency for 30-minute total reserves = max (175 MW, 105 MW, 150 MW) = 175 MW

4) Available transmission headroom = 100 MW – 50 MW = 50 MW

   - **10-minute spinning reserve requirement in reserve area:**

     = (10-minute spinning multiplier * Largest source contingency) – transmission headroom

     = 0.25 *150 MW – 50 MW

= 37.5MW - 50MW = -12.5 MW < 0 MW (As there is available transmission headroom, the spinning reserve requirement for this interval is 0 MW)

- **10-minute total reserve requirement in reserve area:**

  = (10-minute total multiplier * Largest source contingency) – transmission headroom

  = (1*150 MW) – 50 MW

  = 100 MW

- **30-minute total reserve requirement in reserve area:**

  = (30-minute total multiplier * Largest source contingency) – transmission headroom

  = (2*175 MW) – 50 MW

  = 300 MW

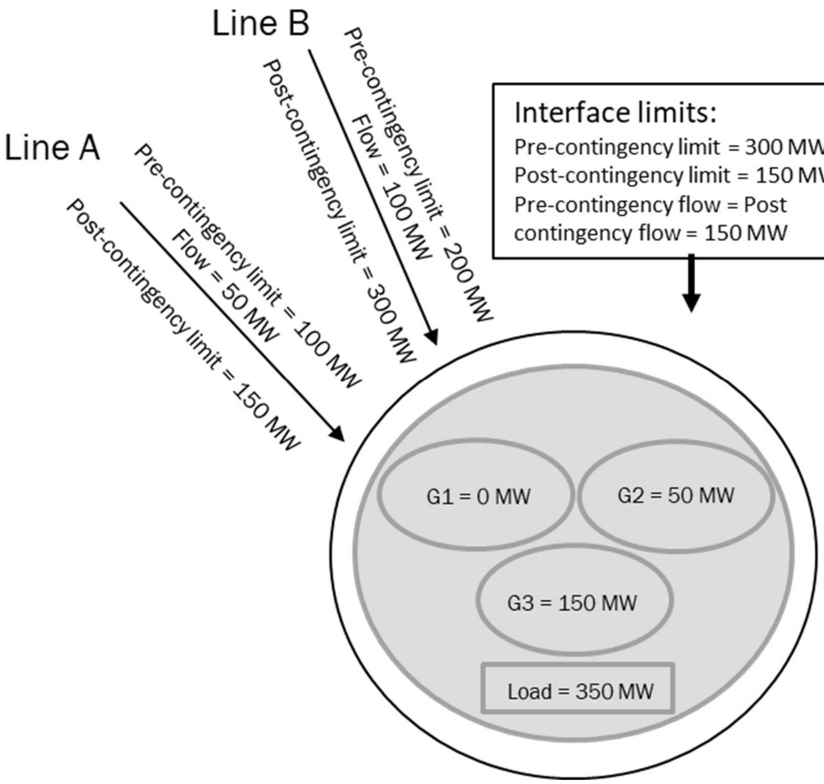
Example 2: Securing Operating Reserves for Loss of Transmission in a Reserve Area

Assumptions for Example:

- Three resources (G1, G2 and G3) exist within a reserve area:
  - G1: Energy schedule = 0 MW; UOL = 100 MW
  - G2: Energy schedule = 50 MW; UOL = 200 MW
  - G3: Energy schedule = 150 MW; UOL = 150 MW
- The reserve area has the following security multipliers:
  - 10-minute spinning reserves: 0.25
  - 10-minute total reserves: 1
  - 30-minute total reserves: 2

- Limits/flows on transmission lines importing power into the reserve area:
    - Line A: Pre-contingency transfer limit = 100 MW; Current flow = 50 MW; Post-contingency transfer limit = 150 MW
    - Line B: Pre-contingency transfer limit = 200 MW; Current flow = 100 MW; Post-contingency transfer limit = 300 MW
    - Total interface limits: Pre-contingency transfer limit = 300 MW; Pre-contingency flow = post-contingency flow = 150 MW

Figure 6: Illustration of Example 2



Solution:

1) Largest transmission contingency is Line B as this is the line with the largest pre-contingency limit that reduces the interface transfer capability.

2) For loss of Line B, post-contingency flow on Line A = 50 MW + 100 MW = 150 MW, which is equal to the pre-contingency flow as this example represents a closed interface which would not be redispatched.

- **10-minute spinning reserve requirement in reserve area:**

  = 10-minute spinning multiplier * (Post-contingency flow (A)- Post-contingency transfer limit)

  = 0.25* (150 MW – 150 MW) = 0 MW

- **10-minute total reserve requirement in reserve area:**

  = Post-contingency flow(A) - Post-contingency transfer limit(A)

  = 150 MW - 150 MW = 0 MW

- **30-minute total reserve requirement in reserve area:**

  = Post-contingency flow(A) - Pre-contingency transfer limit (A)

  = 150 MW - 100 MW

  = 50 MW

Example 3: Securing Operating Reserves in a Reserve Area by considering both Loss of Generation and Loss of Transmission

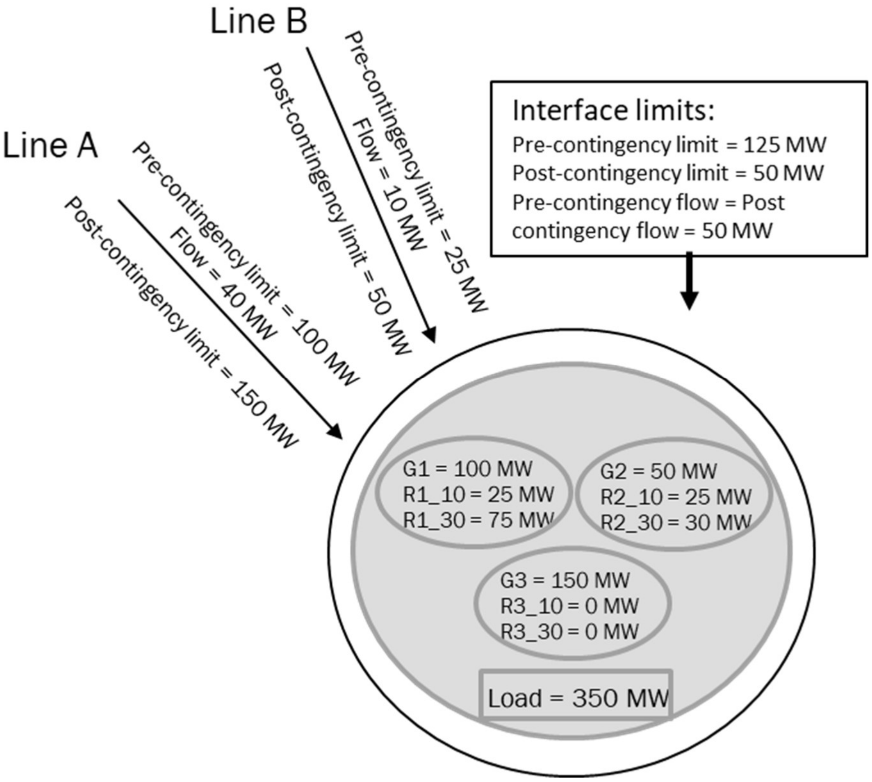
Assumptions for Example:

- Three resources (G1, G2 and G3) exist within a reserve area
  - G1: Energy schedule = 100 MW; 10-minute total reserve schedule = 25 MW; 30-minute total reserve schedule = 75 MW; UOL = 200 MW
  - G2: Energy schedule = 50 MW; 10-minute total reserve schedule = 25 MW; 30-minute total reserve schedule = 30 MW; UOL = 150 MW
  - G3: Energy schedule = 150 MW; 10-minute total reserve schedule = 0 MW; 30-minute total reserve schedule = 0 MW; UOL = 150 MW
- The reserve area has the following security multipliers:
  - 10-minute spinning reserves: 0.25
  - 10-minute total reserves: 1
  - 30-minute total reserves: 2
- Limits/flows on transmission lines importing power into the reserve area:
  - Line A: Pre-contingency transfer limit = 100 MW; Current flow = 40 MW; Post-

contingency transfer limit = 150 MW

- Line B: Pre-contingency transfer limit = 25 MW; Current flow = 10 MW; Post-contingency transfer limit = 50 MW
- Total interface limits: Pre-contingency transfer limit = 125 MW; Pre-contingency flow = post-contingency flow = 50 MW

Figure 7: Illustration of Example 3



Solution:

1) **G1:** Energy + 10-minute total reserve schedule = 100 MW+ 25 MW = 125 MW; Energy + 10-minute total reserve schedule + 30-minute total reserve schedule = 100 MW + 25 MW+ 75 MW = 200 MW

   G2: Energy + 10-minute total reserve schedule = 50 MW + 25 MW = 75 MW; Energy + 10-minute total reserve schedule + 30-minute total reserve schedule = 50 MW + 25 MW+ 30 MW = 105 MW

   G3: Energy + 10-minute total reserve schedule = 150 MW+ 0 MW = 150 MW; Energy + 10-minute total reserve schedule + 30-minute total reserve schedule = 150 MW + 0 MW + 0 MW = 150 MW

2) Single largest source contingency for 10-minute total and 10-minute spinning reserves

3) = max (125 MW, 75 MW, 150 MW) = 150 MWSingle largest source contingency for 30-minute total reserves

= max (200 MW, 105 MW, 150 MW) = 200 MW

4) Available transmission headroom = (100 MW – 40 MW) + (25 MW – 10 MW) = 75 MW

- **10-minute spinning reserve requirement for loss of generation in reserve area:**

  = (10-minute spinning multiplier * Largest source contingency) – transmission headroom

  = (0.25*150 MW) – 75 MW = -37.5 MW < 0MW (As there is available transmission headroom, the spinning reserve requirement for this interval is 0 MW)

- **10-minute total reserve requirement for loss of generation in reserve area:**

  = (10-minute total multiplier * Largest source contingency) – transmission headroom

  = (1*150 MW) – 75 MW = 75 MW

- **30-minute total reserve requirement for loss of generation in reserve area:**

  = (30-minute total multiplier * Largest source contingency) – transmission headroom

  = (2*200 MW) – 75 MW

  = 315 MW

5) Largest transmission contingency is Line A as this is the line with the largest pre-contingency limit that reduces the interface transfer capability.

6) For loss of Line A, post-contingency flow on Line B = 40 MW + 10 MW = 50 MW, which is equal to the pre-contingency total interface flow, as this example represents a closed interface which would not be redispatched.

  - **10-minute spinning reserve requirement for loss of transmission in reserve area:**

    = 10-minute spinning multiplier * (Post-contingency flow (B)- Post-contingency transfer limit(B))

    = 0.25 * (50 MW – 50 MW) = 0 MW

  - **10-minute total reserve requirement for loss of transmission in reserve area:**

    = Post-contingency flow(B) – Post-contingency transfer limit(B)

    = 50 MW - 50 MW

= 0 MW

- **30-minute total reserve requirement for loss of transmission in reserve area:**

  = Post-contingency flow (B) - Pre-contingency transfer limit(B)

  = 50 MW - 25 MW

  = 25 MW

- **30-minute total reserve requirement for both loss of generation and transmission in reserve area:**

  = Largest source contingency – transmission headroom + Post-contingency transfer limit (B) - Pre-contingency transfer limit(B)

  = 200 MW -75 MW + 50 MW – 25 MW

  = 150 MW

7) The more limiting of the Loss of Generation and Loss of Transmission determines the applicable 10-minute spinning and 10-minute total reserve requirements
   a. 10-minute spinning reserve requirement = max (Loss of Generation, Loss of Transmission)
      i. Loss of Generation requirement = 0 MW
      ii. Loss of Transmission requirement = 0 MW
   b. 10-minute total reserve Requirement = max (Loss of Generation, Loss of Transmission)
      i. Loss of Generation requirement = 75 MW
      ii. Loss of Transmission requirement = 0 MW
8) The more limiting of the Loss of Generation, Loss of Transmission and both Loss of Generation and Loss of Transmission determines the applicable 30-minute total reserve requirement
   a. 30-minute reserve Requirement = max (Loss of Generation, Loss of Transmission, Loss of Generation and Loss of Transmission)
      i. Loss of Generation requirement = 315 MW
      ii. Loss of Transmission requirement = 25 MW
      iii. Loss of Generation and Transmission = 150 MW

9) In this scenario, the 10-minute spinning reserve requirement is 0 MW

10) In this scenario, the more limiting 10-minute total requirement is for the Loss of Generation

    a. max (75 MW, 0 MW) = 75 MW

11) In this scenario, the more limiting 30-minute total requirement is for the Loss of Generation

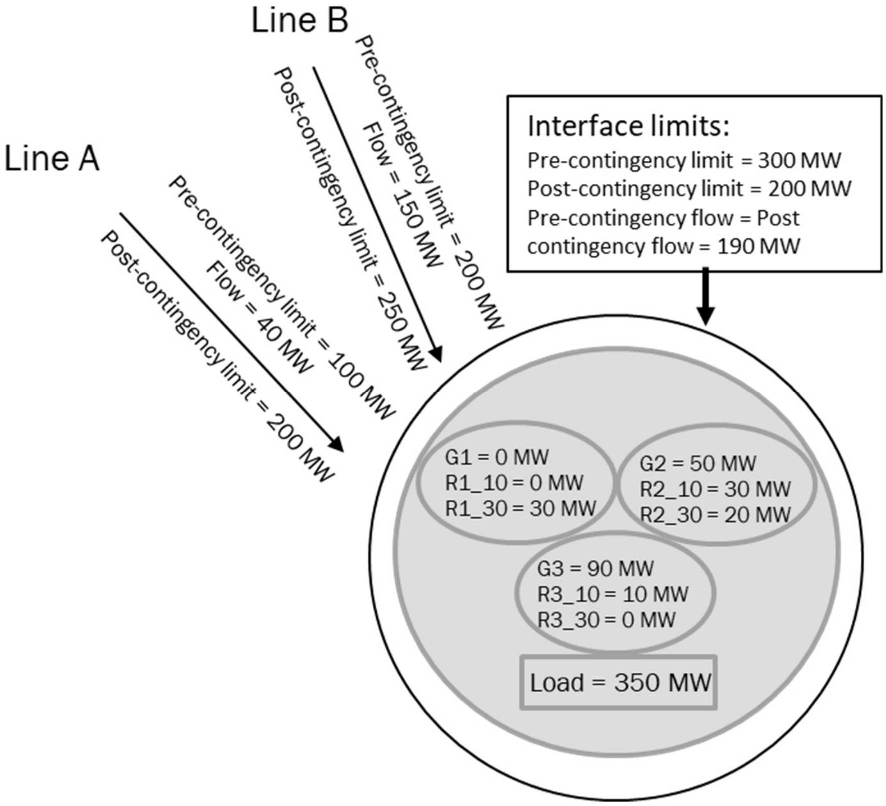
    a. max (315 25 MW, 150 MW) = 315 MW

Example 4: Securing Operating Reserves in a Reserve Area by considering both Loss of Generation and Loss of Transmission

Assumptions for Example:

- Three resources (G1, G2 and G3) exist within a reserve area
    - G1: Energy schedule = 0 MW; 10-minute total reserve schedule = 0 MW; 30-minute total reserve schedule = 30 MW; UOL = 30 MW
    - G2: Energy schedule = 50 MW; 10-minute total reserve schedule = 30 MW; 30-minute total reserve schedule = 20 MW; UOL = 100 MW
    - G3: Energy schedule = 90 MW; 10-minute total reserve schedule = 10 MW; 30-minute total reserve schedule = 0 MW; UOL = 100 MW
- The reserve area has the following security multipliers:
    - 10-minute spinning reserves: 0.25
    - 10-minute total reserves: 1
    - 30-minute total reserves: 2
- Limits/flows on transmission lines importing power into the reserve area:
    - Line A: Pre-contingency transfer limit = 100 MW; Current flow = 40 MW; Post-contingency transfer limit = 200 MW
    - Line B: Pre-contingency transfer limit = 200 MW; Current flow = 150 MW; Post-contingency transfer limit = 250 MW
    - Total interface limits: Pre-contingency transfer limit = 300 MW; Pre-contingency flow = post-contingency flow = 190 MW

Figure 8: Illustration of Example 4



Solution:

1) **G1:** Energy + 10-minute total reserve schedule = 0 MW+ 0 MW = 0 MW; Energy + 10-minute total reserve schedule + 30-minute total reserve schedule = 0 MW +0 MW + 30 MW = 30 MW

   G2: Energy + 10-minute total reserve schedule = 50 MW+ 30 MW = 80 MW; Energy + 10-minute total reserve schedule + 30-minute total reserve schedule = 50 MW + 30 MW+ 20 MW = 100 MW

   G3: Energy + 10-minute total reserve schedule = 90 MW+ 10 MW = 100 MW; Energy + 10-minute total reserve schedule + 30-minute total reserve schedule = 90 MW + 10 MW+ 0 MW = 100 MW

2) Single largest source contingency for 10-minute total and 10-minute spinning reserves

   = max (0 MW, 80 MW, 100 MW) = 100 MW

3) Single largest source contingency for 30-minute total reserves

   = max (30 MW, 100MW, 100 MW) = 100 MW

4) Available transmission headroom = (100 MW – 40 MW) + (200 MW – 150 MW) = 110 MW

- **10-minute spinning reserve requirement for loss of generation in reserve area:**

  = (10-minute spinning multiplier * Largest source contingency) – transmission headroom

  = (0.25*100 MW) – 110 MW = -85 MW < 0MW

  Note: As there is available transmission headroom, the spinning reserve requirement for loss of generation in this interval is 0 MW

- **10-minute total reserve requirement for loss of generation in reserve area:**

  = (10-minute total multiplier * Largest source contingency) – transmission headroom

  = (1*100 MW) – 110 MW = -10 MW < 0 MW

  Note: As there is available transmission headroom, the spinning reserve requirement for loss of generation in this interval is 0 MW

- **30-minute total reserve requirement for loss of generation in reserve area:**

  = (30-minute total multiplier * Largest source contingency) – transmission headroom

  = (2*100 MW) – 110 MW

  = 90 MW

5) Largest transmission contingency is Line B as this is the line with the largest pre-contingency limit that reduces the interface transfer capability.

6) For loss of Line B, post-contingency flow on Line A = 40 MW + 150 MW = 190 MW, which is equal to the pre-contingency total interface flow, as this example represents a closed interface which would not be redispatched.

- **10-minute spinning reserve requirement for loss of transmission in reserve area:**

  = 10-minute spinning multiplier * (Post-contingency flow (A)- Post-contingency transfer limit(A))

  = 0.25 * (190 MW – 200 MW) = -2.5 MW < 0 MW

- **10-minute total reserve requirement for loss of transmission in reserve area:**

  = Post-contingency flow(A) – Post-contingency transfer limit(A)

  = 190 MW - 200 MW

= -10 MW < 0 MW

- **30-minute total reserve requirement for loss of transmission in reserve area:**

  = Post-contingency flow (A) - Pre-contingency transfer limit(A)

  = 190 MW - 100 MW

  = 90 MW

- **30-minute total reserve requirement for both loss of generation and transmission in reserve area:**

  = Largest source contingency – transmission headroom + Post-contingency transfer limit (A) - Pre-contingency transfer limit(A)

  = 100 MW -110 MW + 200 MW – 100 MW

  = 90 MW

7) The more limiting of the Loss of Generation and Loss of Transmission determines the applicable 10-minute spinning and 10-minute total reserve requirements
   a. 10-minute spinning reserve requirement = max (Loss of Generation, Loss of Transmission)
      i. Loss of Generation requirement = 0 MW
      ii. Loss of Transmission requirement = 0 MW
   b. 10-minute total reserve Requirement = max (Loss of Generation, Loss of Transmission)
      i. Loss of Generation requirement = 0 MW
      ii. Loss of Transmission requirement = 0 MW
8) The more limiting of the Loss of Generation, Loss of Transmission and both Loss of Generation and Loss of Transmission determines the applicable 30-minute total reserve requirement
   a. 30-minute reserve Requirement = max (Loss of Generation, Loss of Transmission, Loss of Generation and Loss of Transmission)
      i. Loss of Generation requirement = 90 MW
      ii. Loss of Transmission requirement = 90 MW
      iii. Loss of Generation and Transmission = 90 MW

9) In this scenario, the 10-minute spinning reserve requirement and 10-minute total reserve requirement are both 0 MW.

10) In this scenario, the 30-minute total requirement is the same for Loss of Generation, Loss of Transmission, and Loss of Generation and Transmission.

    a. max (90 MW, 90 MW, 90 MW) = 90 MW