Interface Congestion Management in Load Pockets Using Dynamic Nodal Reserve Modeling

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***Abstract*— Load pockets, such as New York City (NYC), are often subject to interface congestion due to limited internal generation and heavy reliance on power imports. In systems with nested reserve zone structures, static zonal reserve (SZR) requirements fail to capture real-time system conditions, often leading to inefficient reserve allocation, uniform zonal pricing, and limited post-contingency flexibility. To address these shortcomings, this paper leverages a dynamic nodal reserve (DNR) framework that endogenously determines reserve requirements within the optimization process, considering the impact of reserve deployment on post-contingency flows. The model is implemented in a day-ahead security-constrained unit commitment (SCUC) formulation using the New York Independent System Operator (NYISO) grid as a case study. Numerical results show that DNR dynamically adjusts reserve quantities with system conditions, procures reserves from resources most effective in alleviating congestion, produces differentiated nodal prices, and more effectively manages interface congestion in load-pocket areas.**

***Index Terms*—Ancillary services, congestion management, dynamic reserve, load pocket, nodal reserve requirements.**

NOMENCLATURE

Sets:

I	Set of generators, $i \in I$.
I_z	Set of generators in zone z.
J	Set of buses, $j \in J$.
T	Set of time intervals, $t \in T$.
TC	Set of transmission constraints, $tc \in TC$.
DRC	Set of dynamic reserve constraints, $drc \in DRC$.
Z	Set of reserve zones, $z \in Z$.

Parameters (index t denotes time interval):

$D_{j,t}$	Load at load bus j.
$L_{tc,t}$	Line limit for transmission constraint tc.
$L_{drc,t}$	Line limit for reserve constraint i.
$SF_{tc,i/j,t}$	Shift factor of generator i/load bus j for transmission constraint tc.
$SF_{drc,i/j,t}$	Shift factor of generator i/load bus j for reserve constraint drc.
$RQ^z_{10S/10T/30T,t}$	10Spin/10Total/30Total reserve requirements in zone z.

Variables (index t denotes time interval):

$e_{i,t}$	Energy schedules for generator i.
${g_t}^{1stL/2ndL}$	First-/second-largest generation contingency.
$r_{i,10S/10T/30T,t}$	10Spin/10Total/30Total reserve schedules for generator i in zone z.

Prices and Shadow Prices (index t denotes time interval):

$LMORP_{i,10S/10T/30T,t}$	10Spin/10Total/30Total LMORP for generator i.
$MCP^z_{10S/10T/30T,t}$	10Spin/10Total/30Total MCP for zone z.
$\alpha^z_{10S/10T/30T,t}$	10Spin/10Total/30Total constraint shadow price for zone z.
$\alpha^s_{10S/10T/30T,t}$	10Spin/10Total/30Total system-wide constraint shadow price.
$\mu^{LossT}_{drc,t}$	Shadow price of DRC for loss of transmission.
$\mu^{LossTG}_{drc,t}$	Shadow price of DRC for Loss of transmission and generation.

I. INTRODUCTION

A load pocket is a geographically constrained region where electricity demand is high, but local generation capacity is limited, making the area highly dependent on power imports from outside regions. New York City (NYC) is a prime example of such a load pocket. One of the key operational issues in managing a load pocket is congestion on the transmission interface. Congestion occurs when the limits of the transmission network restrict the flow of power into the load pocket, preventing lower-cost resources from being fully utilized and creating a bottleneck between external supply resources and internal demand. Economically, congestion raises marginal energy and ancillary service prices by dispatching a local expensive unit or by activating facility demand curves and increasing congestion rent. Operationally, congestion reduces system flexibility, limiting the ability to dispatch the most efficient resources. Reliability risks are also heightened, since the load pocket's dependence on a limited set of internal and external resources makes it vulnerable to contingencies such as generator or transmission failures.

Interface congestion can also necessitate out-of-market (OOM) interventions by system operators, which undermine market efficiency and contribute to price volatility. The New York Independent System Operator (NYISO) had to use OOM interventions on 238 days in 2024 to manage congestion in NYC [1]. One potential approach to mitigating interface congestion is the deployment of internal reserves, which can reduce reliance on imports into the pocket. However, procuring reserves based on zonal requirements may not be effective for post-contingency reliability as zonal procurement relies on aggregated shift factors that dilute locational deliverability. Moreover, zonal procurement produces reserve market clearing prices (MCPs), that may not adequately compensate operating reserve providers for their role in managing congestion. By contrast, nodal reserve procurement can allocate reserves from resources with the greatest impact on congestion relief, while also producing more accurate and efficient MCPs that provide

979-8-3315-8138-1

clear pricing signals to incentivize resources contributing to interface congestion relief. In addition, NYISO must ensure that, under a contingency, no transmission facility exceeds its Long-Term Emergency (LTE) rating, which represents the maximum allowable flow that can be sustained for up to four hours. Availability of operating reserves in NYC allows the grid operator to increase flows on the interface transmission lines into NYC without violating the transfer criteria for post-contingency flow. By leveraging internal reserves, NYISO can operate transmission facilities up to their Mid-Term Emergency (MTE) rating, which represents the maximum allowable capacity for fifteen minutes, thereby increasing the effective transfer capability into load pockets.

Ref [2] proposed a framework for post-zonal reserve deployment transmission constraints, designed to account for the largest contingency within each reserve zone. The method explicitly models post-contingency flows on selected interfaces by incorporating the effect of reserve deployment. In doing so, it allows zonal reserve requirements to be optimally allocated within the market process. Nevertheless, the formulation assumes that all nodes within a reserve zone share a uniform aggregated sensitivity to interface flows, which can lead to inaccuracies as system conditions evolve. Recognizing these limitations, the Pennsylvania–New Jersey–Maryland (PJM) Interconnection has proposed a sub-zonal reserve structure intended to improve spatial precision in reserve allocation. This structure aims not only to strengthen deliverability but also to produce more efficient and granular price signals [3].

The NYISO designs its reserve zones in a nested structure, with NYC placed in the innermost layer to ensure that sufficient reserves are procured locally, even when those reserves are more expensive than resources in outer zones. Moreover, reserves procured in inner layers can be exported to satisfy requirements in outer layers. This design maintains system reliability when interface transmission constraints limit the ability to import power into NYC. Zonal reserve requirements for the NYC zone can be predefined as static values, similar to the approach in [4]. However, static requirements do not reflect real-time operating conditions and may lead either to over-procurement, imposing unnecessary costs, or under-procurement, leaving the system vulnerable during contingencies. To address this limitation, [5] models zonal reserve requirements as decision variables within the optimization process, allowing requirements to be adjusted dynamically based on system conditions. Nonetheless, that approach does not incorporate nested reserves, nor does it extend to nodal-level requirements.

This paper advances the literature by studying interface congestion management for load pockets under nested reserve zones using dynamic nodal requirements, an area not previously explored. In this study, dynamic reserve requirements are determined endogenously within the optimization process, ensuring that sufficient reserves are procured inside the load pocket to maintain reliability under the contingency of a transmission interface. By doing so, the procured reserves provide operators with confidence to operate interface lines at their higher MTE ratings rather than LTE ratings, effectively increasing usable interface capacity.

The remainder of this paper is organized as follows. Section II discusses the modeling of static and dynamic reserve requirements. Section III presents the numerical results, and Section IV concludes the paper.

II. Static and Dynamic Reserve Requirements Modeling

Event-based operating reserve products represent the portion of active power capacity that can be deployed above scheduled energy to maintain system balance in response to contingencies. The response time and operational status of reserve resources define the different types of operating reserves. In this study, three categories of reserves are considered as follows:

- 10-minute spinning reserve (10Spin): Provided by synchronized units capable of ramping up and delivering the deployed reserve within 10 minutes.
- 10-minute total reserve (10Total): Provided by all resources eligible for 10Spin, plus offline units that can start up, synchronize, and inject the deployed reserve within 10 minutes.
- 30-minute total reserve (30Total): Provided by synchronized units capable of ramping up and delivering the deployed reserve within 30 minutes, as well as offline units that can start up, synchronize, and inject the deployed reserve within 30 minutes.

Figure 1 illustrates the NYISO nested reserve zones. NYC and Long Island (LI), as two load-pocket areas characterized by high demand and limited, high-cost generation capacity, are located in the innermost layers of the reserve structure. The figure also shows the transmission interfaces connecting from the outer zones to NYC, indicating that only four major transmission lines import power to the city from the rest of New York State. This limited interface capacity means that, when even one of the four lines has an emergency outage, the remaining lines can become heavily overloaded. In such cases, deploying reserves from within NYC can help mitigate interface congestion. The nested reserve structure ensures that sufficient reserves are procured within NYC and LI to respond to contingencies such as local generator outages or transmission line failures. The reserve procurement approach plays a critical role in the efficiency of congestion management and the accuracy of price signals. The following sections discuss two reserve procurement approaches: static zonal reserve (SZR) and dynamic nodal reserve (DNR) procurement.

Moreover, in a nested reserve structure, reserves procured in inner zones can satisfy the reserve requirements of outer zones, whereas reserves from outer zones cannot be used to meet the requirements of inner zones. For example, reserves procured within NYC can fulfill the zonal reserve requirements of Southeast New York (SENY), East, and the New York Control Area (NYCA). However, reserves located in SENY but outside NYC and LI -the yellow area in Figure 1- cannot satisfy the reserve requirements of NYC or LI, though they may contribute toward meeting the requirements of East and NYCA.

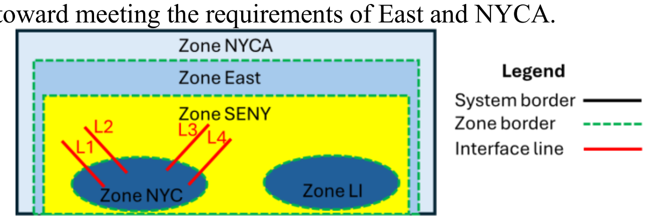

Figure 1 NYISO nested reserve zones.

a. *Static Zonal Reserve (SZR) Requirements*

In the SZR approach, the reserve requirements for each zone and reserve product are predetermined based on criteria such as the capacity of the largest generator within the zone. These

979-8-3315-8138-1

requirements are defined without considering the real-time operating conditions of the grid in either the pre- or post-contingency states. The predefined zonal reserve requirements are provided to the security-constrained unit commitment (SCUC) model as input parameters. Equations (1), (2), and (3) represent the zonal reserve requirement constraints for 10Spin, 10Total, and 30Total reserves, respectively. The requirements are cascading, meaning that higher-quality products (faster response times) can satisfy the requirements of lower-quality products (slower response times). Accordingly, 10Spin reserves can fulfill both 10Total and 30Total requirements, while 10Total can fulfill 30Total requirements. Shadow prices are shown in brackets.

$$\sum_{i\in I_z} r_{i,10S,t} \geq RQ^z_{10S,t}\ ,\ \{\alpha^z_{10S,t}\} \quad (1)$$

$$\sum_{i\in I_z} r_{i,10S,t} + r_{i,10T,t} \geq RQ^z_{10T,t}\ ,\ \{\alpha^z_{10T,t}\} \quad (2)$$

$$\sum_{i\in I_z} r_{i,10S,t} + r_{i,10T,t} + r_{i,30T,t} \geq RQ^z_{30T,t},\ \{\alpha^z_{30T,t}\} \quad (3)$$

The network security analysis (NSA) module evaluates post-contingency power flows on transmission lines following the outage of a line and generates transmission constraints (TCs) to be enforced within the network-constrained unit commitment (NCUC). Equation (4) represents a TC that ensures the post-contingency flow does not exceed the corresponding emergency limit. The NSA computes the shift factors $SF_{tc,i,t}$ and $SF_{tc,j,t}$ based on the post-contingency network topology, which are then used to represent the sensitivity of the monitored flow to power injections and withdrawals at generator i and load bus j, respectively.

$$\sum_i SF_{tc,i,t}\, e_{i,t} - \sum_j SF_{tc,j,t}\, D_{j,t} \leq L_{tc,t} \quad (4)$$

The SZR approach produces zonal MCPs for each reserve product. MCPs for 10Spin, 10Total, and 30Total reserves are calculated by equations (5), (6), and (7), respectively. The MCP of each reserve product is obtained as the sum of the shadow prices of all constraints that the product satisfies. Accordingly, the 10Spin MCP is the summation of the shadow prices from the 10Spin, 10Total, and 30Total reserve requirement constraints, while the 10Total MCP is the summation of the shadow prices from the 10Total and 30Total constraints. Furthermore, because reserves procured in inner zones can satisfy the reserve requirements of outer zones, the MCP for a given zone is determined as the summation of the shadow prices associated with that zone and all zones nested within it ($k \in \{z\} \cup inner\ (z)$).

$$MCP^z_{10S,t} = \sum_{k\in\{z\} \cup inner\ (z)} \alpha^k_{10S,t} + \alpha^k_{10T,t} + \alpha^k_{30T,t} \quad (5)$$

$$MCP^z_{10T,t} = \sum_{k\in\{z\} \cup inner\ (z)} \alpha^k_{10S,t} + \alpha^k_{10T,t} \quad (6)$$

$$MCP^z_{30T,t} = \sum_{k\in\{z\} \cup inner\ (z)} \alpha^k_{30T,t} \quad (7)$$

b. Dynamic Nodal Reserve (DNR) Requirements

In contrast to the SZR approach, the DNR framework determines reserve requirements endogenously within the optimization problem, ensuring that the amount of procured reserves is optimal, neither over- nor under-procured. Constraints (8) and (9) identify the first-largest contingency (FLC) and second-largest contingency (SLC) in the system by considering the total scheduled energy and reserve provided by each generator, where $i \neq i'$ indicates that the two generators are distinct units. Unlike the conventional approach, which evaluates contingencies based solely on generator capacity, the DNR method assesses the actual power contribution (energy plus reserve) of each generator to determine contingency severity. This distinction is important because a generator with the largest nameplate capacity may not necessarily be producing or providing the highest combined energy and reserve at a given time.

$$g_t^{1stL} \geq e_{i,t} + r_{i,10S,t} + r_{i,10T,t} + r_{i,30T,t} \quad (8)$$

$$g_t^{1stL} + g_t^{2ndL} \geq e_{i,t} + r_{i,10S,t} + r_{i,10T,t} + r_{i,30T,t} + e_{i',t} + r_{i',10S,t} + r_{i',10T,t} + r_{i',30T,t}\ , \qquad i \neq i' \quad (9)$$

The system-wide reserve requirements for 10Spin, 10Total, and 30Total reserves are represented by constraints (10), (11), and (12), respectively. The minimum requirements for each reserve product are defined in relation to the FLC and SLC identified in the system. Specifically, the 10Spin requirement equals half of the FLC, the 10Total requirement equals the FLC, and the 30Total requirement equals the sum of the FLC and SLC.

$$\sum_{i\in I} r_{i,10S,t} \geq 0.5 g_t^{1stL}\ ,\ \{\alpha^s_{10S,t}\} \quad (10)$$

$$\sum_{i\in I} r_{i,10S,t} + r_{i,10T,t} \geq g_t^{1stL}\ ,\ \{\alpha^s_{10T,t}\} \quad (11)$$

$$\sum_{i\in I} r_{i,10S,t} + r_{i,10T,t} + r_{i,30T,t} \geq g_t^{1stL} + g_t^{2ndL}\ ,\quad \{\alpha^s_{30T,t}\} \quad (12)$$

In addition to the system-wide dynamic requirements, reserves are also procured based on dynamic reserve constraints (DRCs) generated by the NSA. Constraints (13), and (14) represent DRCs corresponding to a single transmission contingency (N-1), and a simultaneous transmission–generation contingency (N-2), respectively. These constraints not only ensure the adequacy of procured reserves, but also guarantee that reserves are scheduled from appropriate locations to maintain post-contingency power flows within the DRC limits. By procuring reserves more accurately in both quantity and location, DNR can reduce reliance on OOM operator interventions, which are suboptimal and often increase price volatility and uplift payments. Tight coupling with nodal energy constraints provides a new degree of freedom, improving the optimization's congestion cost mitigation helping to dampen potentially increased price volatility inherent in all nodal markets where supply stacks become lumpier as granularity increases. Transmission losses are modeled in the power balance equation, and are implicit in the DRC formulation and parallel transmission constraints. The 10Total reserves secure transmission facilities up to their LTE limits under the loss of one transmission element (13), while the 30Total reserves secure the transmission facilities under the loss of one transmission and one generation element simultaneously (14). In constraints (14), the energy and reserve contributions of the failed generator (m) are excluded from the summation ($i \neq m$) to properly reflect the post-contingency condition. In (14), shift factors are computed based on the post-contingency network topology resulting from the transmission line outage, since generator loss does not alter network topology.

$$\sum_{i\in I} SF_{drc,i,t}\, e_{i,t} - \sum_j SF_{drc,j,t}\, D_{j,t} + \sum_i SF_{drc,i,t}\, r_{i,10T,t} \leq L_{drc,t}\ ,\ \{\mu^{LossT}_{drc,t}\} \quad (13)$$

$$\sum_{i\in I, i\neq m} SF_{drc,i,t}\, e_{i,t} - \sum_j SF_{drc,j,t}\, D_{j,t} + \sum_{i\in I, i\neq m} SF_{drc,i,t}\, r_{i,30T,t} \leq L_{drc,t}\ ,\ \{\mu^{LossTG}_{drc,t}\} \quad (14)$$

The DNR framework produces locational marginal operating reserve prices (LMORPs), which are nodal prices specific to each generator. LMORPs for the 10Spin, 10Total, and 30Total products are calculated by equations (15), (16), and (17), respectively. Each LMORP is derived from the shadow prices of the dynamic system-wide reserve constraints satisfied by the corresponding product, combined with the shadow prices of the DRCs weighted by their respective shift factors. For

979-8-3315-8138-1

example, the 10Spin product satisfies constraints (10)-(12); therefore, its LMORP includes the shadow prices associated with these constraints. In addition, because 10Total and 30Total products encompass 10Spin, the shadow prices of constraints (13)-(14), weighted by the shift factors, are also included in the 10Spin LMORP (15). This formulation captures both the system-wide and locational effects of reserve deployment, ensuring that the resulting prices reflect the true operational value of reserves at each node.

$$LMORP_{i,10S,t} = \alpha^{s}_{10S,t} + \alpha^{s}_{10T,t} + \alpha^{s}_{30T,t} + \sum_{drc} SF_{drc,i,t} \left(\mu^{LossT}_{drc,t} + \mu^{LossTG}_{drc,t}\right) \quad (15)$$

$$LMORP_{i,10T,t} = \alpha^{s}_{10T,t} + \alpha^{s}_{30T,t} + \sum_{drc} SF_{drc,i,t} \left(\mu^{LossT}_{drc,t} + \mu^{LossTG}_{drc,t}\right) \quad (16)$$

$$LMORP_{i,30T,t} = \alpha^{s}_{30T,t} + \sum_{drc} SF_{drc,i,t}\, \mu^{LossTG}_{drc,t} \quad (17)$$

Although the DNR framework considers nodal attributes (such as shift factors) when procuring, it does not introduce explicit new market products. Instead, dynamic nodal reserve requirements are enforced implicitly through system-wide reserve constraints and DRCs, consistent with how NSA transmission security constraints are handled in current SCUC workflows. In practice, DNR framework would impact the distribution of reserves procurement, and reserve payments, however it does not change the operational philosophy of distribution of reserves throughout the control area. Operators monitoring cleared/available reserves, post-contingency flows, and shadow prices remain unchanged.

III. Numerical Results

The discussed SZR and DNR approaches are implemented within a day-ahead SCUC model using the NYISO grid. The nested reserve zones of NYISO are illustrated in Figure 1, and the associated static zonal reserve requirements are available in Ref [6]. While multiple credible transmission and generation contingencies are modeled through the security analysis, the contingencies discussed in the following are those that become binding and produce non-zero shadow prices, as these directly impact reserve procurement outcomes and LMORPs:

- Cont. 1: The loss of interface L1 during all intervals, with post-contingency flow analyzed on line L2. According to constraint (13), the 10Total reserve secures line L3 to its LTE limit for this contingency.
- Cont. 2: The simultaneous loss of interface L1 and generator G46 (located in NYC) during all intervals, with post-contingency flow analyzed on line L2. According to constraint (14), the 30Total reserve secures line L2 for this combined contingency.

a. Total System-Wide and Zonal Procurment Analysis

Figure 2(a) presents the NYCA-wide (system-wide) procurement of 30Total reserves. In the SZR approach, both zonal and system-wide requirements are predetermined based on predefined criteria without considering real-time grid conditions. The largest generator capacity in NYCA is 1310 MW, and NYISO's 30Total static requirement equals twice this value (2620 MW) [6]. Consequently, the procured 30Total reserve in all intervals remains constant at 2620 MW, which can lead to periods of over-procurement or under-procurement depending on system conditions. In contrast, under the DNR approach, the NYCA 30Total requirement is endogenously determined within the optimization problem based on the scheduled output of the FLC and SLC generators (12). This allows DNR to reflect real-time operating conditions. Moreover, DNR can suppress the scheduled output of the FLC and SLC generators when doing so minimizes the total system cost, thereby achieving a more cost-efficient reserve allocation.

Figure 2(b) illustrates the 10Total procured within the NYC zone. Under the SZR, at least 500 MW of 10Total reserves are allocated within the NYC in all intervals, corresponding to the static zonal 10Total requirement of 500 MW. Due to the nested zone structure, reserves procured in inner zones can satisfy the requirements of outer zones. As a result, in some intervals, the total procured reserves in NYC exceed the predefined requirement. In contrast, under the DNR, the quantity of reserves within each region is determined endogenously, driven by the system-wide dynamic requirements and the DRCs. Consequently, the 10Total reserves are cleared optimally across intervals based on the prevailing system conditions and the modeled contingencies. Overall, the results demonstrate that DNR reduces the quantity of reserves cleared from locations, i.e., outer layers, that do not contribute effectively to contingency response, and instead increases the procurement of reserves from critical inner zones like NYC.

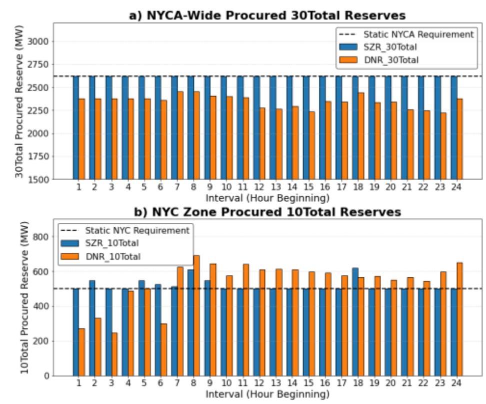

Figure 2 Differences in reserve procurement quantities: (a) NYCA-wide procured 30Total reserves and (b) NYC-zone procured 10Total reserves.

b. Generator-Wise Procurment and Price Analysis

In the SZR, reserves are procured to meet zonal static requirements, leading to uniform prices within each zone. DNR, in contrast, considers each resource's effectiveness in responding to contingencies and relieving congestion, resulting in nodal reserve prices. Figure 3(a) and 3(b) show differences in reserve procurement and reserve prices (DNR – SZR) for the 10Total and 30Total at interval 12, when both Cont. 1 and Cont. 2 are binding. When line L1 (an NYC interface) and generator G46 (inside NYC) fail, more 10Total and 30Total reserves are cleared from NYC—specifically, 10Total from G63 and G34, and 30Total from G56, G59, G64–G66, G68, and G71–G73. Deploying reserves from these internal resources reduces imported energy needs and mitigates the overload on L2, while fewer reserves are allocated from SENY, East, and NYCA, as those outer-layer zones provide limited benefit to congestion management.

Nodal reserve prices rise for resources that relieve congestion and fall for those that aggravate it. For example, 10Total prices in NYC are 7.66–9.56 $/MWh higher under DNR than SZR. Resources with greater congestion-mitigation impact receive higher prices; for instance, although G12 and G27 are in the same zone, G12 earns more because it relieves congestion more effectively. Conversely, generators outside NYC that do not aid congestion are paid less, for example, G363 earns about 5 $/MWh less under DNR than SZR.

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TABLE I. CONTINGENCY ANALYSIS RESULTS

Interval (HB)	Cont.	Failed Elements	Inter face	Normal Limit (MW)	LTE Limit (MW)	MTE Limit (MW)	Pre-Cont. Flow (MW)		Post-Cont. Flow (MW)		Post-Reserve Flow (MW)		Mitigated Flow (MW)	
							SZR	DNR	SZR	DNR	SZR	DNR	SZR	DNR
12:00	Cont. 1	L1 (N-1)	L2	741	858	1048	714	714	904	1048	628.8	691	275.2	357
12:00	Cont. 2	L1 and G46 (N-2)							1200	1717	534.2	835.8	665.8	881.2

The cleared 10Total and 30Total reserves from G46 decrease by 138 MW and 204 MW, respectively, under DNR, since G46 fails as part of Cont. 2 and is therefore unavailable. This highlights a limitation of SZR, which may clear reserves from generators whose outages are modeled in the contingency set. Accordingly, G46 does not experience the price increases observed for other NYC resources, as it is the source of the contingency rather than a contributor to congestion management. Finally, certain units such as G4 see higher nodal prices without increased 10Total procurement because they operate at upper capacity limits; although additional reserves cannot be procured, they are still compensated for their marginal contribution to congestion mitigation.

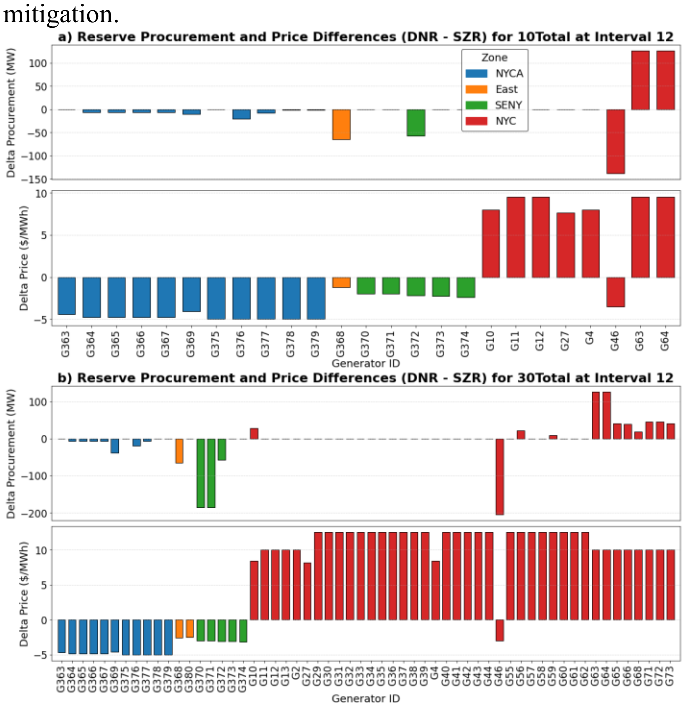

Figure 3 Economic impacts of DNR through differentiated reserve clearing and pricing (DNR – SZR): (a) reserve procurement differences and (b) reserve price differences for 10Total and 30Total at interval 12.

c. Contingency Analysis

Contingency analysis results are summarized in Table I. Under Cont. 1, where line L1 fails, the post-contingency flow on L2 in the SZR case increases from 714 MW to 904 MW, exceeding its LTE rating of 858 MW. In contrast, under the DNR case, the availability of operating reserves within NYC enables the grid operator to increase the post-contingency flow on L2 up to its MTE rating. This effectively increases the post-contingency transfer capability of L2 by 190 MW, resulting in a flow of 1048 MW. After reserve deployment, congestion is mitigated by 257.2 MW in SZR and 357 MW in DNR, representing a 38.8% improvement in congestion mitigation under DNR. Similarly, under Cont. 2, the DNR model increases the post-contingency transfer capability of L1, allowing flows to reach 1717 MW compared to 1200 MW in the SZR case. Following reserve deployment, 665.8 MW of congestion is mitigated under SZR and 881.2 MW under DNR, demonstrating approximately 32% better performance for DNR. All post-contingency flows remain below the LTE limit, indicating that the lines can be safely operated for up to four hours at their LTE ratings.

IV. CONCLUSION

This paper leveraged a DNR approach to manage interface congestion in load-pocket areas within a nested reserve zone structure. DNR co-optimizes reserve procurement and deployment impacts under multiple contingency scenarios. The main findings are as follows:

- DNR dynamically adjusts reserve quantities based on system conditions, avoiding the over- or under-procurement inherent in SZR's static requirements.
- Reserves are cleared from resources that most effectively relieve congestion, leading to higher nodal prices for impactful generators that relieve congestion and lower prices for those that exacerbate it.
- DNR increases post-contingency transfer capability more effectively than SZR and shows better congestion mitigation performance, achieving 32–38.8% more mitigation.

Overall, DNR enhances economic efficiency, reliability, and interface utilization by linking reserve procurement to real-time system and network conditions.

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REFERENCES

[1] D. B. Patton, P. L.VanSchaick, J. Chen, and J. Coscia, "2024 state of the market report for the New York ISO markets" [Online]. Available: https://www.nyiso.com/documents/20142/2223763/2024-State-of-the-Market-Report.pdf/63b4d5c8-7e8c-45ac-02f7-7885406bae71

[2] Y. Chen, P. Gribik and J. Gardner, "Incorporating post zonal reserve deployment transmission constraints into energy and ancillary service co-optimization," *IEEE Transactions on Power Systems*, vol. 29, no. 2, pp. 537-549, March 2014.

[3] L. Morelli, "Reserve zone & synchronized reserve market proposal overview" [Online]. Available: https://www.pjm.com/-/media/DotCom/committees-groups/task-forces/epfstf/20180418/20180418-item-06-epfstf-reserve-zone-synchronized-reserve-market-proposal-overview.ashx

[4] T. Zheng and E. Litvinov, "Contingency-based zonal reserve modeling and pricing in a co-optimized energy and reserve market," *Transactions on Power Systems*, vol. 23, no. 2, pp. 277–186, May 2008.

[5] J. M. Arroyo and F. Galiana, "Energy and reserve pricing in security and network-constrained electricity markets," *Transactions on Power Systems*, vol. 20, no. 2, pp. 634–643, May 2005.

[6] NYISO, "NYISO Locational Reserve Requirements" [Online]. Available: https://www.nyiso.com/documents/20142/3694424/Locational-Reserves-Requirements.pdf

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