

# 2017 ISO New England System Operational Analysis and Renewable Energy Integration Study – Highlights\*

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**Abstract**—The generation mix of ISO New England is fundamentally changing. The representation of nuclear, coal and oil generation facilities is set to dramatically fall, and natural gas, wind and solar facilities will come to fill their place. Solar and wind introduce greater uncertainty and must be accurately forecasted. This paper introduces the findings of a study launched by ISO New England on 12 predefined scenarios, six for 2025 and six for 2030, with varying penetration of variable energy resources (VERs) as well as dispatchable generation. The heart of the study’s methodology is a novel, but now extensively published, holistic assessment approach called the Electric Power Enterprise Control System (EPECS) simulator. The EPECS methodology has been published and validated by ISO New England. The findings of this study highlight the need for more holistic assessment of operational techniques such as in the determination of operating reserves and curtailment. For cases with high penetration of VERs (2025-3, 2030-2, 2030-3 and 2030-6) the study shows the system’s inability to mitigate imbalances due to inadequate load-following, ramping and regulation reserves. The potential for congestion on the interfaces is also observed for these scenarios. In addition to these issues, the study highlights the integral role of curtailment in dealing with negative net load in the presence of “must-run” generation.

## I. INTRODUCTION

The bulk electric power system in New England is fundamentally changing. The representation of nuclear, coal and oil generation facilities is set to dramatically fall, to be replaced by natural gas, wind and solar generation facilities [1]. This shift is driven by retirements of most nuclear, coal, and oil power plants [1], and lower natural gas prices [2]. For instance, the percentage of nuclear generation is expected to drop to 9% by 2025 as compared to the 30% in 2015 [3]. While the percentage of natural gas generation is expected to grow to 55% of the overall generation mix in 2025 [4]. Additionally,

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state mandates and renewable portfolio standards are expected to significantly increase the percentage of solar and wind generation as well as energy efficiency measures in the region [5]. Fig. 1 represents a snapshot of the ISO-NE generation mix in 2005 and 2015.

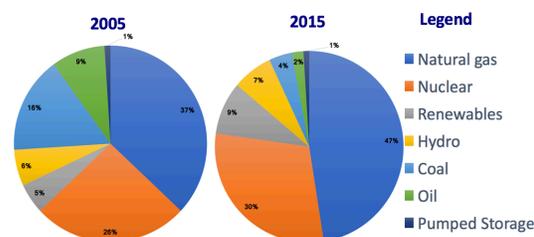


Fig. 1: ISO New England generation mix in 2005 and 2015 [1], [3].

The introduction of VERs like solar and wind, however, necessitates fundamental changes in the power grid’s dynamic control and operation [6]. As VERs displace traditional thermal generation, the overall dispatchability of the electricity grid decreases. Additionally, VERs increase the uncertainty level in the electricity supply system as they have low forecast accuracy even in the short term [7], [8]. VERs also introduce greater intermittency and thus require greater quantities of operating reserves. As a result, these new power system dynamics and their impacts on ISO New England’s operations need to be systematically and rigorously assessed. To that end, ISO New England launched the 2017 System Operational Analysis and Renewable Energy Integration Study (SOARES) to be conducted by the Laboratory for Intelligent Integrated Networks for Engineering Systems (LIINES) at the Thayer School of Engineering at Dartmouth. The project specifically sought to study ISO-NE operations in the years 2025 and 2030 for the 12 scenarios identified by ISO-NE stakeholders [9].

The heart of the project’s methodology is a novel, but now extensively published, holistic assessment approach called the EPECS simulator [10]. This simulator comprises of the physical power grid and its multiple layers of control including commitment decisions, economic dispatch, and regulation services. These include load following and ramping reserves, curtailment of renewables, interface & tie-line performances, regulation reserves and the system balancing performance. Consequently, it

has the ability to provide clear trade-offs for any changes to the physical power grid and its associated layers of control.

This paper applies the EPECS methodology that has been adapted for the ISO-NE system [11] to study the 12 scenarios. The study addresses the 12 hypothetical scenarios that were agreed upon consensually among ISO New England stakeholders and are described in Section III. The paper also provides a comprehensive discussion of the impact of the 12 predefined scenarios on a) load-following, ramping and regulation reserves, b) interface and tie-line performance, c) the curtailment of VERs, and d) the balancing performance on the ISO-NE operations in Section IV. The goal of the paper is to inform on the system-level performance of these 12 scenarios rather than promote any particular resource or approach.

## II. METHODOLOGY

This section briefly describes the EPECS simulator. The simulator includes a physical power grid layer and several layers of primary, secondary, and tertiary enterprise control functions as shown in Fig. 2. The first layer of control is the security-constrained unit commitment (SCUC) whose goal is to select the right set of generators to meet demand in the day-ahead market. The second layer is the real-time unit commitment (RTUC) that commits and de-commits only *fast-start* units in the real-time. Finally, the security-constrained economic dispatch (SCED) moves available online generator outputs to new setpoints (dispatch) in the most cost-efficient way. A more comprehensive description of this methodology and the mathematical formulations of each control layer can be found in [10], [11]. This methodology has been analyzed and validated by ISO-NE.

The pseudo-steady-state approximation of the regulation service model that ties directly to a power flow analysis model of the physical power grid is used in this study. Normally, the imbalances at the output of the regulation service model would be represented in frequency changes. However, for steady-state simulations, the concept of frequency is not applicable. Instead, a designated *virtual* swing bus consumes the mismatch of generation and consumption to make the steady-state power flow equations solvable. Within the simulator, variable energy resources are studied as time-dependent, spatially-distributed exogenous quantities that contribute directly to the net load. The EPECS simulator also allows for the study of several types of energy resources defined as follows:

- 1) **Variable Energy Resources (VERs):** Normally, wind, solar, run-of-river hydro, and tie-lines are assumed to be VERs.

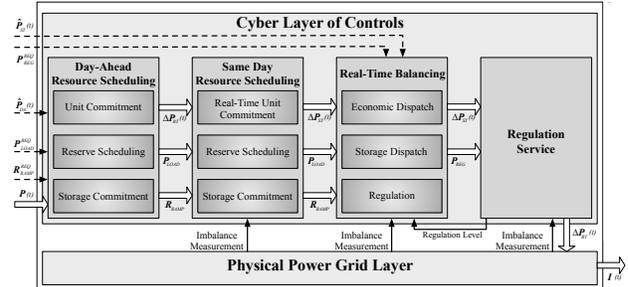


Fig. 2: The architecture of the Electric Power Enterprise Control System (EPECS) simulator customized for ISO New England operations [11]

- 2) **Semi-Dispatchable Resources:** Energy resources that can be dispatched downwards (i.e curtailed) from their uncurtailed power injection level. When curtailment is allowed for VERs, they become semi-dispatchable. In this study, wind, solar, run-of-river hydro, and tie-lines are treated as semi-dispatchable resources.
- 3) **Dispatchable Resources:** Energy resources that can be dispatched up and down from their current value of power injection. In this study, all other resources are assumed to be dispatchable.

The EPECS simulator methodology employs the operating reserves concepts presented in [12], [13] with only minor changes. In this study, solar and wind integration is studied within the context of normal operating reserves as the outage of any individual wind or solar plant has a smaller impact on the overall system than say, the largest thermal generation unit [12]. Normal operating reserves are classified as load following, ramping, and regulation reserves based on the mechanisms upon which they are acquired and activated. Their definitions are as follows:

- 1) **Load Following Reserves** [12], [13]: Power capacity available during normal operations for assistance in active power balance to correct any anticipated imbalances upward or downward.
- 2) **Ramping Reserves** [12], [13]: Ramp rate capacity available during normal operations for assistance in active power balance to correct any future anticipated upward or downward imbalances.
- 3) **Regulation Reserves** [12], [13]: Power capacity available during normal conditions for assistance in active power balance to correct the current imbalance that requires a fast, real-time, automatic response.

Together, these three types of operating reserves are used to respond to forecast errors and variability in the net load during normal operation. In all cases, the actual quantities of these reserves are physical properties of the power system. They exist regardless of whether the system operator places requirements on these physical

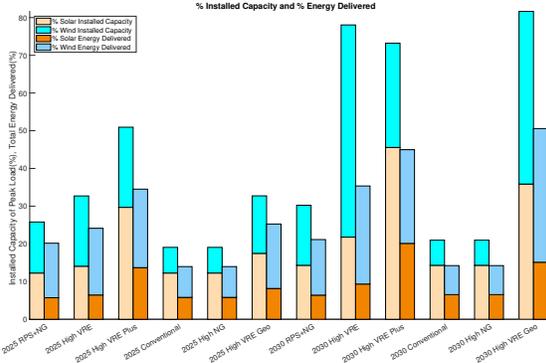


Fig. 3: This figure highlights the installed capacity of solar and wind as a percentage of the peak load and the actual energy delivered as a percentage of total energy delivered for all 12 scenarios.

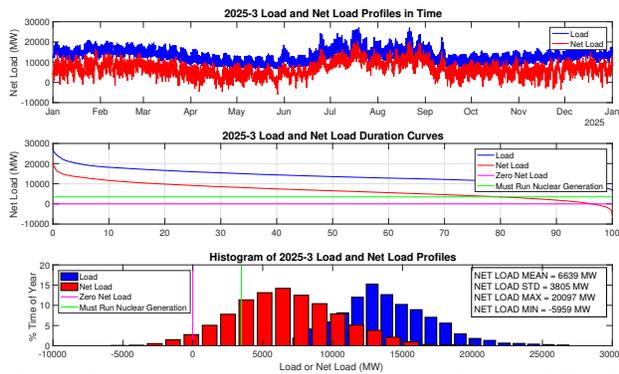


Fig. 4: Comparison of load and net load for Scenario 2025-3

quantities or they incentivize generators to provide these reserve quantities in the form of reserve products.

### III. ISO NEW ENGLAND CASE STUDY

#### A. Study Scenarios

A total of 12 scenarios are studied for the years 2025 and 2030; six scenarios for each year. Each scenario is described by different characteristics of load profiles, renewable energy integrated, and the generation base [11]. Additionally, each scenario was characterized by varying penetration of VERs. Fig 3 represents the capacities for solar and wind for all scenarios in 2030 and 2025, and the actual total energy delivered by these two resources.

#### B. Net Load Profiles

The net load is defined as the difference between the aggregated system load and the total generation produced by VERs. For scenarios with a high penetration VERs, the overall aggregated net load tends to be much lower and at times falls below zero. Given that a significant percentage of the generation fleet are nuclear units that operate on a “must-run” basis, the possibility of excess generation in the system and hence curtailment of VERs rises.

TABLE I: Load profile statistics for 2025 & 2030 scenarios

	2025-1	2025-2	2025-3	2025-4	2025-5	2025-6
<b>Max (MW)</b>	27,950	27,950	26,950	27,950	27,950	27,950
<b>Min (MW)</b>	7,142	7,142	6,302	7,142	7,142	7,142
<b>Energy (TWh)</b>	127	127	122	127	127	127
<b>Mean (MW)</b>	14,483	14,483	13,927	14,483	14,483	14,483
<b>STD (MW)</b>	3,587	3,587	3,302	3,587	3,587	3,587
	2030-1	2030-2	2030-3	2030-4	2030-5	2030-6
<b>Max (MW)</b>	28,604	28,604	26,335	28,604	28,604	28,604
<b>Min (MW)</b>	7,840	7,840	5,189	7,840	7,840	7,840
<b>Energy (TWh)</b>	133	133	118	133	133	133
<b>Mean (MW)</b>	15,180	15,180	13,465	15,180	15,180	15,180
<b>STD (MW)</b>	3,583	3,583	3,378	3,583	3,583	3,583

Fig. 4 highlights the system load and the corresponding net load for one of the high renewables scenarios, 2025-3. The graphs show that the overall system demand decreases, and the shape of the histogram shifts to the left. For this particular scenario, the net load also drops below zero at different instances throughout the year. This raises a question of whether the system is prepared to effectively harvest the power generated by renewable energy units given the limitations of the associated generation fleet. This negative net load is due to excess renewables as well as a large presence of “must-run” generation in the system. The problem is further complicated when considering that most renewable energy generation is located in the remote areas of Maine that are relatively far from major consumption areas, such as Massachusetts. Table I summarize the load statistics for the 12 Scenarios. Due to energy efficiency and plug-in-electric vehicles integration, scenarios 2025-3 and 2030-3 have a lower peak load and minimum load levels compared to the other scenarios. 2030 scenarios exhibit a trend similar to that of 2025 scenarios with a slight increase in peak load values. A close examination of the net load profiles indicates negative net loads for part of the year for scenarios 2, 3, and 6 in both 2025 and 2030 scenarios.

Table II defines the forecast errors for each type of resource used in this study. Each of the SCUC, RTUC and SCED optimization programs uses different forecasts of the net load and, has different forecast error parameters associated with it. The trend shows that the smaller the time horizon of the optimization program, the more accurate the forecast as it is easier to forecast for closer time intervals.

TABLE II: Forecast error statistics

	Load	Wind	Solar
<b>SCUC</b>	1.65%	12%	7%
<b>RTUC</b>	1.5%	3%	3%
<b>SCED</b>	0.15%	3%	3%

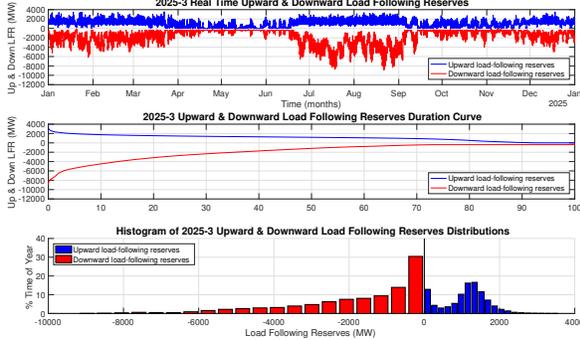


Fig. 5: Load following reserve profiles for Scenario 2025-3

#### IV. RESULTS AND DISCUSSION

This section presents the results on how the system performs based on various key performance factors namely; operating reserves, balancing performance, curtailment, and tie-line & interface congestion.

##### A. Load Following Reserves

As an example, the performance of load following reserves for Scenario 2025-3 is shown in Fig. 5. Both upward and downward load following reserves are often exhausted or nearly so. The integration of massive amounts of renewable energy in this scenario reduces the system net load significantly. This, coupled with the “must-run” nuclear units, fosters situations with nearly no downward load following reserves and an excess of upward load following reserves. In the meantime, as the system net load rises, upward load following reserves can become constrained before additional units can be committed. Fig. 5 shows that in the Spring and Fall, the ability to track such low net load conditions is particularly constrained.

In contrast to Scenario 2025-3, the amounts of upward and downward load following reserves fluctuate over time but are never completely exhausted in the “business-as-usual” scenario 2025-4 as shown in Fig. 6. The closest the system gets to exhausting its downward load following reserves is during low-load spring and fall periods. Thus, when the system follows the evolutionary path of Scenario 2025-4, it is able to operate reliably without the need for more load following reserves.

The behavior portrayed in Figs. 5 and 6 is also observed in the 2030 scenarios 3 & 4. Unlike the 2025 scenarios, 2030 scenarios contain larger quantities of renewables which is reflected in the exhaustion of load-following reserves. All 2030 scenarios except 2030-4 exhaust their upward & load-following reserves at least 5% of the time. While scenario 2030-3 experiences upward load following reserve shortages more often and requires an increase of such resources to maintain the balance of the system.

While the primary purpose of load following reserves is to mitigate the system imbalances induced by the net

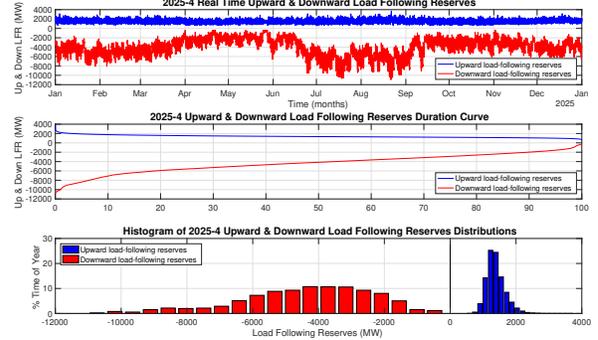


Fig. 6: Load following reserve profiles for Scenario 2025-4

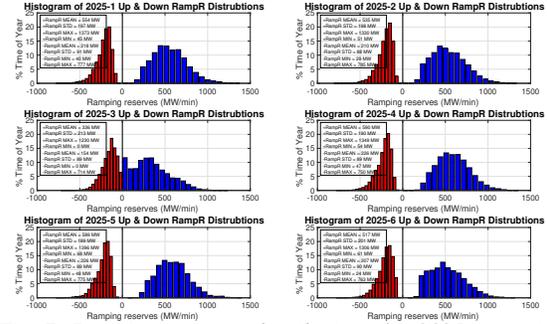


Fig. 7: Ramping reserves distributions for 2025 scenarios

load variability and day-ahead forecast errors, increasing the load following reserve amount in the system is not always a comprehensive solution for imbalance mitigation. Certain portions of imbalances may be due to inadequate ramping capabilities of the resources or topological limitations of the system.

In conclusion, all 2025 scenarios have sufficient downward load following reserves and, of the 2025 scenarios, only scenario Scenario 2025-3 would benefit from additional upward load following reserves. Also, all 2030 scenarios, except for Scenarios 2030-4, would benefit from additional upward load following reserves.

##### B. Ramping Reserves

A close examination of all 2025 scenarios shows that downward ramping reserves for all scenarios hit the zero value at some point during the year. This is reflected in Fig. 7. As for Scenario 2025-3, both upward and downward ramping reserves have zero values far more often. It can be concluded that the addition of significant renewable energy sources to Scenario 2025-3 requires more upward and downward ramping reserves to maintain the system’s ability to follow the net load fluctuations.

##### C. Curtailment of Semi-Dispatchable Resources

In the absence of adequate load following and ramping reserves, curtailment of generation from VERs, serves a vital balancing function. While the curtailment of renewable resources may be less desirable, it provides

more flexibility and can help overcome topological limitations of the system when load following and ramping reserves might be ineffective. It is also important to emphasize that some of these topological limitations are due to integration of semi-dispatchable resources in remote areas that replace the traditional generation units located close to the main consumption centers. Thus, these resources might have a self-limiting feature which also defines the ability of the system to accommodate them.

As an example, Fig. 8 shows the curtailment profile for Scenario 2025-3. The graph shows that some form of curtailment occurs for the most part of the year. Also, the largest curtailments occur during spring and fall when the system net load is at its lowest. Generally, the

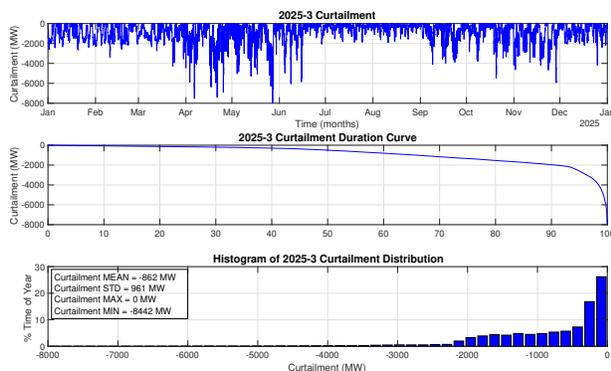


Fig. 8: Curtailments for Scenario 2025-3

largest curtailments are observed in scenarios with large amounts of variable resources or the most retirements of dispatchable generation. As a result, scenarios 2025-2, 2025-3 exhibit large curtailments for 2025 scenarios while scenarios 2030-2, 2030-3 and 2030-6 have the largest curtailments of the 2030 scenarios. For instance, scenario 2030-6 presents the second largest curtailments due to the integration of large amounts of offshore wind units. It can, therefore, be observed that the curtailment of semi-dispatchable resources is often times a way to mitigate topological limitations of the system amplified by the integration of the same semi-dispatchable resources.

#### D. Interface and Tie-Line Performances

As mentioned in the previous section, one of the main reasons for the curtailment of semi-dispatchable resources is the topological limitations of the system. These limitations are primarily due to the enforcement of several interface flow limits, which may cause congestion in the system and require curtailment. The performance of four key interfaces, a) Orrington-South, b) Surowiec-South, c) North-South, and d) SEMA-RI Import, is discussed here.

Table III shows that the system experiences significant congestion on the Orrington-South interface for Scenar-

ios 2025-1, 2025-2, 2025-3, and 2025-6 compared to Scenarios 2025-4 and 2025-5 that have no congestion at all. A similar pattern, but to a lesser degree, is observed on the Surowiec-South interface. The important observation here is that these scenarios are defined by the significant increase of renewable energy resources in the system. The power generated by these resources needs to flow towards the main consumption centers, such as Massachusetts, which causes the congestion on these two interfaces. On the other hand, the North-South interface exhibits congestions only in rare cases. This is due to the fact that the North-South interface has much higher interface limit, 2,725 MW, and is able to pass the additional renewable energy generation coming through the Orrington-South and the Surowiec-South interfaces without being congested. Finally, the SEMA-RI import interface exhibits some congestion for all 2025 interfaces. The results for 2030 are fairly similar to those for 2025.

Matching the congestion results in this section to the curtailment results Section IV-C, the following conclusion can be drawn; the integration of significant VERs increases the potential of congestion on several key interfaces, such as Orrington-South and the Surowiec-South, leading to heavy curtailments of these resources. Thus, the ability of the system to accommodate more renewables is limited by its topology, particularly, that of the four key interfaces discussed above.

#### E. Regulation Reserves

Fig. 9 illustrates the regulation performance of 2025 scenarios. It is obvious that scenarios 2025-4 and 2025-5 are barely saturated indicating sufficient and efficient use of regulation reserves. In contrast, scenarios 2025-1, 2025-2, 2025-3, 2025-6, show heavy saturation of regulation reserves due to the high penetration of renewables. A closer inspection of the regulation reserve performances of 2030 scenarios also indicates a similar behavior. Although, saturation occurs more often compared to 2025 scenarios due to the higher renewable energy penetration in 2030 scenarios.

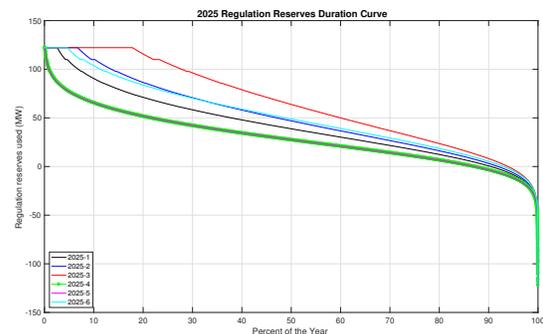


Fig. 9: Regulation reserve performance for Scenario 2025-4

TABLE III: Interface congestion statistics for 2025 scenarios

% Time Congested	2025-1	2025-2	2025-3	2025-4	2025-5	2025-6
Orrington South	20.49	19.05	27.06	0.00	0.00	13.91
Surowiec South	4.39	11.82	4.41	0.00	0.00	0.90
North-South	0.15	0.38	0.51	0.00	0.00	0.04
SEMA-RI Import	3.09	3.61	9.88	3.22	3.07	2.00
% Time Congested	2030-1	2030-2	2030-3	2030-4	2030-5	2030-6
Orrington South	25.80	27.84	17.14	0.00	0.00	24.05
Surowiec South	4.17	21.83	12.00	0.00	0.00	16.30
North-South	0.15	1.13	0.48	0.00	0.00	0.54
SEMA-RI Import	3.45	2.92	9.91	2.65	3.07	1.63

### F. Balancing Performance

The balancing performance of the system can be assessed from the residual imbalances after the regulation service has been deployed. As shown in the previous section, all scenarios exhibited regulation service saturation to varying degrees. For this reason, all scenarios should contain some residual imbalances. Imbalances for Scenarios 2025-4 and 2030-4 are well-controlled with zero mean and moderate variability on the order of 75MW for the overwhelming majority of the year. Such a low value indicates that these two scenarios are well-equipped to mitigate the imbalances effectively.

Fig. 10 show the imbalance ranges for all scenarios. Scenarios 2030-2 and 2030-6 and to a lesser extent Scenario 2030-3 have a wider range between the maximum and minimum imbalance values, which can be described as a measure of the intensity of improbable/extreme events. On the other hand, all scenarios except these three maintain imbalance variability of less than 50MW, despite the saturation of regulations reserves observed in the previous section.

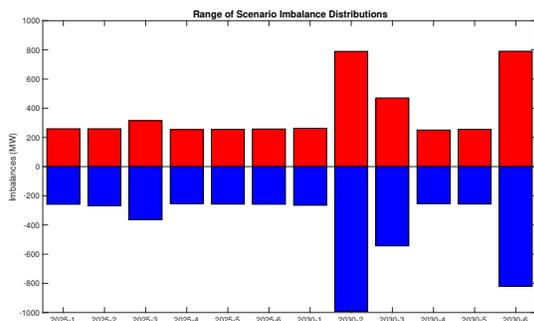


Fig. 10: Imbalance ranges for 2025 and 2030 scenarios

## V. CONCLUSION & FINAL INSIGHTS

This paper describes the methodology and the key findings of the 2017 ISO New England System Operational Analysis and Renewable Energy Integration Study (SOARES). The findings show that cases with high penetration of VERs (2025-3, 2030-2, 2030-3 and 2030-6) require more load-following, ramping as well

as regulation reserves in order to mitigate imbalances. The potential for congestion on the interfaces is also observed for these scenarios. In addition to these issues, the study highlights the integral role of curtailment in dealing with negative net load in the presence of “must-run” generation. To conclude, the topological constraints in the case of interface limits, constrain the system’s ability to mitigate imbalances. A relaxation of this constraint as well as the “must-run” constraint on nuclear generation would significantly improve the system’s performance during both low- and high-load periods. Additionally, the role of curtailment in the provision of operating reserves must not be neglected.

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