WEATHER-DEPENDENT MODELING OF GAS-FIRED GENERATOR OUTPUT IN EXTREME WINTER CONDITIONS

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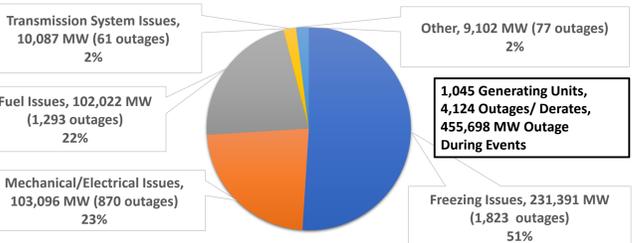
WASHINGTON STATE UNIVERSITY

1. BACKGROUND AND MOTIVATION

- Almost $1.4 trillion economic loss due to weather-related events [1].

- Winter storms and freeze event alone cost $141.6B since 1980 [1].

- Very less attention on impact of extreme winter on power grid in the existing literature [2].

- Gas fired generators are the most affected by extreme cold (63% during winter storm Elliot), resulting multiple power plants failure and blackouts [3].

- Need of a framework to analyze the uncertain impacts of extreme cold to proactively plan the available resources.

2. PAST WINTER STORMS: IMPACTS [2]
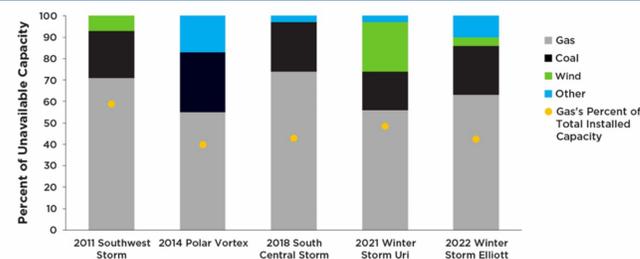
Total MW loss of Incremental Unplannaed Generator Outages, Derates, and Start-up Failures by Cause, Total Event Area (Winter Storm Uri)

- Transmission System Issues, 10,087 MW (61 outages) 2%
- Other, 9,102 MW (77 outages) 2%
- Fuel Issues, 102,022 MW (1,293 outages) 22%
- Mechanical/Electrical Issues, 103,096 MW (870 outages) 23%
- Freezing Issues, 231,391 MW (1,823 outages) 51%
- 1,045 Generating Units, 4,124 Outages/ Derates, 455,698 MW Outage During Events

3. KEY RESEARCH QUESTIONS

- How do extreme winter weather conditions affect the operational capacity and reliability of gas-fired generators?

- What are the key factors (e.g., temperature, demand, generator type) influencing generator performance and outage probabilities during extreme cold events?

- Which modeling approach best captures the relationship between weather conditions and generator performance, ensuring accurate and reliable predictions?

- How can the findings of this study inform grid operators, planners, and policymakers to enhance grid preparedness and mitigate risks during extreme winter weather?
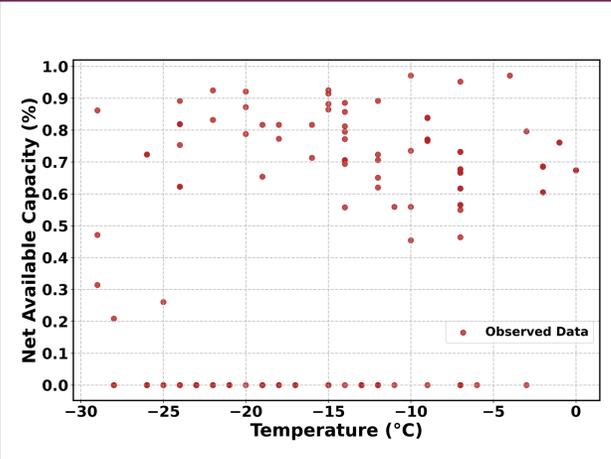
4. OUTAGE DATASET (GADS by NERC)
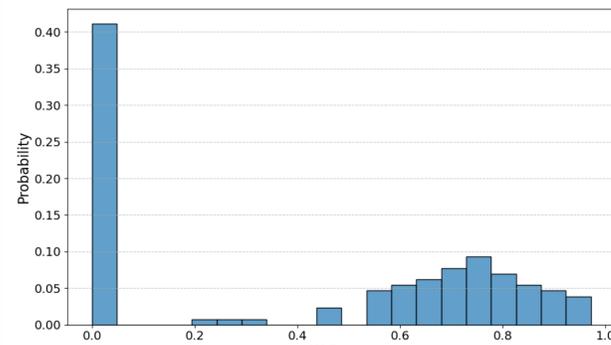
- Year : 2013 – 2022
- Months: Dec, Jan, Feb
- Generator: Gas-fired
- Cause: Storms (Snow, ice)
- Region: Northeastern U.S. = {CT, MA, ME, NH, NJ, NY, PA, RI}
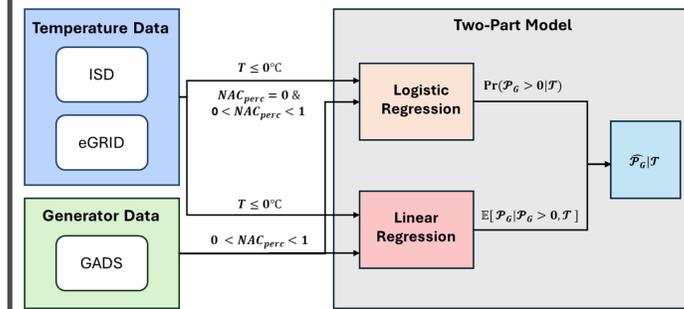- Total Events: 131

5. WEATHER DATASET (NOAA + eGRID)

- Gas-fired Power Plant
- Weather Station
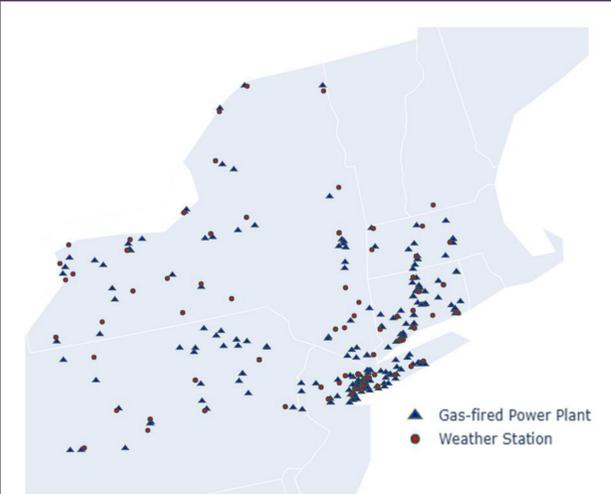
State-wise average minimum temperature for each events computed from nearest weather stations

6. RAW DATA vs TEMPERATURE

- Observed Data

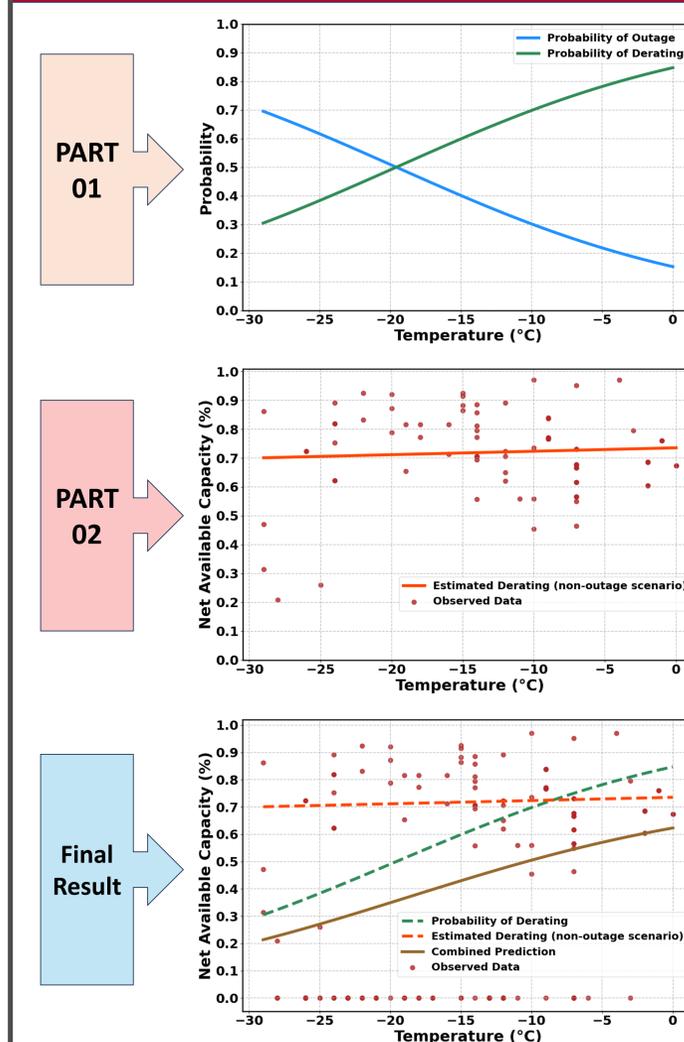## 7. MODEL

Temperature Data
- ISD
- eGRID

Generator Data
- GADS

Two-Part Model

$T \leq 0°C$, $NAC_{perc} = 0$ & $0 < NAC_{perc} < 1$ → Logistic Regression → $\Pr(\mathcal{P}_G > 0 | \mathcal{T})$

$T \leq 0°C$, $0 < NAC_{perc} < 1$ → Linear Regression → $\mathbb{E}[\mathcal{P}_G | \mathcal{P}_G > 0, \mathcal{T}]$

→ $\widehat{\mathcal{P}}_G | \mathcal{T}$

Part 1: Bayesian Logistic Regression for Zero Inflation
$$\varphi(y) = \mathbf{Pr}(\mathcal{P}_G > 0 | \mathcal{T}) = F(x \cdot \delta)$$

Part 2: Bayesian Linear Regression for Positive Derating
$$\mathbb{E}[\mathcal{P}_G | \mathcal{P}_G > 0, \mathcal{T}] = x \cdot \gamma + \epsilon$$

Final Outcome (Law of Total Expectation) [4]:
$$\widehat{\mathcal{P}}_G | x = \mathbf{Pr}(\mathcal{P}_G > 0 | \mathcal{T}) \cdot \mathbb{E}[\mathcal{P}_G | \mathcal{P}_G > 0, \mathcal{T}]$$

8. RESULTS

PART 01
- Probability of Outage
- Probability of Derating

PART 02
- Estimated Derating (non-outage scenario)
- Observed Data

Final Result
- Probability of Derating
- Estimated Derating (non-outage scenario)
- Combined Prediction
- Observed Data

9. MODEL VALIDATION

Metric	Value
Accuracy	0.6046
Precision	0.6333
Recall	0.7753
F1 Score	0.6955
AUC-ROC	0.6670
Pearson Chi-Square	5.0572
Pearson p-value	0.6164
MAE	0.1210
RMSE	0.1587

- Residuals
- Zero Residual Line
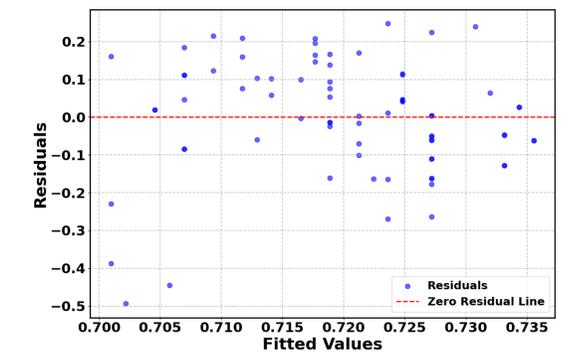
10. CONCLUSION AND FUTURE WORK

- This study serves as a foundational effort in understanding gas-fired generator vulnerabilities during extreme cold events using publicly available data.

- This approach aids system operators in anticipating capacity reductions and identifying vulnerable generating units ahead of severe cold weather events.

- Collaboration is needed to acquire generator-specific outage and weather data will address the data limitation, reduce model uncertainty and increase predictive reliability.

11. REFERENCES

1. NOAA National Centers for Environmental Information, "Billion-Dollar Weather and Climate Disasters," 2024. [Online].

2. S. Murphy et al., "A time-dependent model of generator failures andrecoveries captures correlated events and quantifies temperature depen-dence," Applied energy, vol. 253, p. 113513, 2019.

3. FERC, NERC and Regional Entity Staff Report, "Inquiry into Bulk-Power System Operations During December 2022 Winter Storm Elliott," Online, 2023. [Online].

4. F. Belotti, P. Deb, W. G. Manning, and E. C. Norton, "twopm: Two-part models,"The Stata Journal, vol. 15, no. 1, pp. 3–20, 2015.