A Wildfire-Aware Unit Commitment for Enhanced Grid Resilience and Operational Performance

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***Abstract*—The growing threat of wildfires poses a dual risk to electric power systems, which can both cause ignitions and suffer from large-scale outages. While Public Safety Power Shutoffs (PSPS) are a common mitigation tool, they result in significant social and economic costs. This paper proposes a pragmatic Wildfire-Aware Unit Commitment (WAUC) formulation to proactively manage wildfire risk in day-ahead market operations without resorting to widespread de-energization. Our approach augments the standard unit commitment objective with a tunable, risk-weighted penalty on power flows through transmission lines with high wildfire outage probabilities. This incentivizes the system to find alternative, lower-risk dispatch patterns. Numerical experiments on a geographically-informed mini-WECC test system demonstrate that the WAUC approach successfully reroutes power from high-risk corridors. The proposed method significantly reduces the expected magnitude of involuntary load shedding and transmission line overload hours while maintaining competitive operational costs with more predictable economic outcomes. The proposed penalty-based framework thus offers a practical and effective tool for system operators to enhance grid resilience against wildfire threats.**

***Index Terms*—Unit commitment (UC), wildfire risk, grid resilience, load shedding, transmission overload, operational cost**

I. Introduction

The increasing frequency and intensity of wildfires, exacerbated by climate change, pose a significant and growing threat to both public safety and the reliability of electric power systems [1]. The interplay is dangerously reciprocal: power system equipment can ignite devastating wildfires, while active fires can damage critical infrastructure, leading to widespread outages [2]. This dual risk forces system operators to navigate a complex landscape of operational decisions, balancing the imperative to maintain service against the need to mitigate catastrophic fire ignition risk, particularly during periods of extreme weather.

The primary tool currently employed by utilities to manage this risk is the Public Safety Power Shutoff (PSPS), a preemptive measure involving the de-energization of transmission lines in high-threat areas [3]. While effective at preventing ignitions, PSPS is a blunt instrument that can leave millions of customers without power, causing significant social and economic disruption. This has spurred a wave of research aimed at developing more sophisticated operational strategies that can reduce wildfire risk with less impact on system reliability.

A significant body of work has focused on optimizing PSPS decisions. For example, a two-stage stochastic program has been proposed to plan preemptive de-energization over multiple time periods, minimizing both wildfire damage and load-shedding losses [4]. Similarly, a two-stage robust optimization problem has been formulated to find an improved balance between de-energizing lines and serving customers, especially in systems with high renewable penetration [5]. Taking a more comprehensive approach, a mean-CVaR stochastic framework has been introduced that co-optimizes generator commitment and transmission line de-energization strategies under demand uncertainty [6].

Beyond optimizing shutoffs, other operational levers have been explored. The use of dynamic line ratings (DLR) has been shown to reduce ignition risk by managing line flows more granularly, providing an alternative to complete de-energization [7]. From a long-term planning perspective, a methodology for distribution system investment has been presented that considers how power flow levels endogenously influence line failure probabilities, enabling a more risk-aware grid design [8]. Distinct from grid operations, other research addresses the crucial task of wildfire response itself. One approach models the allocation of firefighting resources as a partially-observable Markov decision process to combat active fires more effectively [2]. In a similar vein, a structured decision-making process has been applied to help reorganize wildfire dispatching systems, improving the efficiency of multiagency response efforts [9].

Despite this progress, a gap remains between complex, computationally intensive stochastic optimization models and the pragmatic needs of day-ahead system operators. While de-energization is a primary focus, less attention has been given to how routine day-ahead unit commitment (UC) can be subtly adjusted to proactively reduce wildfire exposure without resorting to shutoffs. Many models treat de-energization as the main decision and its economic consequences as an output, rather than embedding wildfire risk directly into the commitment and dispatch process itself. This separation can lead to suboptimal commitments that unnecessarily route power through high-risk corridors, leaving the system vulnerable.

This paper proposes a pragmatic wildfire-aware unit commitment (WAUC) formulation that bridges this gap by augmenting a standard day-ahead UC objective with a tunable, risk-weighted penalty on power flows through lines identified as high-risk. Our key contributions are:

- A compact, penalty-based WAUC formulation that biases commitment and dispatch away from high-ignition-

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probability corridors, while preserving standard UC structure and solver compatibility.

- An end-to-end workflow to ingest line-level wildfire risk probabilities and evaluate the resulting operational outcomes via hierarchical Monte-Carlo outage simulations.
- Numerical experiments on a geographically-informed test system demonstrating that our approach reduces expected involuntary load shedding and transmission line overload hours while maintaining competitive operational costs and providing more predictable economic outcomes.

Compared with traditional approaches, such as manual redispatch and adopting powerflow controls, the WAUC approach leverages additional corrective actions by adding risk-weighted flow penalties to market-based generator dispatch decisions.

The remainder of this paper is organized as follows. Section II presents the WAUC mathematical formulation and describes how per-line wildfire probabilities are embedded as flow penalties. Section III discusses results, operational implications, and limitations. Lastly, Section IV concludes and outlines directions for future work.

II. Methodology

This section presents a proactive unit-commitment optimization that incorporates wildfire-induced transmission-line outage probabilities into a conventional unit-commitment formulation via a penalty-based power-flow management term. This approach is consistent with established industry practices of penalizing power flow violations, effectively reducing power flow on specific lines that are highly susceptible to tripping during wildfires. The objective is to reduce the operational exposure of the system to lines that the wildfire-risk model identifies as having elevated outage likelihoods, thereby lowering the expected impact of wildfire-induced line trips while preserving economic efficiency.

A. Wildfire-induced line outage probabilities

The per-line wildfire outage probability used throughout this paper, denoted p_i^c, is obtained from the Wildfire Risk to Energy Systems (WiRES) framework [10]. WiRES combines geospatial wildfire-hazard data, PSPS/response logic, and a conditional sequence of steps (Severity $\rightarrow$ Response $\rightarrow$ Damage $\rightarrow$ Loss) to translate weather, vegetation, and operational factors into a cumulative probability that a transmission line becomes non-operational. In compact form WiRES represents the per-line outage probability as

$$p_i^c \;=\; P[L|T] \;=\; P[L|D]\; P[D|R]\; P[R|S]\; P[S|T], \tag{1}$$

where the right-hand-side terms correspond to the Severity, Response, Damage, and Loss conditional probabilities defined by the WiRES pipeline. Implementation details, input data (for example flame-length probabilities, burn potential, and PSPS modeling), and the WiRES contingency/impact analysis workflow are described in the referenced WiRES technical documentation [10].

The p_i^c outputs inherit spatial and temporal structure from WiRES inputs (e.g., seasonal or forecast-driven updates). In this work we accept WiRES outputs as time-aggregated seasonal probabilities p_i^c. These probabilities are read into the unit commitment routine and mapped to the network model line identifiers prior to optimization.

B. Penalty-based wildfire-aware unit commitment (WAUC)

To encourage preemptive reduction of flows on lines with high wildfire outage probability, we augment the traditional unit commitment objective function with a flow-dependent wildfire-penalty term. For line i define the penalty scaling factor

$$\lambda_i \;=\; \left(100\, p_i^c\right)^2 \beta, \tag{2}$$

where the multiplicative 100 converts probability to percent (improving numeric conditioning) and the quadratic mapping emphasizes higher-risk lines (marginally larger p_i^c receive disproportionately larger penalties). The user-set scalar β controls the trade-off between economic cost and wildfire-risk mitigation. The per-line penalty applied in the unit commitment objective is

$$\Pi_{i,t} \;=\; \lambda_i\, |P_{f,i,t}|, \tag{3}$$

Algorithm 1: Wildfire-Aware Unit Commitment (WiRES-integrated)

Require: System topology, generator parameters, load forecast, and WiRES inputs.
Ensure: Optimal unit commitment schedule $\{u_{g,t}^*, P_{g,t}^*\}$ with wildfire risk mitigation

1: **Initialize:** set scaling ratio β, solver tolerances, convergence tolerance ϵ
2: **Run WiRES (pre-step):** compute per-line outage probabilities $\{p_i^c\}_{i=1}^{N_\ell}$ using the WiRES framework; export p_i^c.
3: **Load:** mapping between WiRES line IDs and unit commitment network line IDs
4: **Compute:** PTDF matrix (or equivalent power-flow linearization)
5: **for** $i = 1$ to N_ℓ **do**
6: $\quad \lambda_i \leftarrow \left(100\, p_i^c\right)^2 \beta$
7: **end for**
8: **Formulate UC problem:**
9: $\quad$ **Add penalty term:** $\Pi_{\text{total}} = \sum_{t,i} \lambda_i |P_{f,i,t}|$ to objective, subject to UC constraints
10: **Solve:** Mixed-integer optimization problem
11: **Extract:** Optimal commitment $\{u_{g,t}^*\}$, dispatch $\{P_{g,t}^*\}$, flows $\{P_{f,i,t}^*\}$
12: **Compute risk metrics:** $\Pi_{\text{total}} = \sum_{t,i} \lambda_i |P_{f,i,t}^*|$, risk-weighted flow $\sum_{t,i} p_i^c |P_{f,i,t}^*|$
13: **Post-analysis:** compare unit commitment outcomes with baseline (no-wildfire-penalty) and run WiRES-driven contingency simulations to quantify expected unserved energy and resilience benefits.

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with $P_{f,i,t}$ the real-power flow on line i at time t. The total wildfire penalty added to the unit commitment objective is

$$\Pi_{\text{total}} = \sum_{t=1}^{T}\sum_{i=1}^{N_\ell} \lambda_i \, |P_{f,i,t}| = \sum_{t=1}^{T}\sum_{i=1}^{N_\ell} \left(100\, p_i^c\right)^2 \beta \, |P_{f,i,t}|. \tag{4}$$

The penalty mechanism operates through economic incentives: by artificially increasing the marginal cost of utilizing high-risk transmission corridors, the optimization algorithm is naturally guided toward alternative, less vulnerable power flow paths. This market-based approach preserves the fundamental structure of unit commitment while systematically reducing exposure to wildfire-induced contingencies. The effectiveness of this methodology depends critically on network topology—sufficient alternative paths must exist to enable meaningful flow redistribution without compromising system reliability constraints. The specific procedure is represented in Algorithm 1.

III. Numerical Tests

A. Simulation Setup

To show the effectiveness of our proposed method, we perform numerical tests on the mini-WECC system, as depicted in Fig. 1. When generating scenarios, we employ a hierarchical Monte Carlo approach: first, we sample from a uniform distribution between 35 and 50 to determine the number of lines out in each contingency, and the specific lines are then selected based on line-specific contingency probabilities derived from WiRES. We compare two cases: the ***BASE* case** adopts the generation dispatch based on the UC solution without the penalty in (4), while the ***WAUC* case** implements the wildfire-aware UC, which includes the penalty term in (4) in the objective function with $\beta = 2.5$. For the analysis, we generate 100 contingency sets representing different wildfire scenarios. Based on these scenarios, we run a day-ahead market simulation using EGRET [11], which is a Python-based grid optimization tool. In each case, we fix the generation dispatch determined by the respective UC formulation and then simulate the impact of the same 100 contingency scenarios on

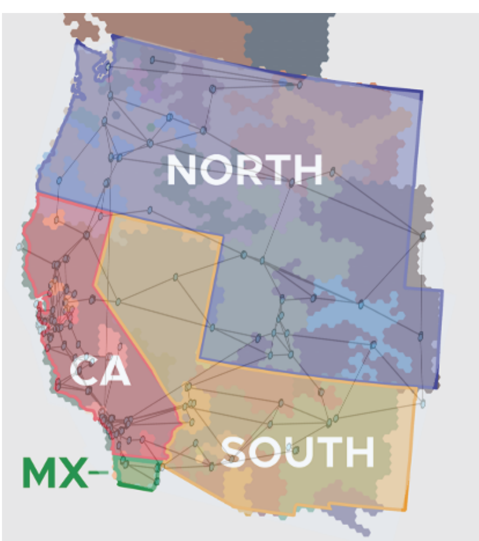

Fig. 1: Mini-WECC system configuration.

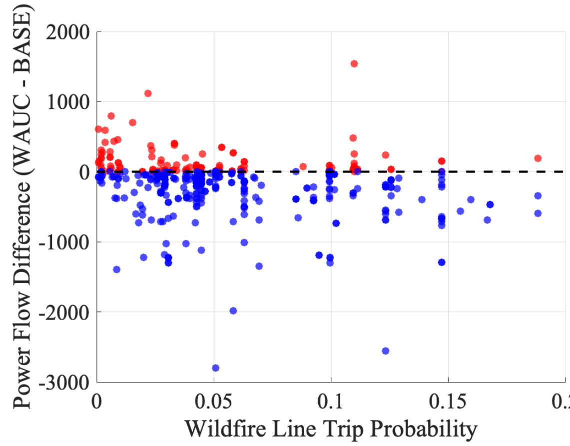

Fig. 2: Power flow difference between *BASE* and *WAUC*.

the system operation. We then compare the key performance metrics, including system-wide total cost, load shedding, and overload hours after the contingencies occur.

B. Power Flow Comparison

To analyze how the penalty term affects system operation, we compare the power flow on each transmission line between the *BASE* and *WAUC* cases. Fig. 2 illustrates this power flow difference (WAUC - BASE) as a function of the wildfire line trip probability.

The results reveal a clear pattern. With the exception of some lines with low trip probabilities (red points), power flow is reduced across the vast majority of the transmission network (blue points). This widespread reduction is a direct consequence of the penalty term (4) applied in the WAUC formulation. By penalizing power transmission, the optimization favors a more localized generation dispatch strategy, where generators serve nearby loads to minimize reliance on the transmission system.

Crucially, the most significant power flow reductions are observed on lines with higher wildfire probabilities. By proactively lowering the amount of power transmitted through these vulnerable corridors, the WAUC strategy reduces the system's dependence on them. Therefore, if a high-risk line is tripped by a wildfire, the resulting operational impact is lessened. This preemptive flow management translates into improved system resilience and reduced load shedding, as demonstrated in the following sections.

C. System-wide Performance Metrics Analysis Comparison

To evaluate the effectiveness of the wildfire-aware unit commitment strategy, we examine three critical system-wide performance metrics. First, we analyze the total system cost, which reflects the economic efficiency of the dispatch strategy. Second, we investigate load shedding patterns, a key reliability indicator that quantifies the system's ability to maintain power delivery during contingency events. Third, we introduce a novel metric of total overload hours to assess network stress and equipment risk during wildfire scenarios.

The comparison of system-wide total costs in Fig. 3 reveals the economic implications of the wildfire-aware dispatch strategy. The penalty term in (4) is excluded from the total cost, as

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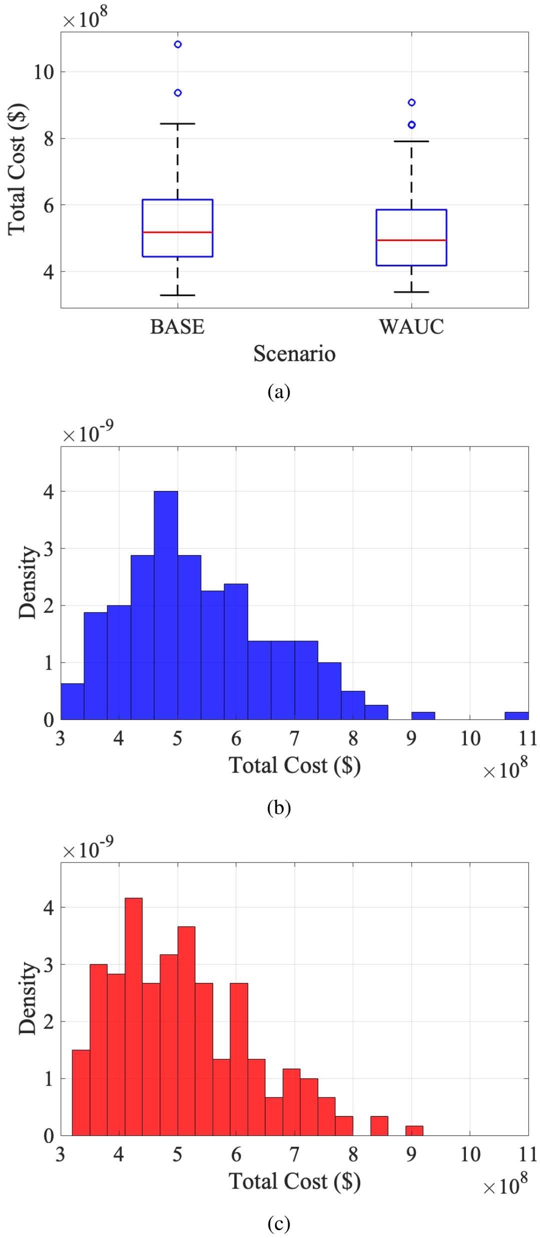

Fig. 3: System-wide total cost (a) boxplot and histogram of (b) *BASE* and (c) *WAUC*.

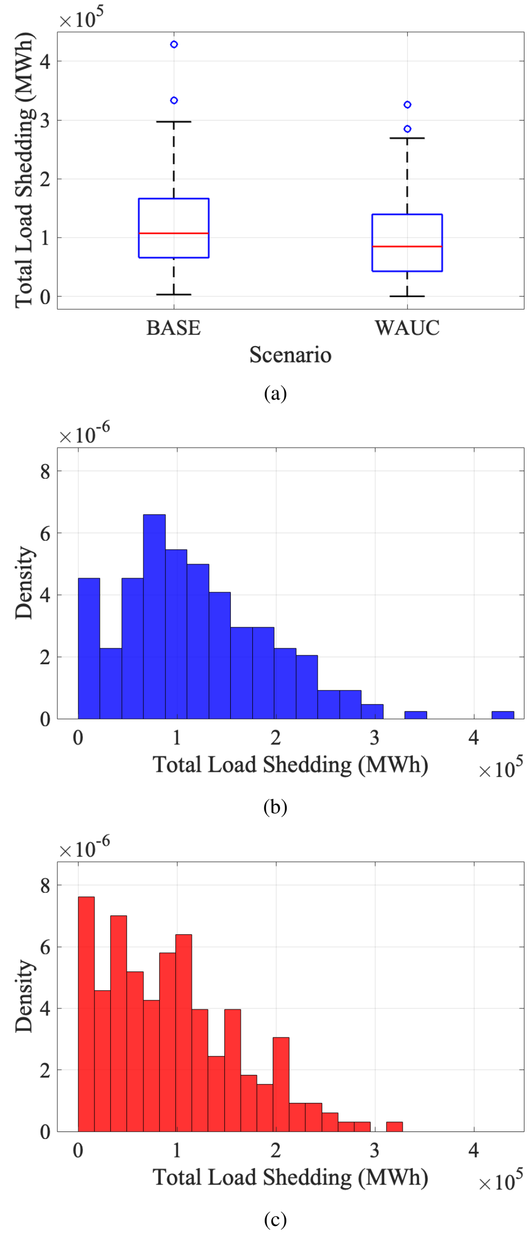

Fig. 4: System-wide load shedding (a) boxplot and histogram of (b) *BASE* and (c) *WAUC*.

it is a modeling artifact for solving the WAUC problem, not an actual cost incurred during system operation. The boxplot in Fig. 3(a) shows that both *BASE* and *WAUC* cases have similar median costs, with the *WAUC* case exhibiting a slightly lower median and a more compact interquartile range. The histograms provide additional insight: while the *BASE* case (Fig. 3(b)) shows a cost distribution spanning from 3.5 to 10×10^8 ($) with a pronounced peak in the 4 to 5×10^8 ($) range, the *WAUC* case (Fig. 3(c)) demonstrates a broader distribution across the 3 to 9×10^8 ($) range. This suggests that while the proactive wildfire-aware approach maintains competitive operational costs, it shows greater variability in economic outcomes across different scenarios.

The analysis of system-wide load shedding in Fig. 4 demonstrates the reliability advantages of the *WAUC* strategy. The boxplot in Fig. 4(a) shows that both cases have median load shedding values around $1{\times}10^5$ (MWh), but the *BASE* case exhibits a slightly higher median and greater variability in load curtailment events. The histogram comparison further emphasizes this difference: both distributions show dominant peaks at zero load shedding, but the *BASE* case (Fig. 4(b)) has a secondary peak around $1{\times}10^5$ (MWh) and a longer tail extending to higher shedding values, whereas the *WAUC* case (Fig. 4(c)) shows a more pronounced peak at zero with a more gradual decay, confirming that the wildfire-aware dispatch effectively mitigates extreme load curtailment scenarios.

Fig. 5 presents the comparison of total overload hours, which quantifies the cumulative time when transmission line power flows exceed their emergency ratings across all network branches. The total overload hours metric is calculated by summing, for each hour in the 24-hour simulation period, the number of transmission lines where the absolute value of

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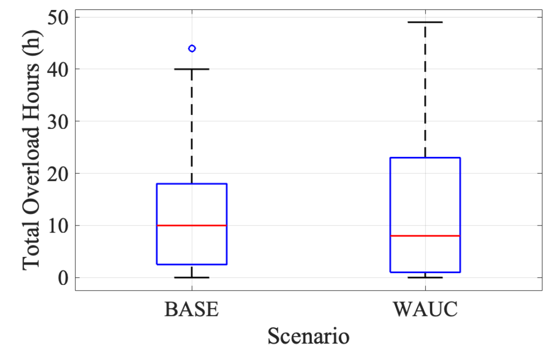
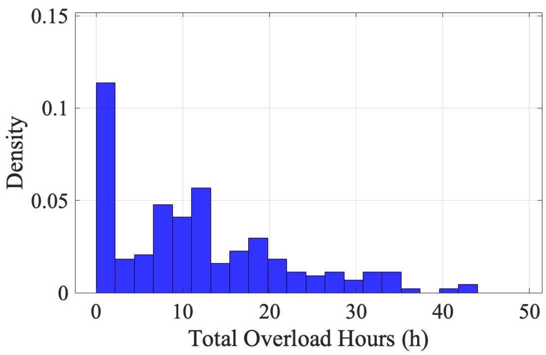


(a)



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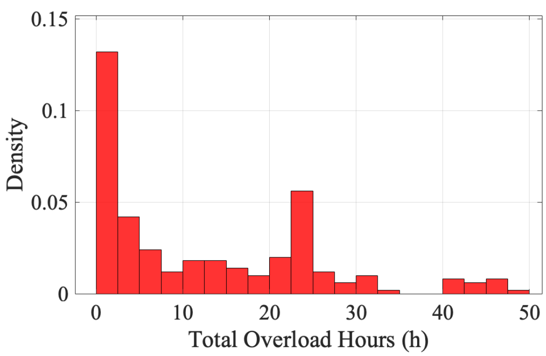

(c)

Fig. 5: System-wide overload hour (a) boxplot and histogram of (b) *BASE* and (c) *WAUC*.

power flow exceeds the line's emergency rating capacity. This metric serves as an indicator of network stress and potential equipment damage risk during wildfire events. The boxplot in Fig. 5(a) reveals a notable difference between the two strategies: the *BASE* case shows a median of approximately 10 overload hours with significant variability, while the *WAUC* case demonstrates a lower median of about 8 hours. The histograms provide complementary evidence: the *BASE* case (Fig. 5(b)) exhibits a prominent peak at zero overload hours followed by a relatively uniform distribution across the 5-40 hour range, indicating frequent occurrence of moderate to high overload conditions. In contrast, the *WAUC* case (Fig. 5(c)) shows an even more pronounced peak at zero overload hours with rapid decay, demonstrating that the proactive dispatch strategy effectively minimizes transmission line stress and reduces the risk of equipment overloading in wildfire scenarios.

IV. Conclusion

We presented a wildfire-aware unit commitment (WAUC) approach that embeds line-level wildfire outage probabilities directly into the day-ahead commitment objective via a risk-weighted line-flow penalty. The formulation preserves the standard UC structure while producing dispatch patterns that reduce exposure to high-ignition-probability corridors. On a mini-WECC case using WiRES-like probability inputs and hierarchical Monte Carlo evaluation, WAUC produced significant operational benefits, as demonstrated on a 240 bus representation of the WECC and contingencies based on probabilities from the WiRES framework. The wildfire-aware strategy effectively reduced expected involuntary load shedding while maintaining competitive total system costs. Additionally, WAUC substantially decreased transmission line overload hours, reducing equipment damage risk and enhancing system resilience during wildfire events. These reliability improvements were achieved with minimal economic penalty, demonstrating that proactive wildfire-aware dispatch can simultaneously enhance safety and maintain operational efficiency.

Future work should explore joint stochastic formulations that co-optimize explicit de-energization and commitment, and investigate dynamic penalty adjustments based on real-time wildfire risk assessment.

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