How Does Wildfire Affect Energy Systems?

GRID–WILDFIRE PANEL

The Grid–Wildfire Feedback Loop

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University of Virginia

DIRECTION 1 · THE WELL-STUDIED SIDE

Wildfires break the grid

- **Physical destruction**
- **Forced de-energization**
- **Cascading outages**
- **Smoke-induced faults**

Case in point

Smokehouse Creek Fire[1]

Texas, 2024

The largest wildfire in Texas history knocked out power to thousands through both pre-emptive shutoffs and direct grid damage.

This direction, fire to grid, is where most of the literature already lives.

DIRECTION 2 · THE DESTRUCTIVE SIDE

The grid ignites wildfires

Conductor slap | Vegetation contact | Equipment failure | Conductor sag | High-impedance arcing

Camp Fire [2]

2018 · PG&E

Arc between a line and a tower dropped molten metal onto dry vegetation.

California's deadliest fire: 85 deaths, ~18,800 structures. Drove PG&E to bankruptcy.

Dixie Fire [3, 4]

2021 · PG&E

A tree contacted energized distribution lines near the Cresta Dam.

Second largest single-ignition fire in state history

Eaton Fire [5]

2025 · SCE

An idle transmission line re-energized during extreme wind.

14,000 acres, 19 deaths, ~9,400 structures.

Lahaina, Maui [6]

2023 · Hawaiian Electric

Downed lines amid hurricane-force winds in tinder-dry conditions.

Deadliest US wildfire in over a century: ~100 deaths. $2B pending settlement.

A small share of ignitions, an outsized share of loss

~2-3%

ignitions are grid-induced (varies by state. ~ 10% in California)

From 2015-2020

~70%

of wildfire damages in California were due to grid-induced fires[7]

Why?

- High energy ignition
- Often happen during extreme weather condition
- Abundant fuel right under high-voltage lines

Why is it rising? (200/yr in the early 1990s to ~2,500/yr today)[8]

Aging infrastructure

Climate-driven aridity

WUI expansion

The literature is split into two silos

Grid resilience against wildfire

MATURE, LARGE BODY OF WORK

- Outage and equipment-damage modeling
- Physical hardening and undergrounding
- Post-disaster restoration and recovery

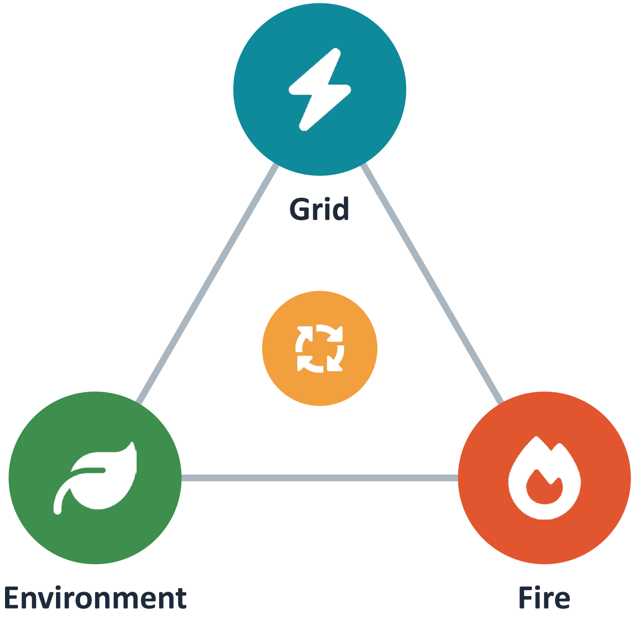
Grid as an ignition source

RECENT AND STILL EMERGING

- Environmental wildfire-risk indices
- Public Safety Power Shutoff optimization
- Isolated fault and waveform studies

THE GAP

What is missing: the feedback loop



Two blind spots

Grid resilience is studied without asking how the grid itself starts or intensifies the fire.

Wildfire mitigation is studied without the lens of grid operations and dynamics.

PLANNING BLIND SPOT

Expansion planning sees fire, but not the grid as its cause

How planning works today

- Wildfire risk from environmental proxies →
- Fed into expansion and routing models →
- Hardened, expanded infrastructure

The blind spot: the grid is modeled only as a victim of fire, not as an endogenous ignition source.

Consequence capital may flow to assets that raise regional fire hazard.

What is needed expansion that accounts for the bidirectional grid–fire interaction.

IGNORED FACT

Grid-induced wildfires potentially leave traces in sensor data

Maui, August 2023 · Whisker Labs "Ting" grid sensors

Ignition, caught twice: The morning of Aug 8, a camera recorded an arc flash as the fire started, and several sensors logged a sharp voltage drop at that same instant.

A storm of faults: 78 sensors logged 122 grid faults from Aug 7 to 8, far above a normal day, with stress climbing for hours before ignition. [9]

Not a one-off: The same sensors caught voltage swings minutes before a 2022 Orange County fire destroyed 20 homes.[10]

THE OPERATIONAL TOOL

PSPS is blunt, and blind to real-time grid data

What it leans on

Historical risk indices and weather forecasts. Decisions are made largely offline, ahead of time.

What it ignores

The rich real-time telemetry already on the grid: high-frequency waveforms and PMU data that carry ignition precursors.

The cost of bluntness

- Over-conservative shutoffs, unnecessary outages
- Reliability sacrificed for a coarse safety margin

THE OPPORTUNITY

Grid-induced fires leave fingerprints in grid data

Arcing and high-impedance faults could leave signatures in high-frequency waveforms and PMU data. Signal processing and ML can potentially surface them before ignition.

Real-time

Detect precursor signatures and trigger autonomous, protective mitigation.

Short-term

Fuse grid and environmental data for days-ahead risk and proactive action.

Long-term

Fire-aware grid expansion and post-fire restoration that hardens by design.

Close the loop: a resilient, wildfire-aware grid.

Challenge: Availability of grid data!

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6-Associated Press (2024, October 3). *Maui fire that killed 102 in Lahaina erupted from earlier blaze firefighters thought they put out, investigation finds.* (via Fortune) https://fortune.com/2024/10/03/maui-fire-killed-102-lahaina-erupted-earlier-blaze-firefighters-investigation

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How Do Wildfires Affect Energy Systems?

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Acknowledgement

SMART GRID LABORATORY
George Washington University

FIRE WALL

THE GEORGE WASHINGTON UNIVERSITY 1821

NSF

UAA
UNIVERSITY of ALASKA ANCHORAGE

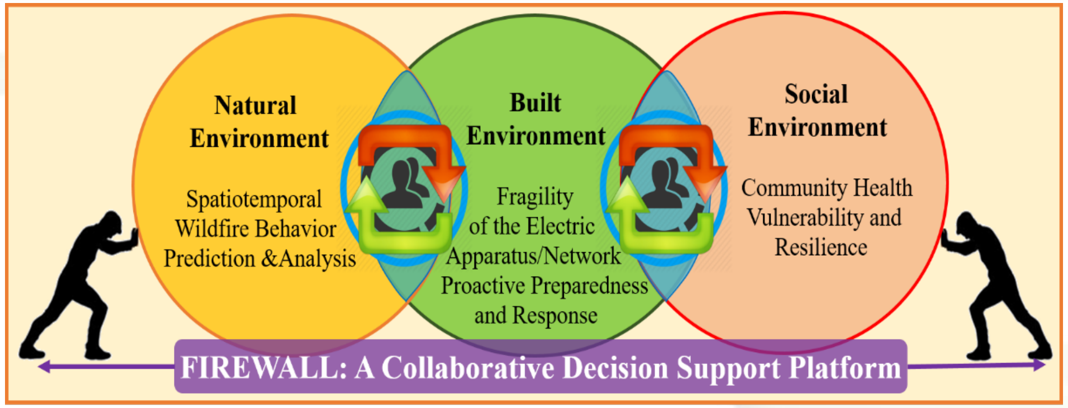
UAF
UNIVERSITY OF ALASKA FAIRBANKS

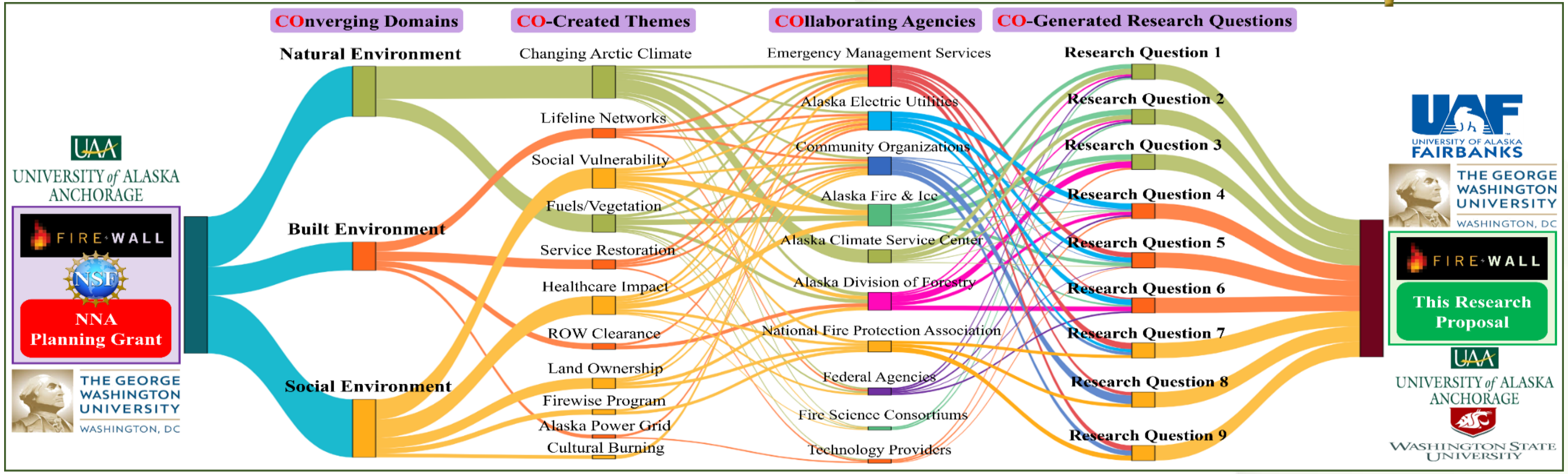
WASHINGTON STATE UNIVERSITY

ALASKA FIRE SCIENCE CONSORTIUM

ACEP
Alaska Center for Energy and Power

Foundations for Improving Resilience in the Energy Sector against Wildfires on ALaskan Lands (FIREWALL)





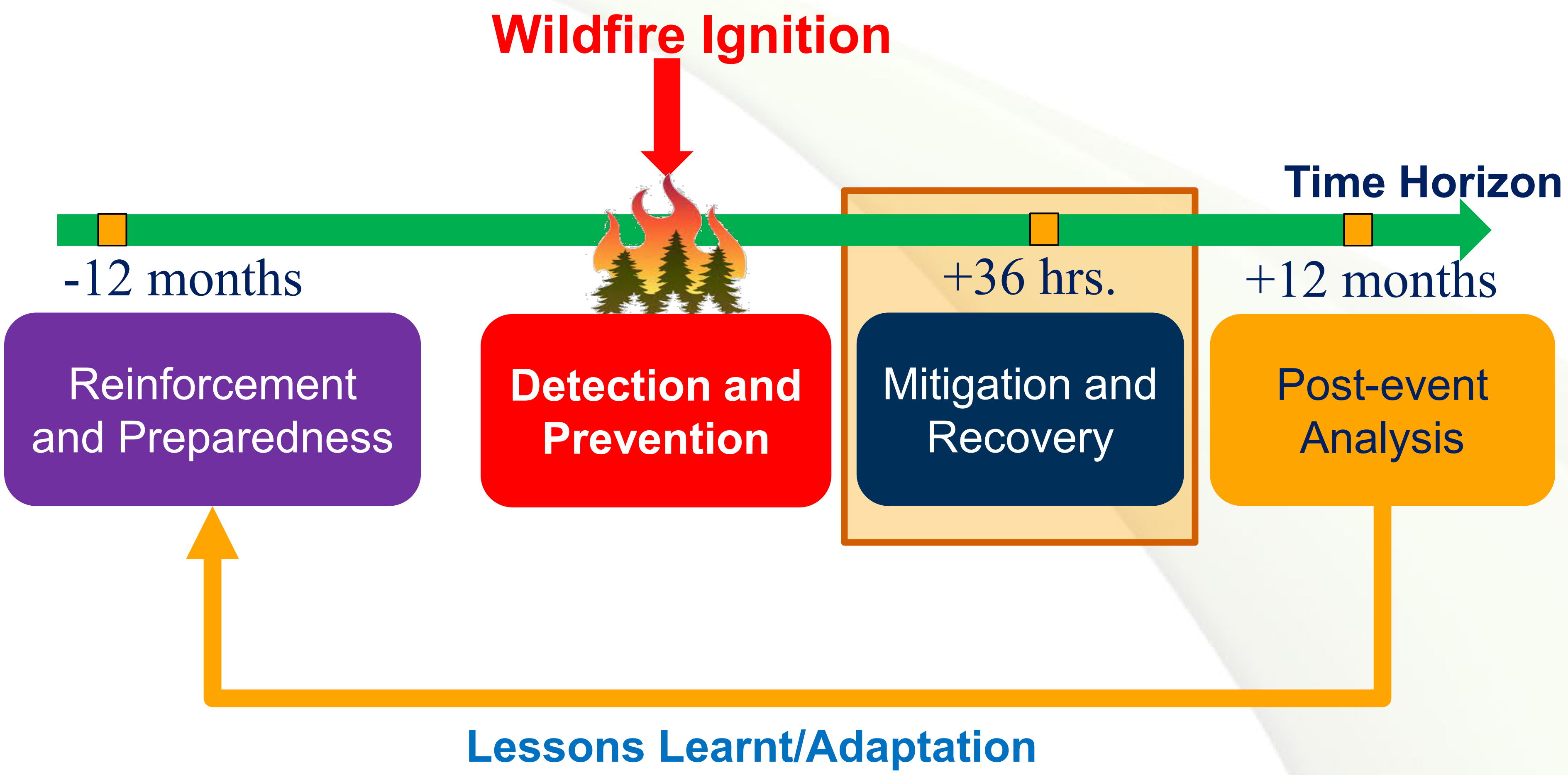
"If we can solve this problem in Alaska, with all of the challenges posed by our unique circumstances, then we can solve it anywhere,"

US Senator Lisa Murkowski,

Keynote Speaker at the FIREWALL Workshop 2021.

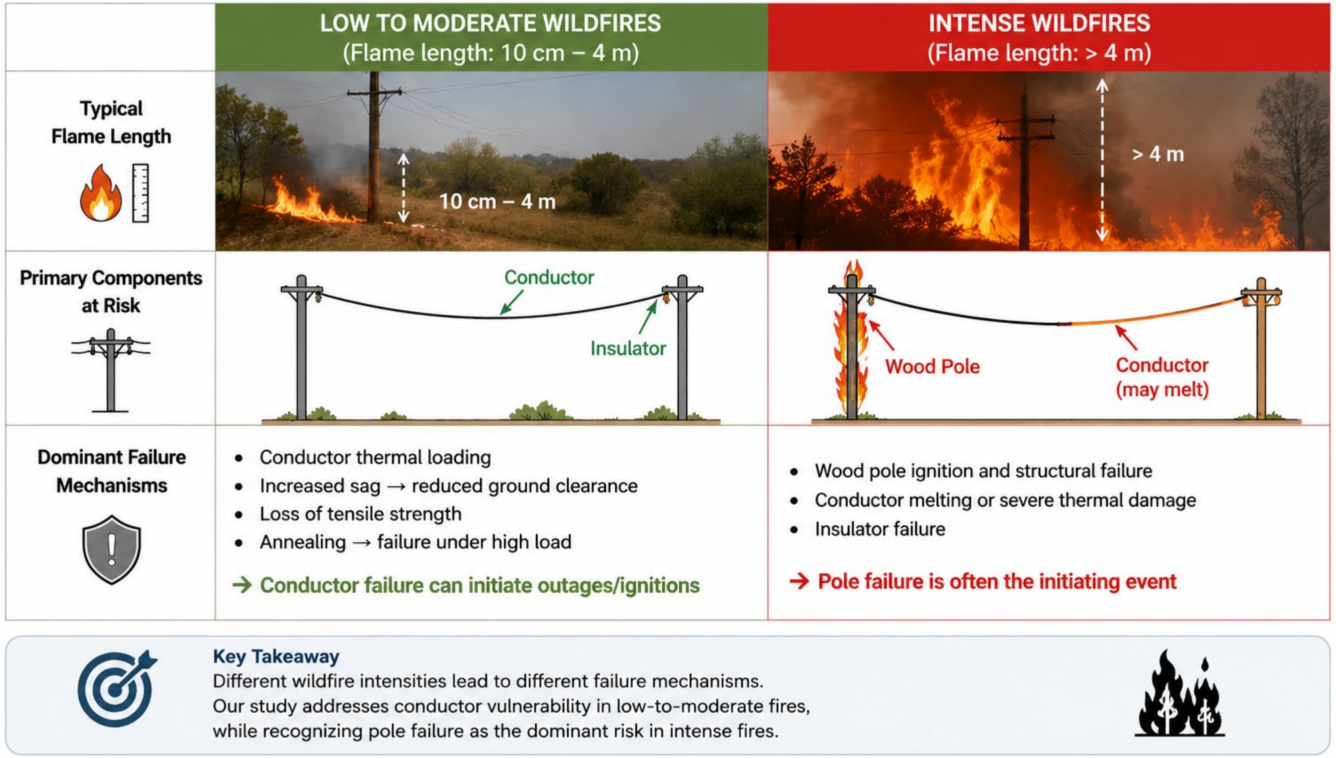
Problem Statement

❑ Wildfires and The Electricity Grid: Strategies



Power Grid Resilience to a Progressive Fire

❑ Heat Transfer Mechanisms Acting on Overhead Power Lines



	LOW TO MODERATE WILDFIRES (Flame length: 10 cm – 4 m)	INTENSE WILDFIRES (Flame length: > 4 m)
Typical Flame Length	10 cm – 4 m	> 4 m
Primary Components at Risk	Conductor; Insulator	Wood Pole; Conductor (may melt)
Dominant Failure Mechanisms	• Conductor thermal loading • Increased sag → reduced ground clearance • Loss of tensile strength • Annealing → failure under high load → Conductor failure can initiate outages/ignitions	• Wood pole ignition and structural failure • Conductor melting or severe thermal damage • Insulator failure → Pole failure is often the initiating event

Key Takeaway
Different wildfire intensities lead to different failure mechanisms.
Our study addresses conductor vulnerability in low-to-moderate fires,
while recognizing pole failure as the dominant risk in intense fires.

Note: Under extreme wildfire exposure, wooden poles may ignite and fail, while conductors may experience melting or severe thermal damage. This study instead focuses on small-to-moderate flame exposures (approximately 10 cm–4 m), where conductors may experience significant thermal stress without necessarily reaching melting conditions.

Power Grid Resilience to a Progressive Fire

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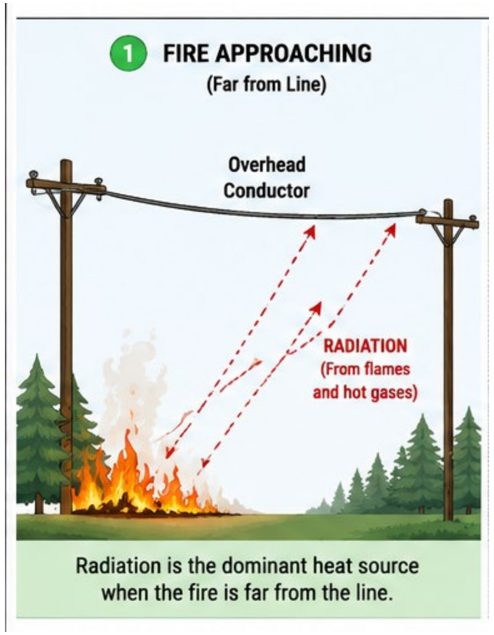

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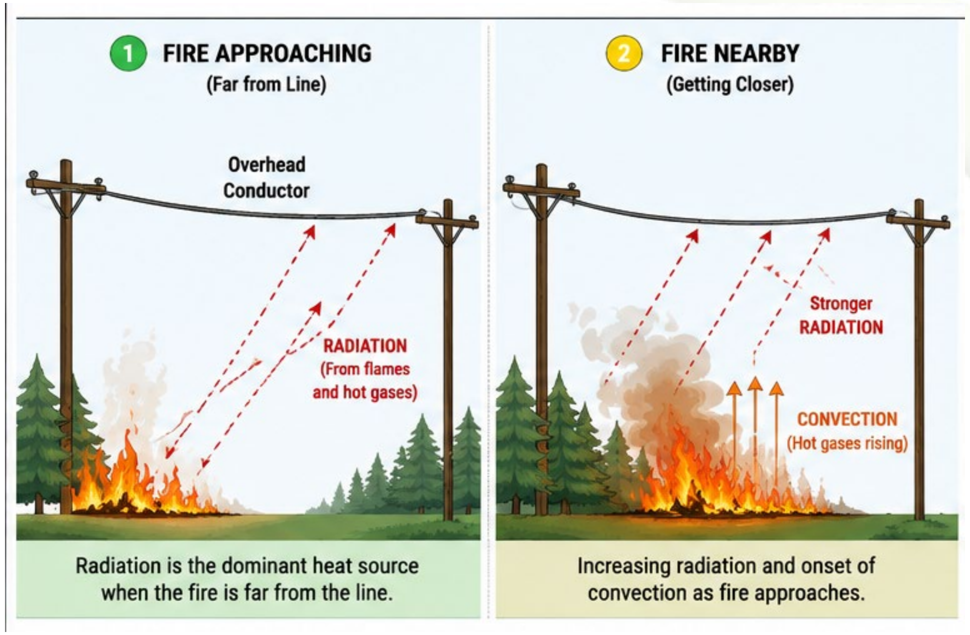

Power Grid Resilience to a Progressive Fire

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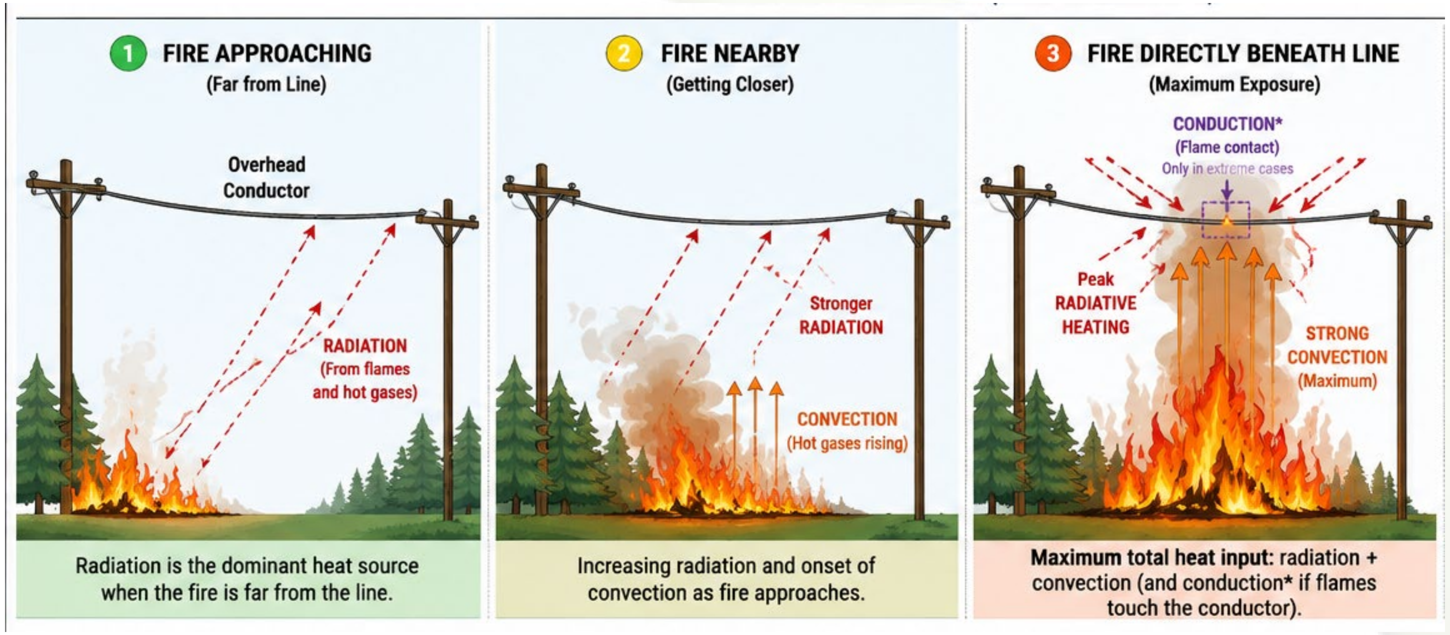

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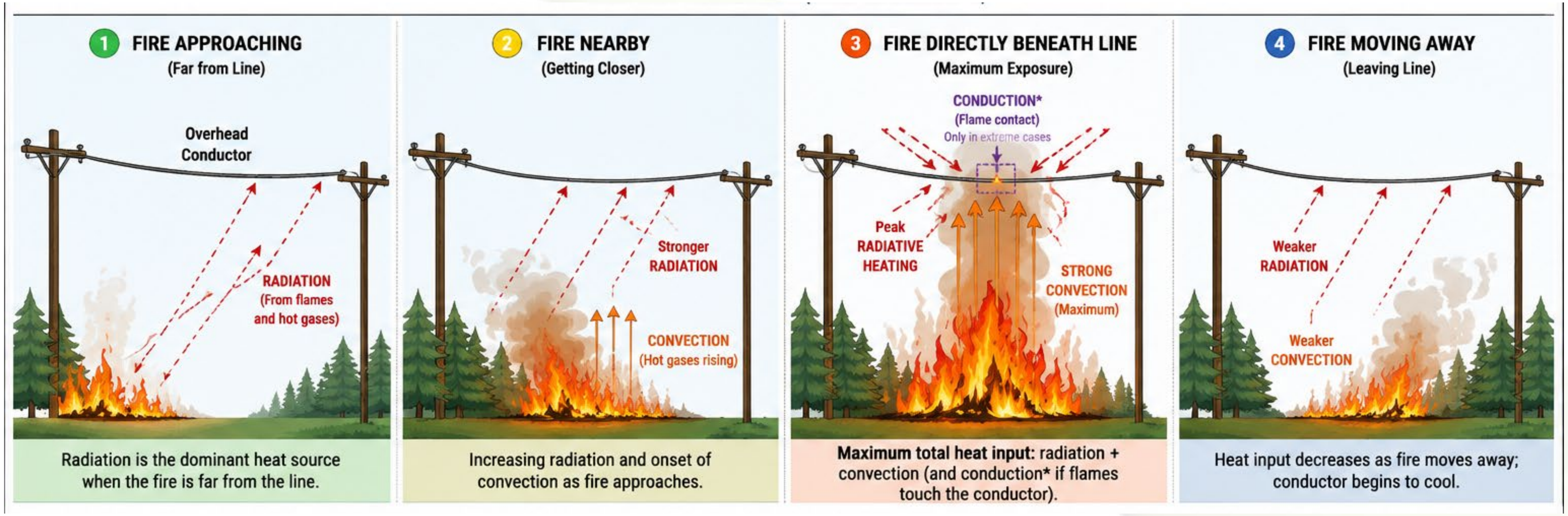

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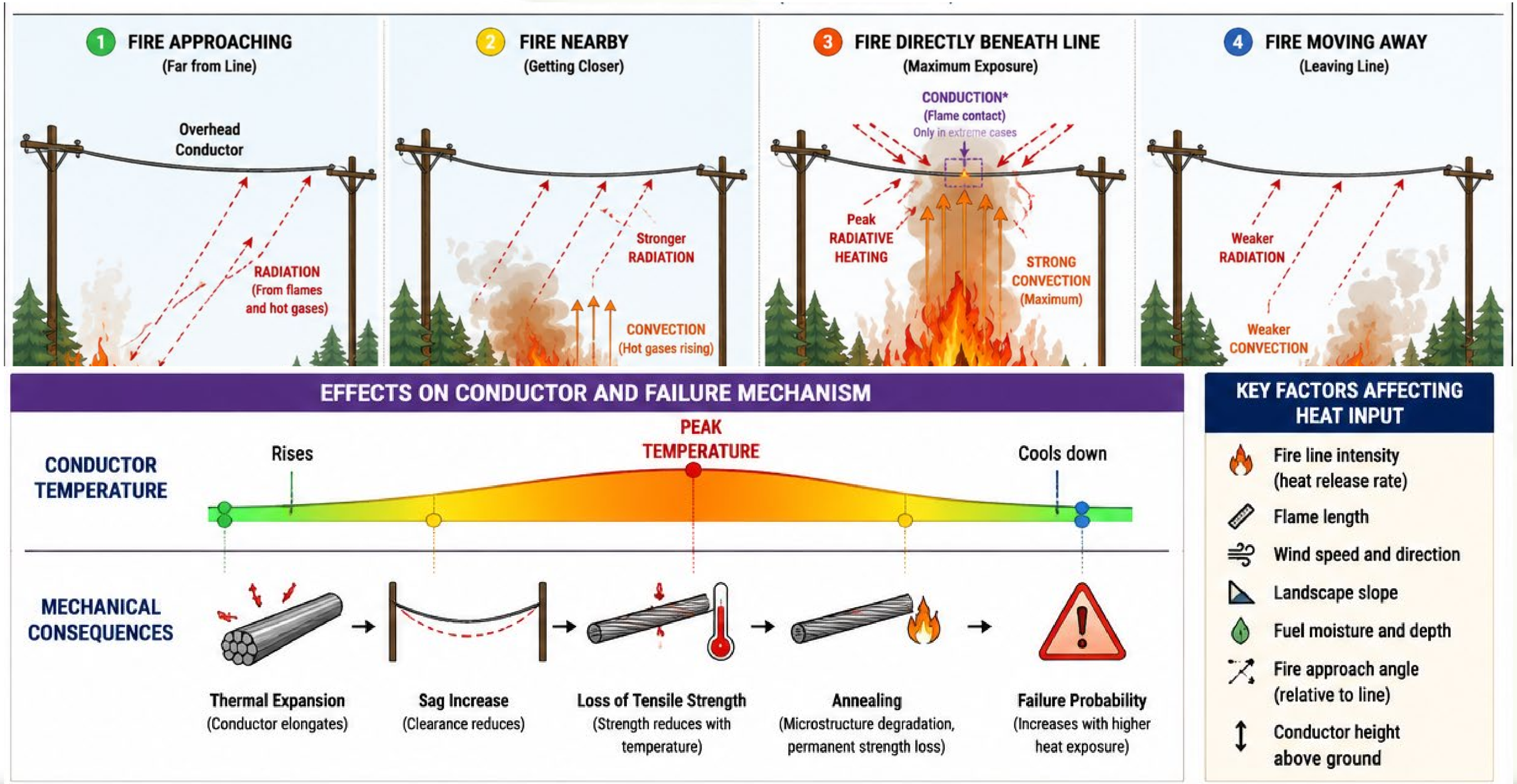

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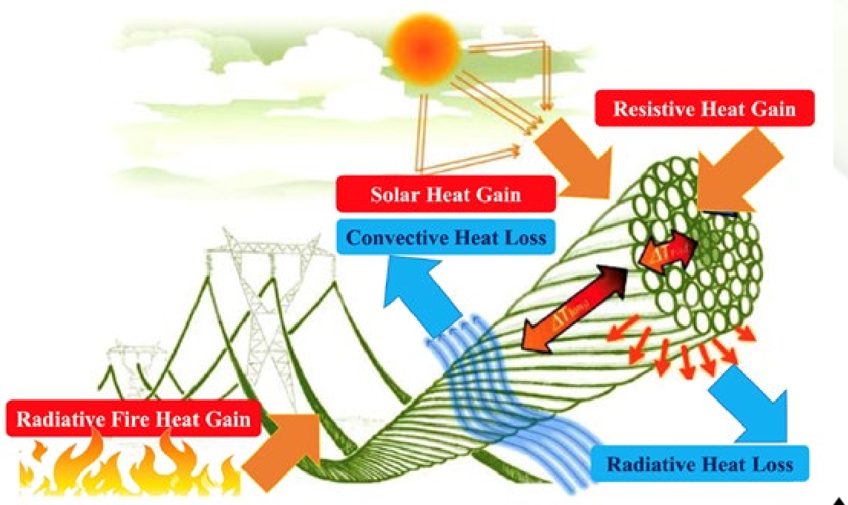
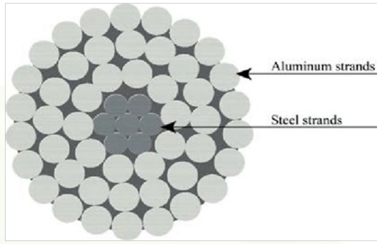
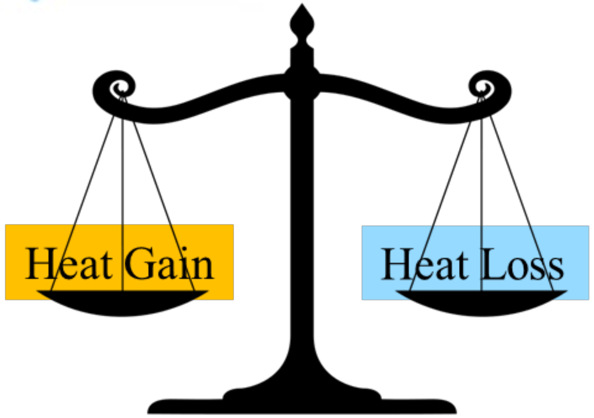
❑ Heat Transfer Mechanisms Acting on Overhead Power Lines

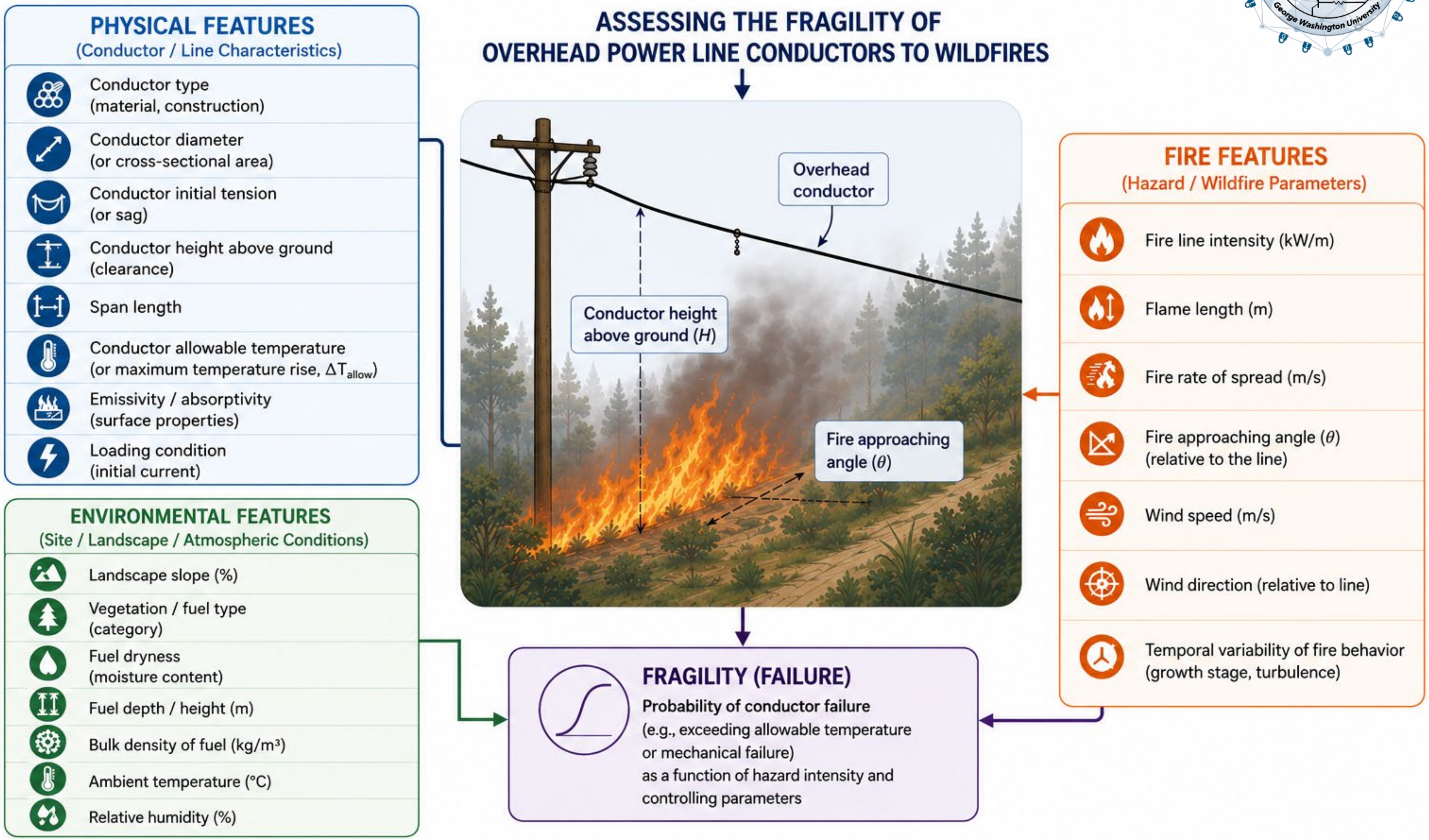






Heat Balance Concept

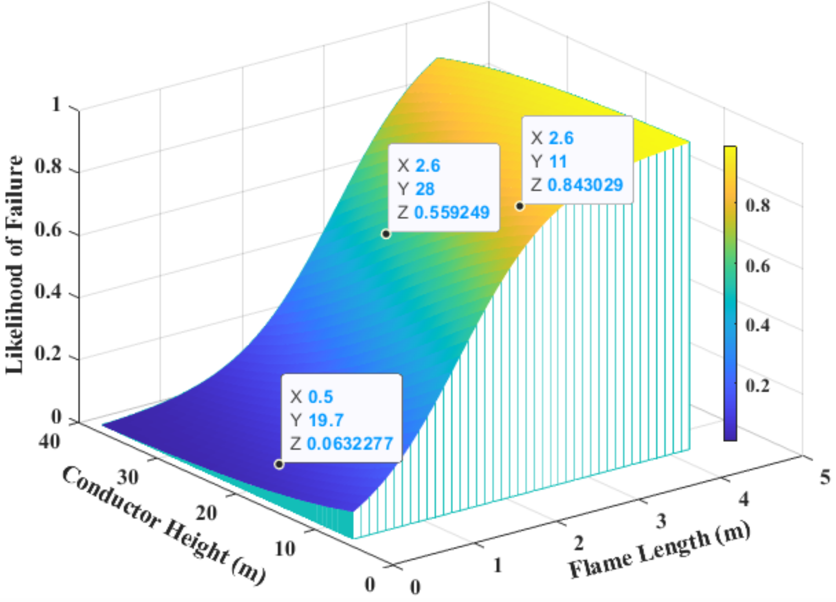
Power Grid Resilience to a Progressive Fire

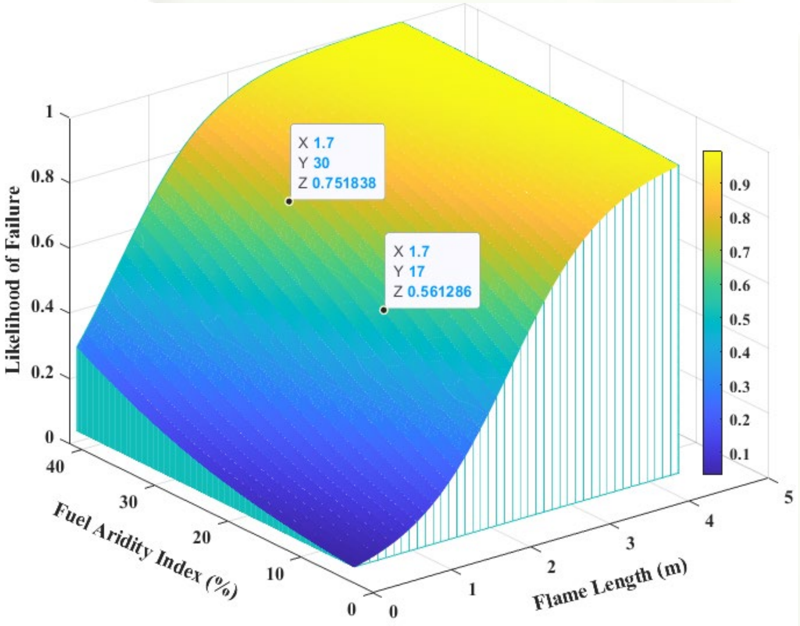


Power Grid Resilience to a Progressive Fire

❑ Parameterized Fragility Functions for Power Lines

$$\mathbf{P}(\textbf{failure}|S, M_s, F_D, V_w, h, L_f) = \frac{1}{1 + \exp\left[-\ell(S, M_s, F_D, V_w, h, L_f)\right]}$$





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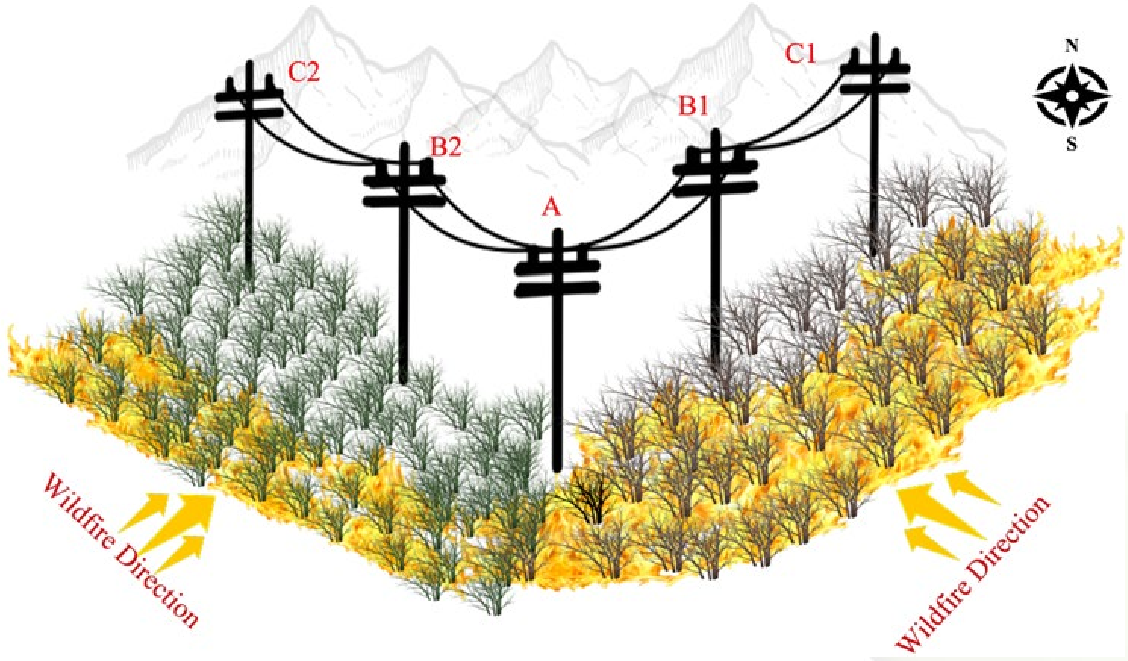


PARAMETERS FOR A WILDFIRE APPROACHING OVERHEAD CONDUCTORS A-B2-C2 AND THE ASSOCIATED TIME-VARIANT FAILURE PROBABILITY

Time	Design Parameters/ Severity Indices						P(Failure)
	S (○)	M_s (%)	F_D (cm)	V_w (km/h)	h (m)	L_f (m)	
t_1	10	5	1	10	15	0.3	0.0691
t_2	12	3	0.5	15	15	0.4	0.0513
t_3	11	8	1	20	15	0.5	0.0711
t_4	15	4	1	25	15	0.6	0.0354
t_5	15	4	1.5	28	15	0.65	0.0322

PARAMETERS FOR A WILDFIRE APPROACHING OVERHEAD CONDUCTORS A-B1-C1 AND THE ASSOCIATED TIME-VARIANT FAILURE PROBABILITY

Time	Design Parameters/ Severity Indices						P(Failure)
	S (○)	M_s (%)	F_D (cm)	V_w (km/h)	h (m)	L_f (m)	
t_1	-5	15	4	10	15	0.5	0.4180
t_2	-4	20	3.5	15	15	0.6	0.4817
t_3	-2	25	3	20	15	0.75	0.5401
t_4	-3	30	2	25	15	1	0.7239
t_5	-1	25	2	40	15	1.5	0.6618

Power Grid Resilience to a Progressive Fire

❑ Parameterized Fragility Functions for Power Lines

IEEE TRANSACTIONS ON POWER SYSTEMS, VOL. 39, NO. 2, MARCH 2024 2517

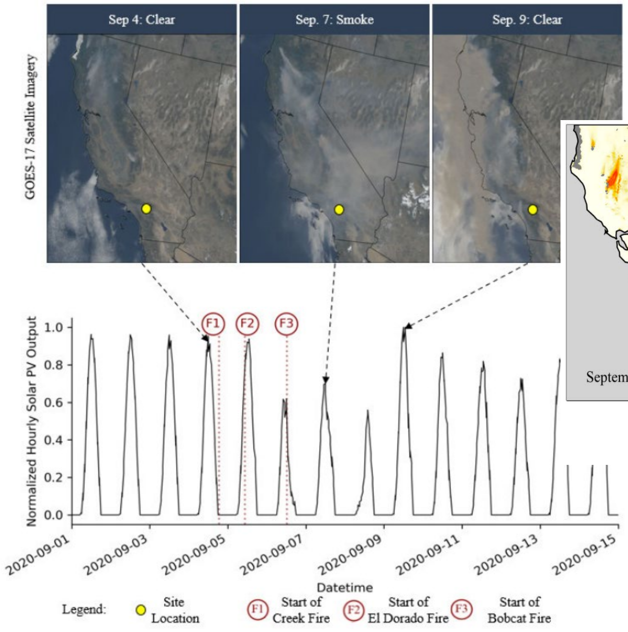
Parameterized Wildfire Fragility Functions for Overhead Power Line Conductors

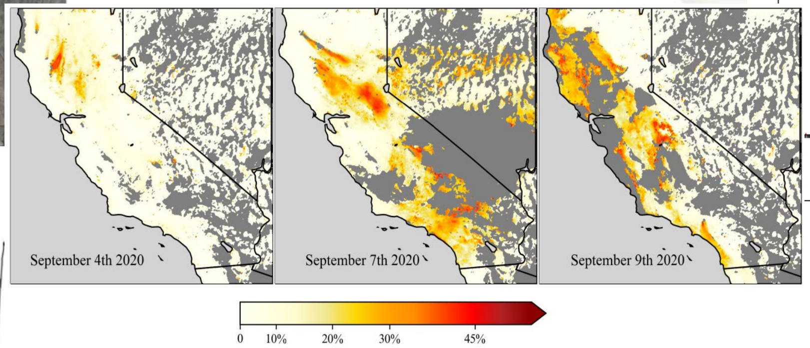
Mostafa Nazemi, *Member, IEEE*, Payman Dehghanian, *Senior Member, IEEE*, Yousef Darestani, and Jinshun Su, *Graduate Student Member, IEEE*

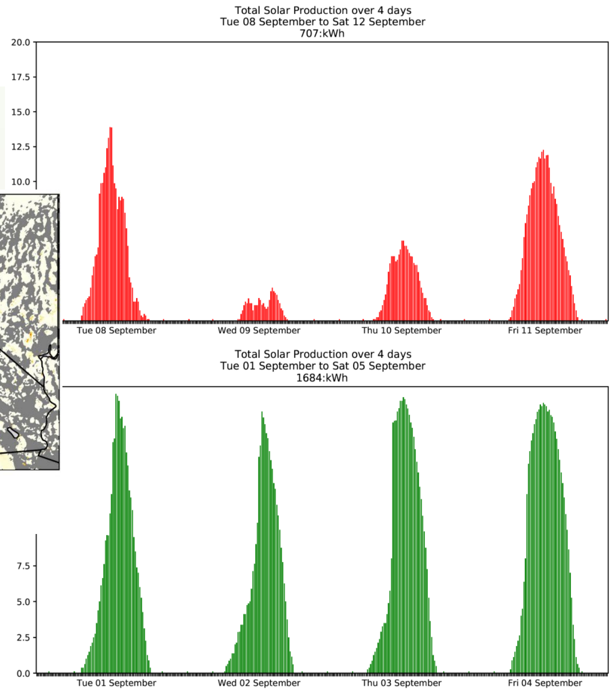
Ongoing Research

Power Grid Resilience to a Progressive Fire

How can we operate the electric power grid resiliently when exposed to wildfire smokes?







Power Grid Resilience to a Progressive Fire

2716 IEEE TRANSACTIONS ON INDUSTRY APPLICATIONS, VOL. 60, NO. 2, MARCH/APRIL 2024

Predictive Analysis of Wildfire Smoke-Induced Wiggle Effect on Low-Inertia Trending Power Grids

Amjad Jebril Ali, *Member, IEEE*, Long Zhao, Mohammad Heidari Kapourchali, *Member, IEEE*, and Wei-Jen Lee, *Life Fellow, IEEE*

Abstract—By the end of 2021, the United States had installe
92.5 gigawatts of solar systems. Simultaneously, the rise of invert
based resources (IBRs) has resulted in a noticeable decline in pow
grid inertia, which poses a risk to frequency stability in pow
systems. With the increasing prevalence of wildfires worldwide
is crucial to examine the impact of wildfire smoke on solar syste
and its implications for power grid operations. This study explo
the oscillatory power output of PV systems named as "Wig
Effect," a phenomenon observed in PV systems during days
fected by wildfire smoke. Distinctive from impact of cloud co
on PV systems, wildfire smoke covers much more landmass a
can cause regional impacts on power grids. Additionally, wild
smoke lasts for a longer time. Therefore, this study investigates
oscillatory patterns of PV power output, which have the poten
to jeopardize the frequency stability of the power grid due
sudden fluctuations in power generation. The study investigates t
effect and its impact on power system stability, focusing on pow

Wildfire Smoke-Aware Operation of PV-Integrated Distribution Systems Using Gaussian Plume Dispersion Modeling

Mehdi Rostamzadeh[1], Justice Evans[2], Mohammad Heidari Kapourchali[2,3], Long Zhao[4], Payman Dehghanian[5]
, and Visvakuma
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Abstract—Power distribution grids with high photovoltaic (PV) penetration are vulnerable to wildfire smoke events, which reduce the solar irradiance reaching PV panels and may lead to significant reductions in PV generation, thus affecting grid operation. This paper proposes a smoke-aware operational planning approach for unbalanced three-phase distribution systems. A Gaussian plume model is used to estimate the spatial distribution of wildfire smoke concentration, and the column-integrated smoke concentration above the PV generator is incorporated into a Beer–Lambert attenuation model to quantify smoke-attenuated irradiance. The operational planning problem is formulated as a mixed-integer linear program (MILP) to minimize the total operating cost. The proposed approach is tested on a modified IEEE 37-node distribution system. Different downwind locations are considered over a 24-hour operating horizon with time-

Powering Through the Haze: Operation Planning of Power Distribution Grids Under Wildfire Smoke

Mehdi Rostamzadeh, *Graduate Student Member, IEEE*, Justice Evans, *Graduate Student Member, IEEE*, Mohammad Heidari Kapourchali, *Member, IEEE*, Long Zhao, *Senior Member, IEEE*, Payman Dehghanian, *Senior Member, IEEE* and Visvakumar Aravinthan, *Senior Member, IEEE*

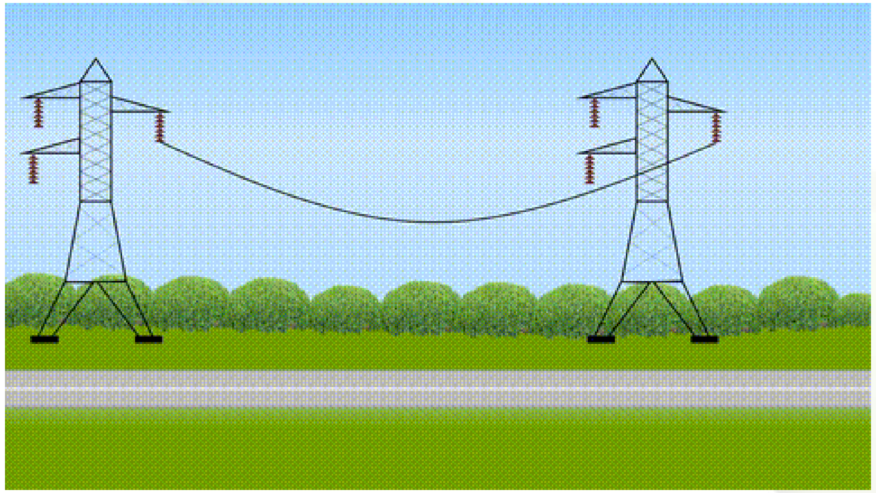
Abstract—Power distribution grids, especially those in close proximity to forested areas, are vulnerable to wildfire smoke. On the power generation side, reduced solar irradiance due to smoke decreases the output of solar panels and can affect the overall power supply, including both the power imported from the upstream network and local dispatchable sources. On the load side, as electric vehicles contribute an increasing share of mobile demand in power systems, their charging patterns can be significantly affected by smoke-related disruptions in traffic flow. This paper introduces an optimization framework for planning the operation of unbalanced three-phase distribution networks under the impacts of wildfire smoke. The transmitted irradiance equation is used to model the effect of wildfire smoke on photovoltaic (PV) generators. Traffic models are used to assess how reduced visibility affects evacuation flow, road capacity, and travel times, leading to potential delays and disruptions. The operation planning model is formulated as a mixed-integer linear program (MILP) to minimize day-ahead operational costs. The proposed framework is tested on a modified IEEE 37-node distribution system under various levels of PV penetration, grid operating modes, smoke severity conditions, and varying spatio-temporal patterns of smoke.

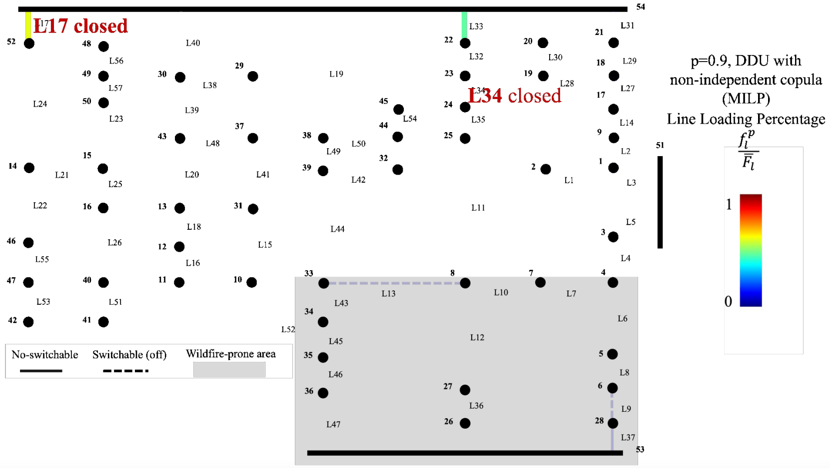
the power grid extends well past the immediate vicinity of the flames. Wildfire smoke can travel long distances, covering vast amounts of landmass and diminishing the amount of sunlight that reaches the Earth's surface and the air.

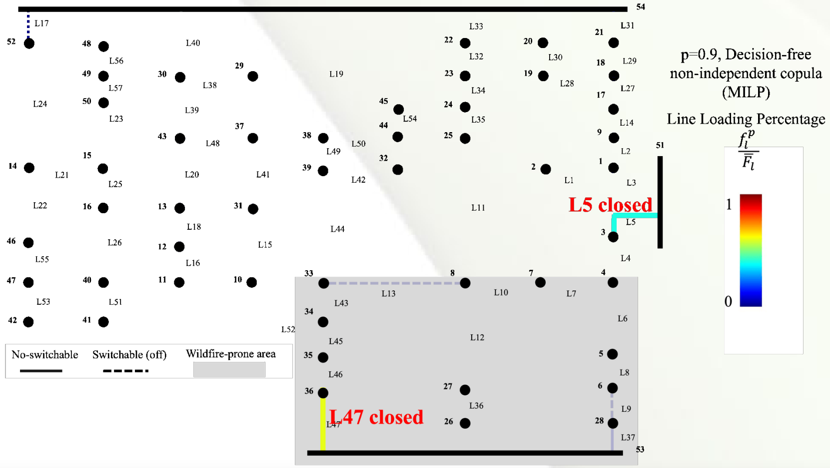
The rising reliance on solar PV systems in power grids makes wildfire smoke a critical factor in impacting energy production [4]. Smoke diminishes the solar irradiance that reaches PV panels, causing a notable reduction in the power generated by photovoltaic systems [5]. Accounting for the impact of wildfire smoke on solar photovoltaic production is essential for effective grid planning and well-informed operational decisions [6]. Several studies have examined the impact of wildfire smoke on solar generation. Solar generation in California in September 2020 was 13.4% lower than 2019, despite a 5.3% increase in installed solar generating capacity since September 2019 [7]. The authors in [8] demonstrate a significant impact of wildfire smoke aerosols on solar irradiance at the 400 to 500 nm wavelength range during

Power Grid Resilience to a Progressive Fire

How should we manage power flows during active wildfires not to further help its expansion and progression?







Thank You!

Payman Dehghanian

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Changing the Way You See the Grid.

Gridware

About Gridware

Founded in 2020, we pioneered active grid response (AGR), focused on monitoring the electrical, physical, and environmental aspects of the grid. Our platform uses high-precision sensors and data science to detect issues in real-time, enabling proactive maintenance and fault identification.

Investors

SEQUOIA

TIGERGLOBAL generation_

true Ventures LOWER CARBON CAPITAL CONVECTIVE CAPITAL

Awards

2022 Forbes Top 30<30
2022 TIME's Best Inventions
2023 Grist50 Fixer
2025 PUF Top Innovator

Hardware
Intelligence
Applications
ON - DEVICE ANALYTICS
SELF-POWERED
POLE MOUNTED MULTISENSOR
ELECTRICAL & PHYSICAL MONITORING
EASY TO INSTALL
EDGE INTELLIGENCE
CLOUD INTELLIGENCE
ALERTS
ALERTS
ALERTS
FAULT PREVENTION
HAZARD RESPONSE
POWER RESTORATION
ASSET MANAGEMENT
MEASURE
UNDERSTAND
ACT


tZERO
Gridware.

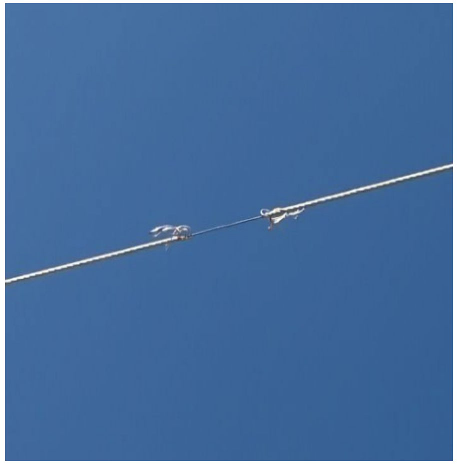
Hazard **Awareness** Delay

Gridware

Wildfire Timeline.

Pre-Ignition | Red Flag Conditions | Ignition | Recovery

Ignition Avoidance | Situational Awareness | Spread Avoidance | Expedited Restoration

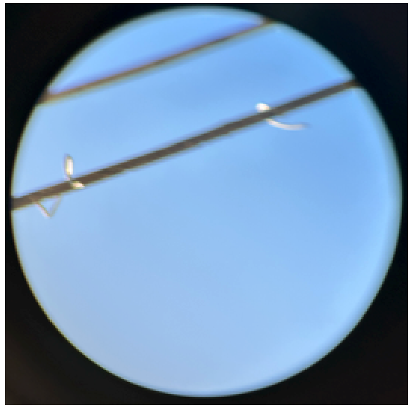


Ignition Avoidance

Detect incipient structural & electrical impacts to assets **before** an outage or ignition.

Momentary Clash Frays Strands.

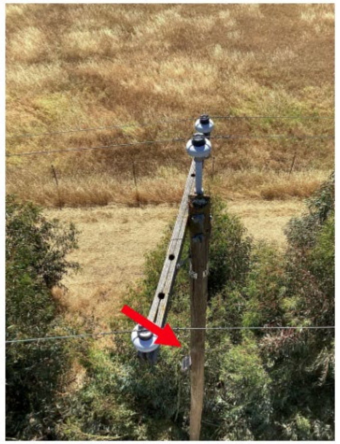
4/30/26@ 10:14a



"Here is a picture of the fault location. ***Looks like wind induced conductor slap. You can see there is conductor damage.*** *It was right where the Gridscope predicted."*

Cracked Crossarm.

5/19/25 @ 10:22am



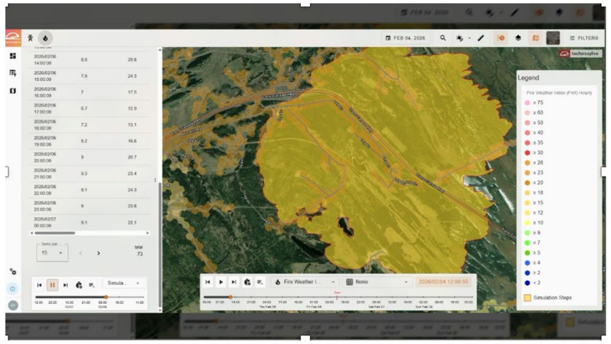
"Major win during a red flag day. Tractor hit the pole and opened up a crack in the crossarm. Insulator was on the verge of falling off the crossarm, risking a line in the grass."

Situational Awareness

Hazard identification supports real-time awareness of imminent faults.

Tree On Energized Line - HIF.

02/04/2026 8:02a



"Report of a 1-degree tilt on a pole with power. Turns out a tree was leaning on the wire.
No other reports. PLT went out because of the Gridware report and the tree was then cleared."

Tree on Covered Conductor.

3/30/25 @ 10:18a

Storm brings tree down across covered conductor – remained energized hanging over road.

Spread Avoidance

Pinpoint hazard locations reduce possibility of spread post ignition.

Bird Phase-To-Phase Causes Ignition.

9/6/24 @ 12:19p

“This would have been a major fire today, if we didn’t get the alert.”

Branch On Line Causes Ignition.

3/12/26 @ 5:48p

At 5:48p, Gridware alerted to a likely branch remaining on energized lines.

5 hours later at 10:42p, the branch finally carbonized, arced, and threw sparks that caused an ignition.

HIF logic in the breaker relay had no detection.

Recovery

De-energized infrastructure monitoring to expedite restoration and recover from high impact events.

Pole Failures During PSPS.

12/17/2025 1:52p

4 adjacent poles failed during PSPS event with winds exceeding 60 mph.

Tree Impacts Line During PSPS.

10/18/24 @9:19a

During PSPS event, large branch impacted lines with a piece of the branch remaining on conductor.

RELIABILITY

RESILIENCE

STORM RESPONSE

ASSET MANAGEMENT

WORKER SAFETY

PUBLIC SAFETY