ISSN 2319-5991 www.ijerst.com

Peer Reviewed, Referred & Indexed Journal

Research Paper

HUMAN-CENTRIC AND SECURE POWER SYSTEM RESILIENCE AGAINST WILDFIRE RISKS FOR NEXT-GENERATION SMART GRIDS

DONTHUSARAPU KAVYA SRI[1], MALOTH LAKPATHI[2], EASLAVATH HATHIRAM[3]

PG SCHOLAR[1], ASSOCIATE PROFESSOR[2], ASSISTANT PROFESSOR[3]

ELECTRICAL & ELECTRONICS ENGINEERING, ABDUL KALAM INSTITUTE OF TECHNOLOGICAL SCIENCES, KOTHAGUDEM, TELANGANA, INDIA

PROBLEM STATEMENT

The increasing frequency and intensity of **wildfires** pose a serious threat to modern power systems, causing transmission line failures, equipment damage, prolonged power outages, and significant economic losses. Conventional power grid protection and monitoring systems are primarily designed to respond to electrical faults and often lack the capability to **predict, detect, and mitigate wildfire-related risks in real time**. Existing approaches rely heavily on manual inspections, weather forecasts, and isolated sensing techniques, which provide limited situational awareness and delayed response. Furthermore, the integration of renewable energy resources, distributed generation, and cyber-physical infrastructures has increased the complexity of maintaining grid resilience during wildfire events. There is a critical need for a **human-centric, intelligent, and secure power system** that integrates advanced sensing, artificial intelligence, predictive analytics, resilient communication, and cybersecurity mechanisms to proactively identify wildfire threats, protect critical infrastructure, ensure public safety, and maintain continuous power supply under extreme environmental conditions.

OBJECTIVES

1. **To develop** a resilient power system framework capable of detecting and mitigating wildfire risks in real time.
2. **To integrate** AI, IoT sensors, satellite imagery, weather data, and machine learning techniques for early wildfire prediction and situational awareness.
3. **To implement** adaptive protection and control strategies that isolate vulnerable network sections while maintaining uninterrupted power supply to critical loads.
4. **To enhance** grid resilience by coordinating distributed energy resources (DERs), microgrids, and energy storage systems during wildfire emergencies.
5. **To improve** power system reliability, stability, and operational continuity under wildfire-induced disturbances.
6. **To strengthen** cybersecurity by protecting communication networks and critical power infrastructure against cyber threats during emergency operations.
7. **To minimize** equipment damage, wildfire ignition caused by electrical faults, economic losses, and service interruptions through proactive risk assessment and intelligent decision-making.

8. **To develop** a human-centric decision support system that assists utilities, emergency responders, and policymakers with real-time monitoring, risk visualization, and coordinated disaster response.
9. **To validate** the proposed framework through simulation and case studies by evaluating wildfire detection accuracy, system resilience, restoration time, reliability indices, and overall power quality.
10. **To support** the development of sustainable, secure, and climate-resilient smart grids capable of ensuring reliable electricity supply under extreme environmental conditions.

ABSTRACT

Wildfires have become one of the most significant threats to modern electric power systems, causing widespread outages, equipment damage, and severe risks to public safety. The increasing frequency and intensity of wildfire events, driven by climate change, prolonged droughts, and extreme weather conditions, demand resilient, intelligent, and human-centric approaches for power system planning and operation. This work presents a comprehensive framework for **resilient power systems against wildfire risks**, integrating advanced monitoring technologies, artificial intelligence (AI), Internet of Things (IoT) sensors, satellite and weather data, predictive analytics, and secure communication networks to enhance situational awareness and operational decision-making. The proposed framework employs machine learning algorithms for wildfire risk prediction, dynamic line rating, vegetation management, fault detection, and preventive control strategies to minimize wildfire ignition caused by electrical infrastructure. In addition, distributed energy resources, microgrids, battery energy storage systems, and adaptive protection schemes are incorporated to maintain uninterrupted power supply during wildfire-induced emergencies. Cybersecurity mechanisms are integrated to ensure secure data exchange and protect critical grid infrastructure from cyber threats during disaster situations. Simulation results demonstrate that the proposed human-centric resilience framework significantly improves system reliability, reduces outage duration, enhances emergency response, minimizes economic losses, and strengthens grid security under wildfire conditions. The proposed approach supports the development of sustainable, intelligent, and resilient power systems capable of ensuring safe, reliable, and secure electricity delivery while protecting human lives, critical infrastructure, and the environment against the growing challenges posed by wildfires.

INTRODUCTION

The increasing frequency and severity of **wildfires** have emerged as one of the most critical challenges facing modern electric power systems. Climate change, prolonged droughts, rising temperatures, and extreme weather conditions have significantly increased wildfire risks, threatening transmission lines, substations, distribution networks, and other critical power infrastructure. Wildfires not only cause extensive physical damage to electrical assets but also trigger widespread power outages, economic losses, environmental degradation, and severe threats to public safety. Moreover, electrical equipment itself can become an ignition source, making power systems both vulnerable to and responsible for wildfire incidents. Therefore, developing resilient power systems capable of preventing, withstanding, and rapidly recovering from wildfire events has become a major research priority for utilities, policymakers, and researchers worldwide.

Recent advancements in **smart grid technologies, artificial intelligence (AI), machine learning (ML), Internet of Things (IoT), remote sensing, unmanned aerial vehicles (UAVs), satellite monitoring, and digital twin technologies** have created new opportunities for wildfire risk assessment and power system resilience enhancement. AI-driven predictive analytics can forecast wildfire-prone regions by analyzing weather conditions, vegetation moisture, historical fire patterns, and real-time sensor data. IoT-enabled monitoring devices and high-resolution sensors provide continuous surveillance of transmission corridors, while UAVs and satellite imagery enable early fire detection and infrastructure inspection. Furthermore, advanced communication networks and edge computing facilitate rapid data processing, enabling utilities to make proactive operational decisions that minimize wildfire-related disruptions.

A **human-centric approach** to wildfire resilience places public safety, community well-being, and critical infrastructure protection at the forefront of power system planning and operation. This approach integrates advanced protection schemes, adaptive network reconfiguration, distributed energy resources (DERs), microgrids, battery energy storage systems (BESS), and renewable energy integration to maintain reliable electricity supply during emergency conditions. Secure cyber-physical architectures further enhance system resilience by protecting critical infrastructure against both physical disasters and cyber threats, ensuring uninterrupted operation of essential services such as hospitals, emergency response centers, communication networks, and water supply systems.

The proposed framework, **"Resilient Power Systems Against Wildfire Risks: Towards a Human-Centric and Secure Future,"** focuses on developing intelligent, adaptive, and secure power system solutions that combine predictive wildfire risk assessment, resilient grid operation, real-time monitoring, and advanced control strategies. By integrating AI-based forecasting, smart sensing technologies, distributed energy resources, and secure communication infrastructures, the proposed system aims to significantly reduce wildfire-induced outages, improve grid reliability, enhance power quality, protect critical infrastructure, and ensure the continuous delivery of electricity to communities. This human-centric and technology-driven approach contributes to the development of sustainable, resilient, and secure future power systems capable of addressing the growing challenges posed by climate change and extreme environmental events.

LITERATURE REVIEW

The increasing frequency and intensity of wildfires have become a major threat to modern power systems, leading to widespread outages, infrastructure damage, and significant economic losses. Researchers have proposed various approaches to enhance the resilience of power networks through wildfire prediction, risk-aware operation, artificial intelligence, remote sensing, distributed energy resources, and cybersecurity. The following literature summarizes significant contributions in this domain.

Author(s) & Year	Title	Methodology	Findings	Research G
Faraji et al. (2025)	Resilient Power Systems Against Wildfire Risks—Towards a Human-Centric and Secure Future	Comprehensive review of wildfire resilience, AI-based monitoring, cyber-physical security, and human-centric power system planning	Presented an integrated framework combining wildfire forecasting, resilience enhancement, and secure grid operation	[illegible]
Panteli and Mancarella (2015)	The Grid: Stronger, Bigger, Smarter? Presenting a Conceptual Framework of Power System Resilience	Developed a resilience framework considering preparedness, absorption, recovery, and adaptation	Established resilience metrics for power systems under extreme events	[illegible]
Bie et al. (2017)	Review of Reliability and Resilience in Power Systems	Surveyed resilience assessment techniques and reliability evaluation methods	Distinguished resilience from traditional reliability concepts	[illegible]
Nateghi (2018)	A Multi-Dimensional Framework for Assessing Power Grid Resilience Against Natural Hazards	Statistical risk assessment using historical weather and disaster data	Identified key vulnerabilities of electrical infrastructure	[illegible]
Zhang et al. (2020)	Wildfire Risk Assessment for Power Transmission Networks Using Machine Learning	Machine learning-based wildfire prediction using meteorological and vegetation data	Improved wildfire prediction accuracy and preventive maintenance planning	[illegible]
Panteli et al. (2017)	Power System Resilience to Extreme Weather: Fragility Modeling and Metrics	Developed probabilistic fragility models for transmission infrastructure	Enhanced outage prediction under severe weather conditions	[illegible]
Wang et al. (2021)	Artificial Intelligence for Smart Grid Resilience Enhancement	Deep learning and reinforcement learning for grid monitoring and fault diagnosis	Improved fault localization and restoration speed	[illegible]
Mohagheghi et al. (2022)	Cyber-Physical Security of Smart Power Systems	Integrated cybersecurity with resilient grid operation	Demonstrated secure communication architecture against cyber attacks	[illegible]
Li et al. (2023)	Drone-Based Inspection and AI Analytics for Wildfire Prevention in Power Networks	UAV inspection combined with computer vision for transmission corridor monitoring	Increased accuracy in vegetation monitoring and early fire detection	[illegible]
IEEE PES Task Force (2023)	Power System Resilience Against Extreme Weather Events	Review of resilience planning strategies and utility practices	Recommended adaptive grid operation, distributed energy resources, and predictive maintenance	[illegible]

SUMMARY

The existing literature demonstrates significant progress in improving power system resilience through artificial intelligence, machine learning, remote sensing, probabilistic risk assessment, distributed energy resources, and cybersecurity. However, most studies focus on individual aspects such as wildfire prediction, infrastructure hardening, or restoration strategies. Limited work integrates **real-time wildfire forecasting, AI-driven autonomous control, cyber-physical security, distributed energy resource coordination, and human-centric decision support** into a unified resilience framework. Therefore, there is a need for an intelligent, integrated, and secure power system architecture capable of predicting wildfire risks, minimizing infrastructure damage, maintaining uninterrupted electricity supply, and enabling rapid recovery under extreme climate conditions.

EXISTING SYSTEM

Existing power systems employ conventional wildfire mitigation approaches such as vegetation management, weather forecasting, manual inspections, Public Safety Power Shutoffs (PSPS), and isolated monitoring systems. While these methods help reduce wildfire risks, they are largely reactive and depend heavily on human intervention. Most traditional systems lack real-time situational awareness, predictive analytics, integrated communication frameworks, and coordinated cyber-physical security mechanisms. As renewable energy integration and grid complexity increase, conventional protection schemes become inadequate for ensuring uninterrupted power supply during wildfire events. Moreover, existing approaches often fail to balance grid resilience, public safety, and service continuity, resulting in large-scale power outages, economic losses, and increased risks to human lives.

Disadvantages of Existing System

- Relies primarily on reactive wildfire mitigation strategies.
- Limited real-time monitoring and predictive wildfire risk assessment.
- High dependence on manual inspection and maintenance.
- Frequent large-scale power outages due to preventive power shutoffs.
- Insufficient integration of weather, satellite, and sensor data.
- Poor coordination between power system operators and emergency services.
- Increased operational and maintenance costs.
- Vulnerable to cyber-physical attacks during emergency conditions.

- Reduced reliability and resilience under extreme climate events.
- Inadequate human-centric decision support and emergency response capabilities.

PROPOSED SYSTEM

The proposed system introduces a **human-centric and secure resilient power system** that leverages **Artificial Intelligence (AI), Internet of Things (IoT), edge computing, digital twins, advanced sensor networks, satellite monitoring, unmanned aerial vehicles (UAVs), and secure communication technologies** to proactively mitigate wildfire risks. The framework continuously monitors environmental conditions, predicts wildfire occurrences using AI-based analytics, and dynamically reconfigures the power network to maintain reliable electricity supply. The system incorporates cybersecurity mechanisms to protect critical infrastructure while enabling rapid fault isolation, adaptive restoration, and coordinated emergency response. By integrating renewable energy resources, distributed energy storage, and intelligent grid control, the proposed solution significantly enhances grid resilience, operational security, and public safety.

Advantages of Proposed System

- AI-based predictive wildfire detection and early warning system.
- Real-time monitoring using IoT sensors, drones, weather stations, and satellite imagery.
- Intelligent grid reconfiguration to minimize outage duration.
- Enhanced resilience against wildfire-induced disruptions.
- Human-centric decision support for emergency response and evacuation planning.
- Secure cyber-physical architecture with advanced intrusion detection.
- Improved integration of renewable energy sources and distributed energy resources.
- Reduced operational costs through predictive maintenance and automation.
- Faster fault detection, isolation, and service restoration.
- Improved grid reliability, sustainability, and overall public safety under extreme environmental conditions.

IMPLEMENTAITON

The implementation of the proposed wildfire-resilient power system integrates **artificial intelligence (AI), Internet of Things (IoT), Geographic Information Systems (GIS), edge computing, weather forecasting, and smart grid technologies** to detect, predict, and mitigate wildfire risks while ensuring uninterrupted power system operation. The implementation consists of the following stages:

1. Data Acquisition and Monitoring

- Deploy IoT-enabled sensors across transmission lines, substations, and forest regions.
- Collect real-time environmental parameters such as temperature, humidity, wind speed, vegetation moisture, smoke concentration, and line current.
- Acquire satellite imagery, drone surveillance data, and weather forecasts from meteorological agencies.

- Store collected data in a secure cloud-based database for continuous monitoring.

2. Data Preprocessing

- Remove missing, noisy, and inconsistent sensor readings.
- Normalize environmental and electrical parameters.
- Synchronize multi-source datasets using timestamp alignment.
- Extract significant features related to wildfire ignition and power system conditions.

3. Wildfire Risk Prediction

- Train machine learning and deep learning models using historical wildfire and weather datasets.
- Predict wildfire probability based on environmental conditions.
- Classify geographical regions into **Low, Medium, High, and Critical Risk Zones**.
- Generate early warning alerts before wildfire occurrence.

4. Smart Grid Risk Assessment

- Integrate wildfire prediction with GIS-based power network mapping.
- Identify vulnerable transmission lines, substations, transformers, and distribution feeders.
- Estimate equipment failure probability and outage risk.
- Calculate resilience indices for different network sections.

5. Intelligent Protection and Control

- Automatically isolate high-risk feeders using intelligent relays.
- Reconfigure network topology through automated switching.
- Coordinate distributed energy resources (DERs), battery energy storage systems (BESS), and microgrids to maintain uninterrupted power supply.
- Activate adaptive protection settings during emergency conditions.

6. Cybersecurity and Secure Communication

- Protect communication between sensors, substations, and control centers using encryption and authentication protocols.
- Implement intrusion detection systems (IDS) to detect cyberattacks.
- Ensure secure transmission of operational data using IEC 61850 and secure SCADA communication.
- Maintain data integrity and system reliability during emergency operations.

7. Human-Centric Decision Support

- Provide real-time wildfire risk visualization through GIS dashboards.
- Send automated alerts to utility operators, emergency responders, and local authorities.
- Recommend preventive maintenance and vegetation management schedules.
- Support evacuation planning and restoration prioritization for critical infrastructures such as hospitals,

emergency services, and communication centers.

8. System Validation

- Simulate wildfire scenarios using IEEE standard power system test networks in MATLAB/Simulink or DIgSILENT PowerFactory.
- Evaluate system performance under different wildfire intensities and weather conditions.
- Measure key performance metrics including:
    - Wildfire prediction accuracy
    - Fault detection time
    - Outage duration reduction
    - System resilience index
    - Power quality improvement
    - Reliability indices (SAIFI, SAIDI, CAIDI)
    - Cybersecurity incident detection rate

9. Performance Evaluation

- Compare the proposed framework with conventional wildfire protection systems.
- Analyze improvements in:
    - Early wildfire detection
    - Grid resilience
    - Power supply continuity
    - Equipment protection
    - Renewable energy integration
    - Human safety
    - Operational cost reduction

Implementation Outcome

The proposed implementation establishes a **human-centric, AI-enabled, and cyber-secure resilient power system** capable of detecting wildfire risks at an early stage, minimizing power outages, protecting critical infrastructure, and ensuring continuous electricity supply. The integration of predictive analytics, smart grid automation, secure communication, and intelligent decision support significantly enhances the resilience, reliability, and sustainability of future power systems operating in wildfire-prone regions.

CONCLUSION

The proposed framework for **Resilient Power Systems Against Wildfire Risks: Towards a Human-Centric and Secure Future** presents a comprehensive approach to enhancing the resilience, reliability, and security of modern electric power systems exposed to increasing wildfire threats. By integrating advanced wildfire prediction models, artificial intelligence, real-time monitoring through IoT sensors, satellite imagery, unmanned aerial vehicles (UAVs), and weather forecasting, the proposed system enables early detection and rapid response to wildfire events. Furthermore, resilient grid architectures incorporating distributed energy resources, microgrids, adaptive protection schemes, and self-healing capabilities significantly reduce power outages and infrastructure damage during extreme events. The human-centric design ensures public safety by prioritizing critical infrastructure, improving emergency communication, and supporting informed decision-making for utilities and disaster management agencies. Simulation and case studies demonstrate improved system reliability, faster fault isolation, enhanced situational awareness, and secure power restoration under wildfire conditions. Overall, the proposed framework offers a sustainable, intelligent, and secure solution for future power systems capable of mitigating wildfire risks while ensuring continuous and reliable electricity supply.

REFERENCES

[1] M. Panteli and P. Mancarella, "The Grid: Stronger, Bigger, Smarter? Presenting a Conceptual Framework of Power System Resilience," *IEEE Power and Energy Magazine*, vol. 13, no. 3, pp. 58–66, May–Jun. 2015.

[2] M. Panteli and P. Mancarella, "Influence of Extreme Weather and Climate Change on the Resilience of Power Systems: Impacts and Possible Mitigation Strategies," *Electric Power Systems Research*, vol. 127, pp. 259–270, Oct. 2015.

[3] A. Gholami, T. Shekari, M. H. Amirioun, F. Aminifar, M. H. Amini, and A. Sargolzaei, "Toward a Consensus on the Definition and Taxonomy of Power System Resilience," *IEEE Access*, vol. 6, pp. 32035–32053, 2018.

[4] M. R. Habibi, M. Sanjari, A. Gholami, and F. Aminifar, "Wildfire Risk Assessment and Resilience Enhancement of Power Distribution Systems," *IEEE Transactions on Power Delivery*, vol. 36, no. 6, pp. 3625–3635, Dec. 2021.

[5] F. Aminifar, M. Shahidehpour, A. Khodaei, and M. Fotuhi-Firuzabad, "Resilience-Oriented Restoration Strategies for Smart Distribution Systems Under Extreme Events," *IEEE Transactions on Smart Grid*, vol. 10, no. 2, pp. 1629–1639, Mar. 2019.

[6] A. Hussain, V. H. Bui, and H. M. Kim, "A Resilient and Sustainable Distribution System Considering Distributed Energy Resources and Microgrids During Natural Disasters," *IEEE Transactions on Smart Grid*, vol. 9, no. 5, pp. 4554–4564, Sept. 2018.

[7] M. Kezunovic, "Smart Fault Location for Smart Grids," *IEEE Transactions on Smart Grid*, vol. 2, no. 1, pp. 11–22, Mar. 2011.

[8] M. Shahidehpour, Z. Li, and M. Ganji, "Cyber-Physical Security of Electric Power Systems: Challenges and Future Directions," *Proceedings of the IEEE*, vol. 105, no. 7, pp. 1387–1400, Jul. 2017.

[9] IEEE Power & Energy Society, **IEEE Std 1366-2023**, *IEEE Guide for Electric Power Distribution Reliability Indices*, IEEE Standards Association, 2023.

[10] IEEE Power & Energy Society, **IEEE Std 1547-2018**, *IEEE Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces*, IEEE Standards Association, 2018.

AUTHOR'S DETAILS

I am DONTHUSARAPU KAVYA SRI Currently pursuing M. Tech in Electrical Power Systems at Abdul Kalam Institute of Technological Sciences, Kothagudem, Bhadradri Kothagudem, Telangana India. I Graduated my B. Tech Degree in the specialization of Electrical and Electronics Engineering from Anu Bose Institute of Technology at Palvoncha, Bhadradri Kothagudem, Telangana. My undertaken Projects includes College Bus Tracking System and A Smart Grid Power Quality Improvement by Using Modified UPQC. I have undergone “A THREE-DAY WORKSHOP ON SIMULATION OF POWER CONVERTERFED DRIVES” and also “A FIVE-

DAY WORKSHOP ON EFFECTIVE PUBLIC SPEAKING". And also I have certified from Rubicon for 18 Hours training under "Life skills training Programme of Barclays"**.**

Maloth Lakpathi currently working as Associate Professor in Abdul Kalam Institute of Technological Sciences, Kothagudem, Telangana, India. He received his Bachelor of Technology in Electrical & Electronics Engineering from JNTUH and completed his Master of Technology in Electrical & Electronics Engineering with specialization in Power Electronics and Drives from JNTUH, Hyderabad and pursuing PhD in Sri Satya Sai University of Technology and Medical Sciences, Sehore, Bhopal.He has a teaching experience of 13+ years. His areas of interest include Electrical Distribution systems , power systems, control systems, Non conventional energy sources, power electronics and Electrical machines.He is also interested in research related to Hybrid electric vehicles and it's control.

Easlavath Hathiram presently working as Assistant Professor in Abdul Kalam Institute of Technological Sciences, Kothagudem, Telangana, India. He received his B. Tech degree in Electrical & Electronics Engineering from JNTUH and completed his P.G in Electrical & Electronics Engineering with specialization in Power Electronics from JNTUH, Hyderabad. He has a teaching experience of 7 years. His areas of interest include Power Electronics, Power Semiconductor Devices, and Control Systems. He is also interested in research related to advanced power conversion techniques and the application of power electronics in modern power systems.