

GridGuardian: A National-Scale Digital Twin Utilizing Multi-Head Self-Attention Bi-LSTMs and Physics-Based Simulations for Power Grid Resiliency

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Abstract

Electric power disruptions present significant operational and economic challenges, emphasizing the need for accessible tools that integrate forecasting, infrastructure visibility, and scenario analysis. This study introduces GridGuardian, an AI-driven digital twin framework designed to support power grid resilience using publicly available data and machine learning techniques. The platform aggregates infrastructure data from sources including the U.S. Energy Information Administration, the Homeland Infrastructure Foundation-Level Database, and OpenStreetMap, forming a unified geospatial model of 111,041 grid components across the United States. For short-term demand forecasting, a stacked bidirectional long short-term memory (Bi-LSTM) model with multi-head self-attention is trained on 26,112 hours of PJM Interconnection load data using 28 engineered features. The model predicts regional electricity demand 24 hours in advance with an R^2 of 0.9409 and a mean absolute percentage error (MAPE) of 3.94%. Additionally, a feedforward neural network trained on residential and commercial building survey microdata estimates building-level energy profiles, achieving a residential R^2 of 0.9730. These predictive models are integrated with weather alert data, physics-based power flow simulation using PyPSA, and an outage impact estimation framework to enable scenario-based analysis. GridGuardian demonstrates how publicly accessible data and artificial intelligence can be combined into a practical digital twin platform for identifying vulnerabilities and supporting resilience planning. A live implementation of the system is available at gridguardianai.com.

Keywords

Digital Twin, AI, Energy Resilience, Power Grid, Load Forecasting.

Biographies

Srivanth Dasu is a motivated high school student in 11th grade with a strong passion for technology, design, and building real-world projects. At 16, he has already developed a growing portfolio that reflects both technical skill and creativity. One of his notable projects includes srionline.org, a web-based platform where he focused on creating a clean, user-friendly interface using HTML and CSS which connects all of his projects. Through this, he strengthened his understanding of full-stack development and user experience design. He also worked on GridGuard, a concept-driven project aimed at solving real-world problems through structured systems and logical thinking, showing his ability to connect software with practical applications. In addition, Srivanth has built several Java programs, including simulations and image-processing tools, where he applied concepts like object-oriented programming, threading, and data structures. He further expanded his skills during a UX Design internship with Oracle's Human Capital Management (HCM) Design Team, where he conducted user research, used ideation methods like Crazy 8s, and created prototypes in Figma. Beyond development, he is exploring cybersecurity through platforms like TryHackMe,

demonstrating curiosity across multiple areas of tech. He is also actively improving his physical fitness through calisthenics. Currently, Srivanth is applying to Middle College, showing his commitment to academic growth and new challenges. With a strong drive to learn and create, he continues working toward a future in technology where he can build impactful and innovative solutions.

Aditya Vengata is a driven high school junior with a passion for computer science, data analysis, and developing impactful, user-centric solutions. Demonstrating strong academic proficiency, they earned top marks in AP Computer Science Principles and hold advanced Python certifications from Codecademy. Aditya's technical portfolio highlights a blend of machine learning, full-stack development, and hardware integration. Notably, they engineered "Grid Guardian," in a team project, a TensorFlow-based power grid outage predictor that won 3rd place at the ACSEF science fair, and "Medi Lock," an award-winning smart pill dispenser combining Fusion 360 design with a Flutter/Dart and Python software stack. Additionally, they developed a mental health app submitted to the Congressional App Challenge and have rapidly prototyped accessible tools, such as a dyslexia-friendly reading application, during various hackathons. Beyond software engineering, Aditya earned a certificate from the Big Data at Berkeley bootcamp, where they presented a comprehensive Jupyter Notebook analysis on the "Digital Divide" using US Census data. They also earned Design Tech High School's Innovation Certificate, a highly prestigious certificate awarded to those who complete a rigorous, well rounded program featuring all aspects of computer science. A well-rounded student-athlete, they balance distance running in Track and Field with active roles in Robotics and Speech and Debate. Dedicated to community impact, Aditya also leads outreach programs for the Computer Science Club, designing curriculum to teach coding to local elementary students and help bridge the digital divide.