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Modernizing the Grid, the Advent of Dawn

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Abstract

The escalating demands of artificial intelligence, cryptocurrency mining, and electric vehicle adoption have exposed critical vulnerabilities in the North American power grid infrastructure. This paper proposes Project DAWN (Digitalization, Adaptability, Wellness, and Network optimization), a comprehensive framework for modernizing the tri-national power grid serving the United States, Canada, and Mexico. Through systematic literature review and comparative technology assessment, this study identifies optimal solutions for three critical smart grid components: cybersecurity architecture, big data management systems, and energy storage infrastructure. The proposed system integrates Dynamic Line Rating (DLR) technology, Phasor Measurement Units (PMUs), Advanced Distribution Management Systems (ADMS), Fault Location Isolation and Service Restoration (FLISR), Advanced Metering Infrastructure (AMI) with blockchain integration, and Distributed Energy Resource Management Systems (DERMS). Financial analysis projects implementation costs between $127-150 billion over a 15-year timeline, with estimated returns exceeding costs by factors of 2.8 to 4.0 through enhanced efficiency, reduced outage costs, and renewable energy integration. The phased implementation strategy encompasses pre-implementation (feasibility and stakeholder engagement), implementation (infrastructure upgrade and technology deployment), and post-implementation (evaluation and continuous improvement) phases. Decision criteria emphasize security, efficiency, reliability, and sustainability. This research contributes practical insights for policymakers, utility operators, and technology vendors navigating the transition to intelligent, resilient, and sustainable power infrastructure capable of supporting 21st-century energy demands while accelerating decarbonization objectives.

Keywords: Smart Grid, Power Grid Modernization, DAWN Framework, Distributed Energy Resources, Advanced Metering Infrastructure, Blockchain Technology, Energy Storage Systems, Grid Resilience, Renewable Energy Integration, Cybersecurity

Introduction

Modernizing the Grid, the Advent of DAWN

In an era of rapidly evolving technology and increasing concerns about climate change and sustainability, governments worldwide seek to modernize the power infrastructure, transitioning from traditional grids that are static, requiring human intervention to deal with interruptions, to smart grids that can dynamically respond to changes in demand, generation, transmission, or operating conditions (Mohamed *et al.*, 2024) [16]. A smart grid can sense, control, compute, and analyze energy data and information by leveraging advances in digital and cyber technologies to inform planning and operations (U.S. Department of Energy, 2022a) [23]. This document will discuss the state of the art of the North American power grid, existing issues necessitating the grid modernization project, and recommendations.

State of the art of the North American Power Grid

The North American power grid is an ultra-large-scale and complex machine that powers the United States, Canada, and Mexico, delivering 1.2 million megawatts to 330 million people (U.S. Department of Energy, 2022a) [23].

The U.S. Department of Energy reports that “38 states and the District of Colombia have completed or are undertaking some form of grid modernization activity that includes the deployment of smart grid technology” (U.S. Department of Energy, 2022a, p. IV) [23]. This leaves 12 states in the U.S. currently operating on legacy grid structures that cannot handle the complexities of integrating renewable energy sources at various edges along the network also known as distributed energy resources (DER) (Jiang, 2021) [13]. The adoption of smart grids across North America is on the rise with investments growing from $3.4 billion in 2014 to $6.4 billion in 2018 and is projected to reach $16.4 billion by 2026 (U.S. Department of Energy, 2022a) [23].

Existing Issues

Although work is underway in many states to drive energy modernization, there exists a need for a holistic approach to coordinating effective and time-dependent functions to ensure reliable operation among all stakeholders (utilities, market operators, and emerging players). Coordination is the synergy between decentralized elements on the grid to solve a common problem, such as power faults (U.S. Department of Energy, 2022a) [23]. Furthermore, a core cyber-physical platform needs to be built to serve as a convergence point for electrical infrastructure and other systems like transport, and telecommunications (U.S. Department of Energy, 2022a) [23]. The proliferation of generative artificial intelligence (GenAI) and cryptosystems although bearing tremendous benefits have posed a massive demand on the energy system (Washington Post, 2024) [27]. Tech giants are already looking to build out their energy sources which could be added to the grid. Without significant investment and enabling policies, the U.S. might be out of power in many regions or might miss out on leading the global transformative efforts in artificial intelligence (AI), all of which bear enormous threats to national security.

Business Justification

Modernizing the North American power grid is a long-term project that will be resource-intensive, with projections between $127 to $150 billion, however, the benefits far outweigh the costs by as much as 4 times (Reshaping Cities, 2010) [19]. The following key factors drive this high return on investment:

Increased Efficiency and Reliability

Smart grids increase the efficiency of electricity usage as they prevent wastage by quickly sensing and selecting faults in the energy supply system. Sensing refers to the ability of the system to detect faults while selecting refers to the ability of the system to accurately locate and classify faults to the smallest possible faulty section (Mohamed *et al.*, 2024) [16]. After identifying and locating faults, smart grids can reconfigure the network topology to avoid power interruption or limit it to the shortest downtime without human intervention thereby leading to reliable energy (Mohamed *et al.*, 2024) [16].

Sustainability

The integration of multiple sources of renewable sources at any point along the grid will directly encourage the transition to clean energy. Consumers with electric vehicles, solar panels, and batteries can be incentivized to not only ingest but produce energy that can be added to the grid via plug-and-play interoperability thus reducing carbon emissions (Ricco *et al.*, 2022) [20]. Interoperability is the ability to safely, securely, and effectively share information between systems without the need to make significant modifications to the network (U.S. Department of Energy, 2022a) [23]. It is only possible with a core and holistic system that strictly follows a set of standards and protocols (U.S. Department of Energy, 2022a) [23].

Research Questions

1. What are the critical technological requirements for modernizing the North American power grid?
2. How can emerging technologies (AI, blockchain, IoT) be integrated to create a resilient smart grid?
3. What implementation framework ensures cost-effective deployment while maintaining grid reliability?
4. What cybersecurity measures are necessary to protect intelligent grid infrastructure?

Research Objectives

1. Conduct comparative analysis of smart grid technologies
2. Design integrated architecture for tri-national grid modernization
3. Develop phased implementation roadmap with budget projections
4. Propose governance and maintenance frameworks for long-term sustainability

Recommendation

Based on the foregoing, it is strongly recommended that the appropriate resources and policies be garnered for embarking on Project DAWN (Digitalization, Adaptability, Wellness, and Network optimization) which will focus on leveraging cutting-edge technologies including artificial intelligence and blockchain to create a modern grid that is smart and secure (U.S. Department of Energy, 2019) [24].

Research Summary

Modernizing the grid by leveraging technological advances presents a unique opportunity for the government to create an efficient, reliable, and sustainable backbone for the economy (Grigoraş *et al.*, 2023) [10]. However, this transformation presents challenges in cyber security, data management, and energy storage. The system is tasked with managing an influx of highly varied data, making sense of this data to perform self-healing and adaptive protection.

After thoroughly reviewing existing literature, various solutions were discovered for securing the grid, managing data, and storing energy. Key findings include adopting a multi-layered, proactive approach to securing the grid by incorporating preventive defense measures, leveraging big data technologies, and the need for durable energy storage solutions (Sánchez *et al.*, 2024) [21]. These insights informed the choice of key modules for project D.A.W.N.

Reda *et al.* (2023) [18] pointed out that given the basic security goals of confidentiality, integrity, and availability, otherwise known as the CIA triad, availability is by far the most important security goal in a smart grid environment. This is followed by integrity and confidentiality respectively.

They identified the energy management system (EMS) in the control center and the state estimator as prime targets for cyber attackers since other parts of the system depend on them. Interestingly, they noted that the same intelligent systems responsible for the success of smart grids can be weaponized by false data injection (FDI) attacks, hence the need for prevention-based strategies in addition to other cyber-security measures. Two prevention-based strategies were named, blockchain and cryptography. Although cryptography has been successfully applied in other fields, it is not feasible in the grid because of limited computational capabilities. Additionally, they mentioned that data-driven strategies like deep learning and reinforcement learning are the most popular defense strategies owing to their ability to adapt to dynamic variables and detect FDI attacks quickly. Amulya *et al.* (2024) [1] supported the efficacy of a data-driven defense strategy in a smart grid but noted that for it to manage dynamism and noise, these must also be present in the training data.

Drilling down into the techniques of data-driven strategy, Hallmann *et al.* (2024) [12] compared four machine learning (ML) models, FFNN, CFNN, ANN, and EL-SCOA. Although excelling only in specific applications, they found the EL-SCOA model more resilient to cyber-attacks. Grigoraș *et al.* (2024) [10] described this phenomenon where ML models are excellent within the premise of a defined goal but woeful outside that goal as the fragility of knowledge. Mohamed *et al.* (2024) [16] highlighted the effectiveness of ML models, realizing an increase of 40% in fault detection, and classification, and a reduction in unnecessary tripping. Furthermore, they recognized data-driven techniques as being scalable, significantly reducing the need for manual intervention in relay settings. Noteworthily, they pointed out that achieving success in implementation and operation meant that decisions from data-driven techniques must be interpretable so that engineers can verify or intervene when needed. When choosing ML models for specific applications, a trade-off exists between black box models like neural networks and interpretable models. Black box models although unexplainable and thus risky when applied to adaptive protection, are highly accurate. On the other hand, interpretable models like decision trees, can be easily swayed by small changes in input data.

The integration of data from multiple sources including power generation data, consumption data, grid data, market data, and planning data yields big data (Hallmann *et al.*, 2024) [12]. Big data is characterized by high volume, variety, and velocity (Grădinaru, 2024) [9]. Choosing the right extraction methods and database management technologies is crucial to achieving efficiency (Grigoraș *et al.*, 2023) [10].

Finally, energy storage systems. Studies have shown that energy storage is a necessary component of the smart grid (Ricco *et al.*, 2022) [20]. This is because although energy sources are eco-friendly and varied, they are fluctuant and pose a threat to grid stability (Hafiz *et al.*, 2023) [11]. Various storage technologies such as Li-ion batteries, flow batteries, supercapacitors, and Hydrogen storage have been explored (Durvasulu *et al.*, 2023) [8]. For example, although supercapacitors offer fast charging, long operational life, and broad operating temperatures, they are expensive and self-discharge very quickly (Durvasulu *et al.*, 2023) [8]. Conversely, flow batteries have a longer life cycle, can be scaled up, and emit less carbon (Vafaeva&Sanjeeva, 2024) [25].

Decision Criteria

Recall that modernizing the North American grid is an ultra-large-scale project. One that spans not just multiple states but countries. Furthermore, the integration of multiple energy sources even from consumers introduces high complexity (Jiang, 2021) [13]. Consequently, all solutions for the project have to be scalable.

Since resources are always limited, ensuring that decisions are made based on efficiency and reliability is crucial to remaining within budget. For example, a solution that requires less computational overhead to reach an outcome will be favored over a similar one with a higher computational overhead. Moreover, the dynamism of the grid necessitates solutions that will be reliable, resilient, and stable during unfavorable conditions. Reliability is also determined by the capacity to perform automated self-healing to mitigate the impact of cyberattacks and restore system operations (Hallmann *et al.*, 2024) [12].

The final consideration is sustainability. This involves a preference for long-term solutions over short-term ones. It also means choosing solutions that will be environmentally friendly over ones that are not.

System Proposal

Based on the foregoing, this study proposes the development of D.A.W.N. The solutions chosen for the key modules of this smart grid system are big-data storage for data management, flow batteries for energy storage, and a combination of data-driven and preventive defense strategies namely ML models and blockchain.

During the selection, big data technologies were compared to traditional data management systems and were deemed capable of handling the storage and processing needs of the grid. Flow batteries were compared to other energy storage systems like supercapacitors and li-ion batteries and were selected for their sustainability benefits. Conclusively, a combination of ML models and blockchain were chosen for their scalability, efficiency, and reliability.

Project Design for D.A.W.N

The smart grid is one huge dynamic system comprised of seven application domains: generation, transmission, distribution, customer, market, service provider, and operator (Reda *et al.*, 2023) [18]. These domains integrate multiple technologies as shown in Figure 1 below

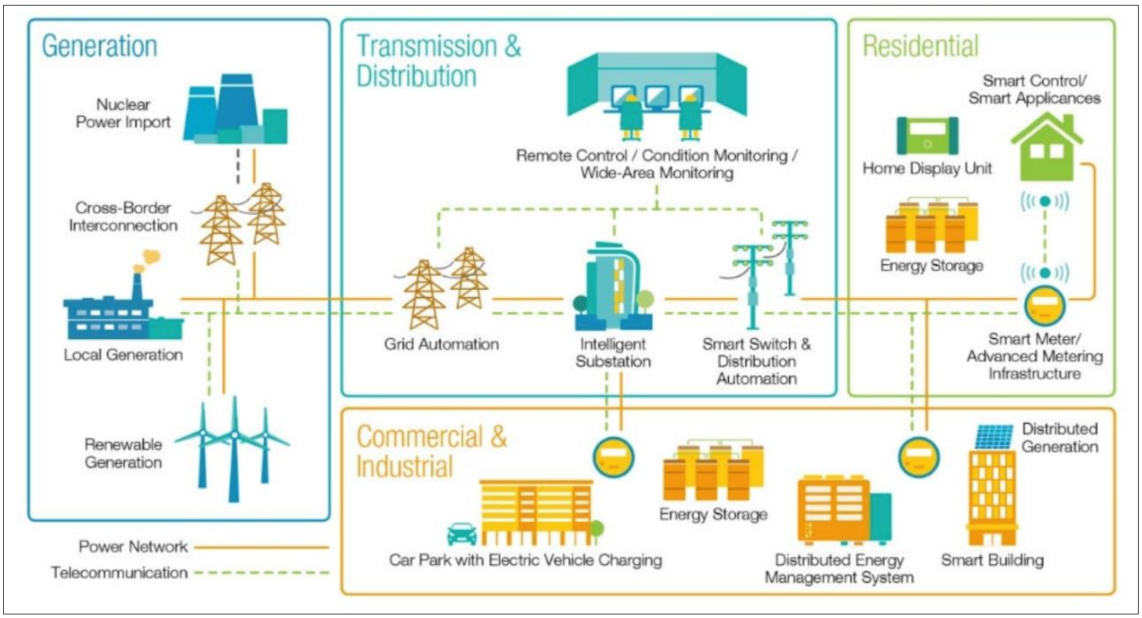

Fig 1: Smart Grid Technologies (U.S. Department of Energy, 2022) [23]

This chapter details the design of necessary components along with their functionalities, and the implementation strategy for project D.A.W.N. This includes the transmission and distribution sub-systems utilizing state-of-the-art technologies like dynamic line rating (DLR), phasor measurement units (PMUs), advanced distribution management systems (ADMS), fault location, isolation, and service restoration (FLISR) systems, advanced metering infrastructure (AMI), and distributed energy resource management systems (DERMS). The chapter concludes with budget considerations for a successful project execution.

Transmission System

This system enables energy to be delivered across great distances from generator plants to distribution systems via high-voltage lines (greater than 69 kV) as shown in Figure 2 (U.S. Department of Energy, 2022). To modernize the transmission system within a smart grid, DLRs and PMUs are essential.

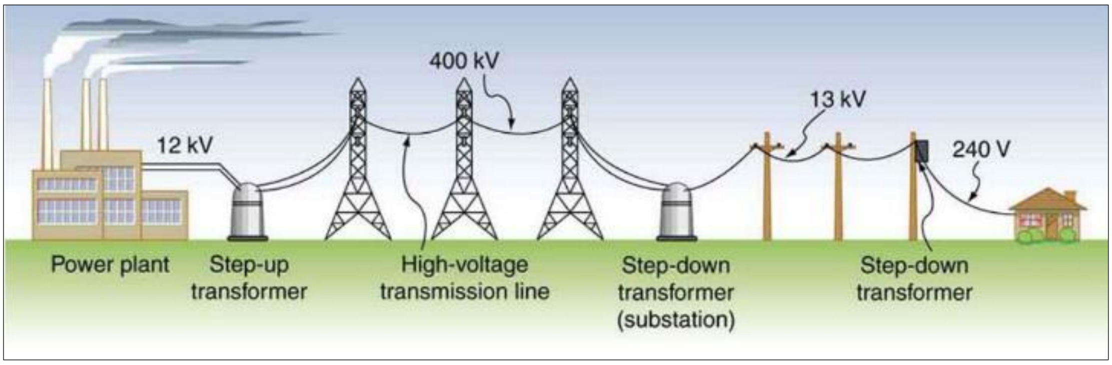

Fig 2: Transmission System (U.S. Department of Energy, 2022) [23]

Dynamic Line Rating (DLR): Transmission lines can only carry a maximum amount of electricity depending on the weather. If this amount is exceeded, the line can sag or even stretch beyond repair which can be hazardous. Hence, line ratings indicate the acceptable level of heating that the line can sustain based on electric current flow and weather conditions (U.S. Department of Energy, 2022) [23]. In the traditional grid, line ratings are static. They are calculated based on worst-case scenarios, consequently, even when weather conditions are favorable, transmission lines in a traditional grid cannot take advantage of the increased carrying capacity. DLR addresses this efficiency issue by dynamically computing and setting the line rating based on a sophisticated time-varying component that considers weather forecasts and line conditions (U.S. Department of Energy, 2022) [23]. Figure 3 shows a DLR device and Figure 4 shows how it is integrated into the transmission system.

Fig 3: DLR device (U.S. Department of Energy, 2022) [23]

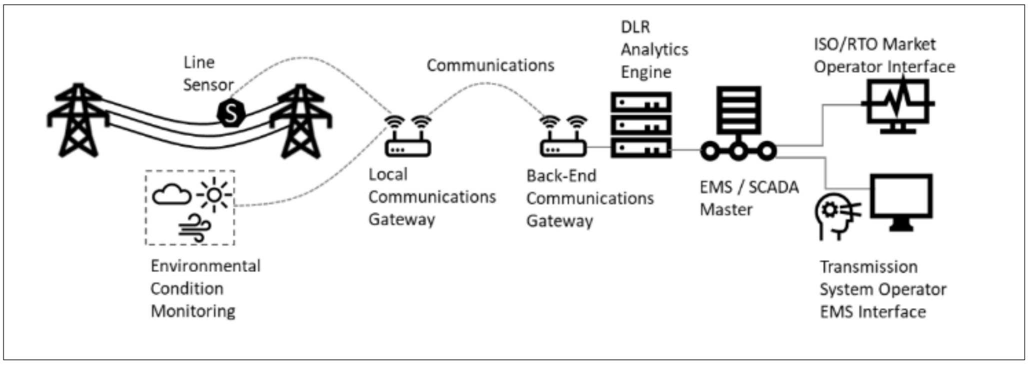

Fig 4: DLR in a transmission system (U.S. Department of Energy, 2022) [23]

Phasor Measurement Units (PMUs): PMUs provide the transmission system with monitoring capabilities by measuring time-stamped voltage, current, and frequency 100 times faster than traditional Supervisory control and data acquisition (SCADA) monitoring (U.S. Department of Energy, 2022) [23]. SCADA is an industrial and power system control application (Reda *et al*., 2023) [18]. With these high-resolution measurements, grid operators can make offline engineering analyses, and more importantly, the grid itself can perform self-healing based on real-time state estimation to combat anomalies and offer stability and reliability (U.S. Department of Energy, 2022) [23]. However, PMUs generate an enormous amount of data, about 50 GB/day and 1.5 TB/month, which necessitates the use of big data technologies for analytics, visualizations, storage, and retrieval. This data will be transferred to a phasor data concentrator (PDC) via Institute for Electronic and Electrical Engineers (IEEE) C37.118.2-2011 messaging using standard communication protocol for interoperability and fiber optics communication medium for low-latency and high-bandwidth as shown in Figure 5 (U.S. Department of Energy, 2022) [23].

Table 1: Comparative Evaluation of Grid-Scale Energy Storage Technologies

Evaluation Criterion	Flow Batteries	Lithium-Ion Batteries	Compressed Air Energy Storage (CAES)	Supercapacitors
Energy Density (Wh/kg)	20–70	100–265	30–60	5–10
Power Density (W/kg)	<100	250–400	50–100	1,000–10,000
Cycle Life (cycles)	10,000–20,000	3,000–5,000	≥10,000	≥500,000
Response Time	Seconds	Milliseconds	Minutes	Milliseconds
Operational Lifespan (years)	20–25	10–15	20–40	15–20
Levelized Cost of Storage (LCOS) *(USD/kWh/cycle)*	0.15–0.25	0.20–0.35	0.10–0.20	0.50–1.00
Environmental Impact	Low	Moderate	Low	Low
Scalability for Grid Applications	High	Moderate	High	Low
AHP Composite Score (0–10)	8.4	7.2	7.8	6.8

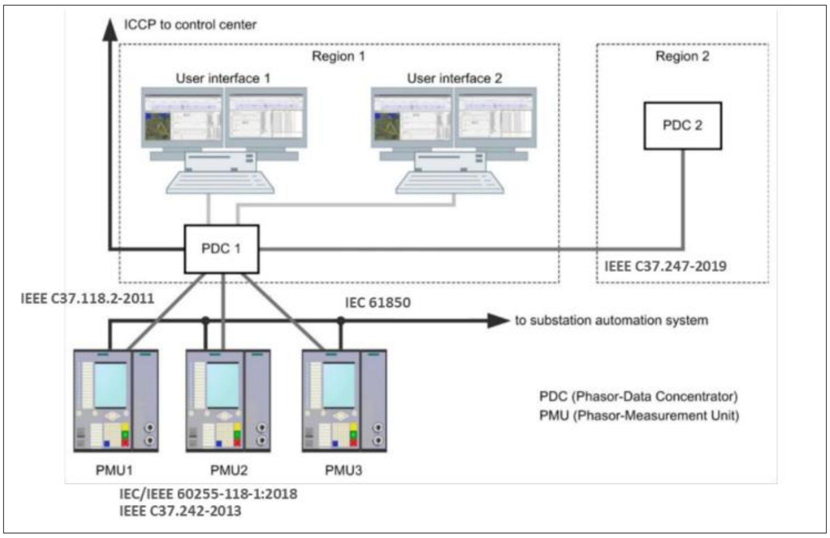

Fig 5: PMU data transfer architecture (U.S. Department of Energy, 2022) [23]

Distribution System

This system is a more expansive network of lower-voltage lines (generally less than 35kV) that deliver electricity from the transmission system to customers as shown in Figure 6 (U.S. Department of Energy, 2022) [23]. Modernizing this system requires the following key components, namely, ADMS, FLISR, AMI, and DERMS.

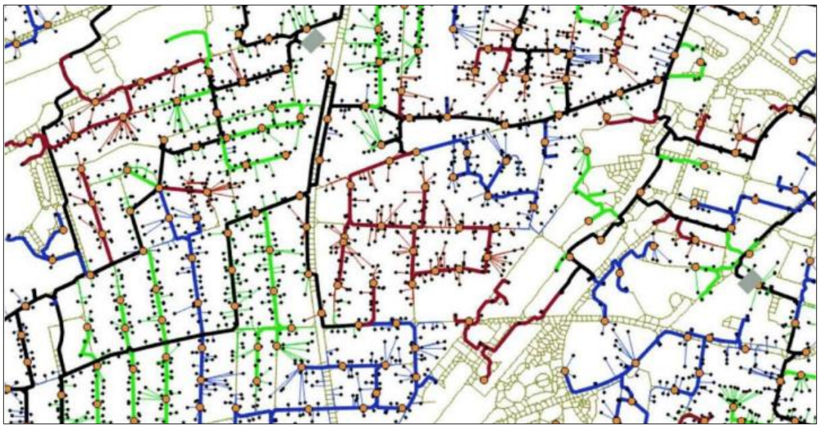

Fig 6: Distribution System (U.S. Department of Energy, 2022) [23]

Advanced Distribution Management Systems (ADMS): This is the control hub that will collect, organize, analyze, and display real-time distribution information across several systems as shown in Figure 7. A consolidated view of data from disparate systems such as GIS, OMS, and CIS, as illustrated in Figure 8, will help prevent overloads thus supporting the overall goal of grid reliability (U.S. Department of Energy, 2022) [23].

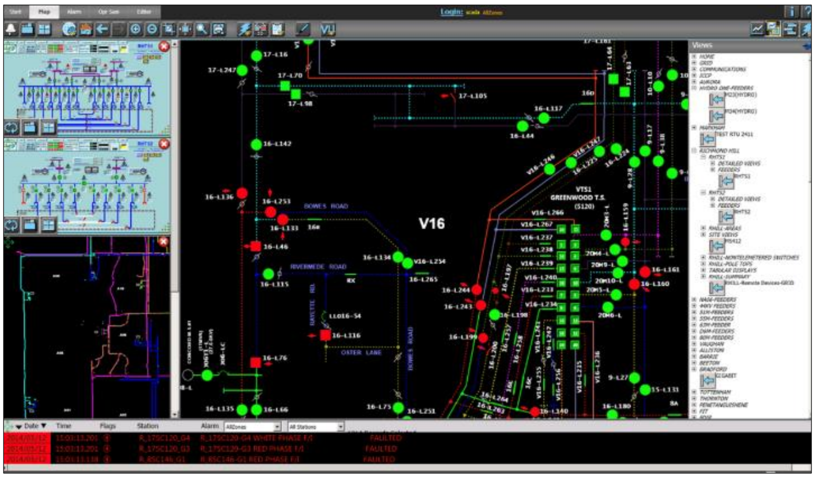

Fig 7: ADMS (U.S. Department of Energy, 2022) [23]

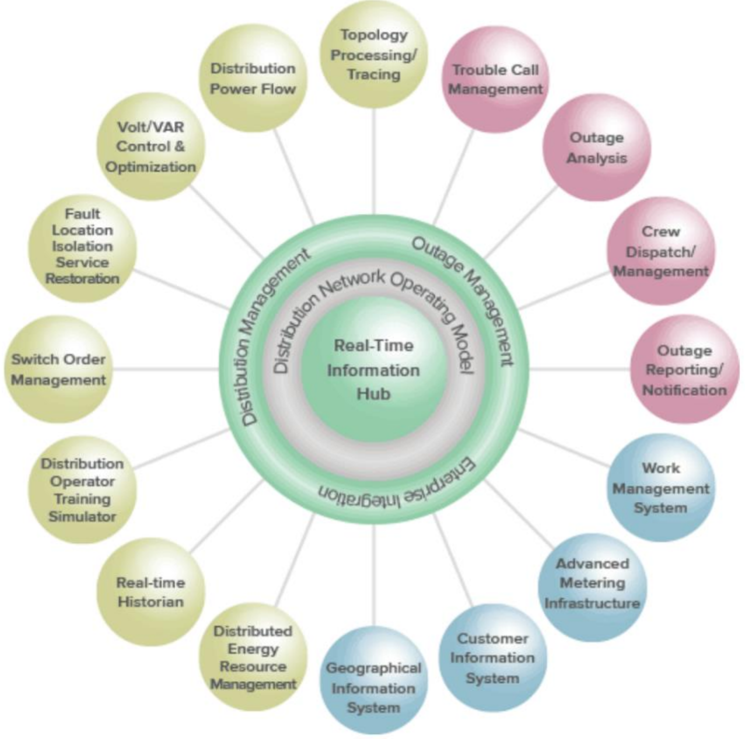

Fig 8: Disparate Systems Connected by ADMS (U.S. Department of Energy, 2022) [23]

Fault Location, Isolation and Service Restoration (FLISR): The FLISR component is an automated fault detection and response software that enhances grid self-healing and service reliability. It uses line sensors, automated switches, and communication networks to isolate faults and reroute power within seconds as shown in Figure 9. Due to scalability and efficiency benefits, FLISR will reside within the ADMS as opposed to being standalone, although the latter reduces single point-of-failure concerns (U.S. Department of Energy, 2022) [23].

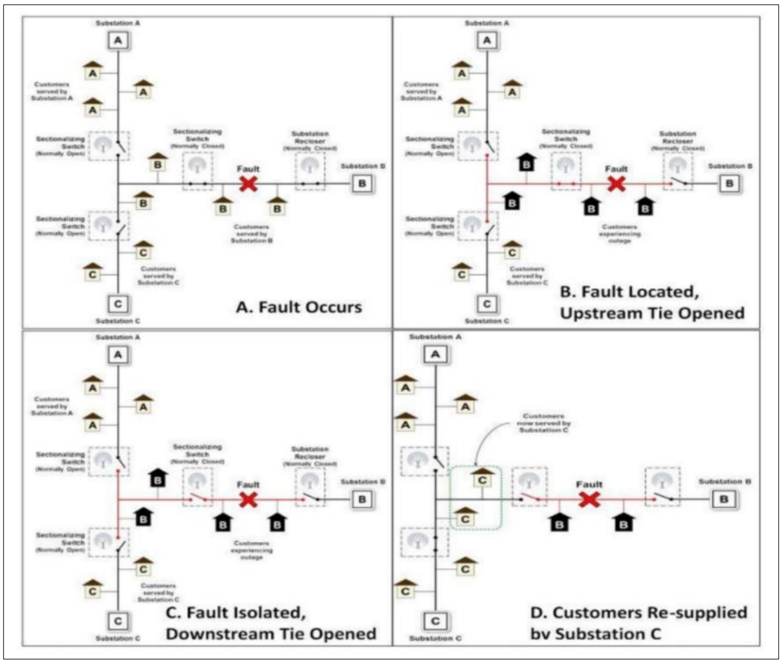

Fig 9: FLISR automating service restoration (U.S. Department of Energy, 2022) [23]

Advanced Metering Infrastructure (AMI)

This component will include smart meters, communication networks, and data management systems. The smart meters will monitor consumer data every fifteen minutes and transmit this data, called transactions, to a consensus node (U.S. Department of Energy, 2022; Vishwakarma *et al.*, 2024) [23, 26]. Every smart meter will be identified as part of a distributed blockchain network by a unique ID generated during its manufacturing as presented in Figure 10.

To prevent a single point of failure, the consensus node will be automatically switched to the nearest consensus node in the event of any faults (Vishwakarma *et al*., 2024) [26]. AMIs will help consumers conserve energy by keeping them informed and offering suggestions to their smart devices to optimize usage (U.S. Department of Energy, 2022; Vishwakarma *et al*., 2024) [23, 26]. This will positively impact sustainability efforts to reduce carbon footprint.

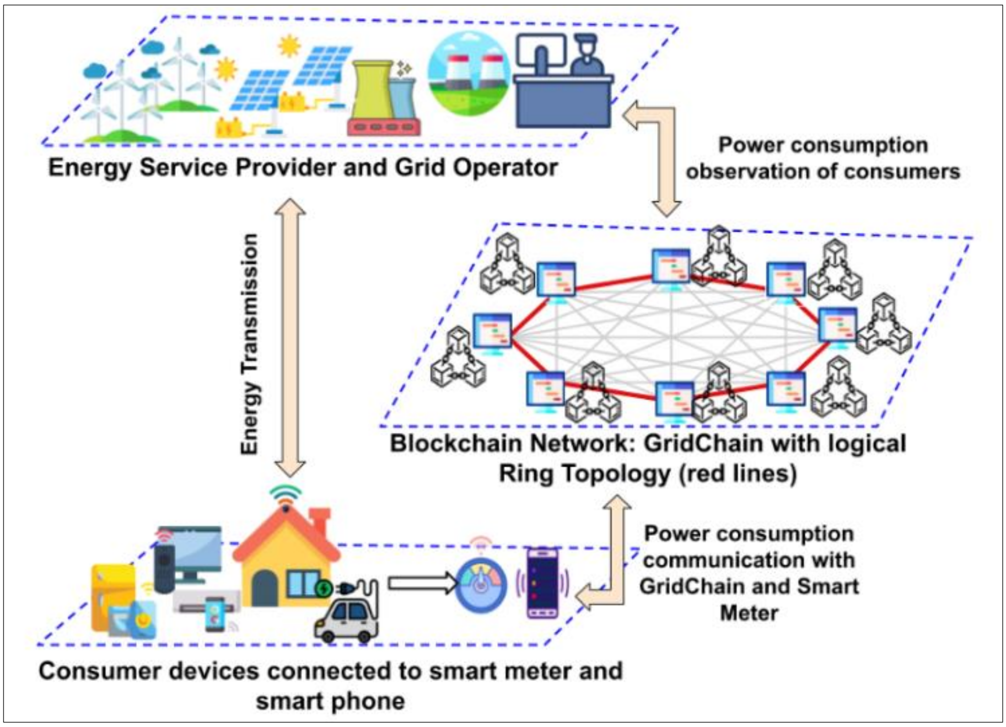

Fig 10: AMI with blockchain technology (Vishwakarma *et al*., 2024) [26]

Distributed Energy Resource Management Systems (DERMS): This software component will allow for the integration and optimization of distributed energy resources (DER) into the grid. DERs are smaller generation units often less than 10 megawatts, that are located on the consumer side of the meter (Australian Energy Market Commission, 2024) [3]. DERMS are needed because DERs, although a welcome addition to energy generation, are unpredictable. DERMS will mitigate this challenge by forecasting DER capabilities so that distribution planners can respond to real-time market price signals as seen in Figure 11 (U.S. Department of Energy, 2022) [23].

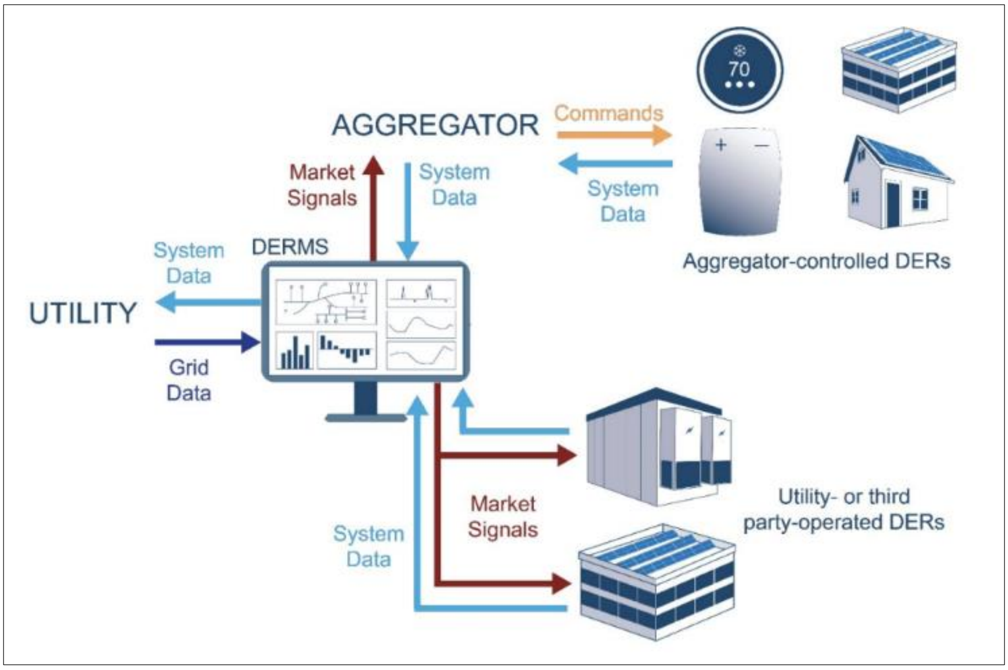

Fig 11: DERMS (U.S. Department of Energy, 2022) [23]

Budget and Financial Planning

As mentioned previously, the modernization of the grid is a capital-intensive project that will require as much as $150 billion. Capital expenditures for investor-owned utilities (IOUs) were forecasted to reach $25 billion in 2019 (U.S. Department of Energy, 2022) [23]. This excludes operation and maintenance costs which got to $14 billion.

Implementation Plan

Modernizing the North American power grid requires meticulous planning as existing infrastructure will be upgraded and advanced technologies integrated, with little to no outages. Project D.A.W.N will be implemented over 25 years. During this time, standards will be developed for interoperability, key stakeholders will be identified and engaged for structural and functional requirements gathering, and components will be researched, tested, demonstrated, and deployed as shown in Figure 12 (U.S. Department of Energy, 2022) [23]. This section outlines the schedule, tasks, and timelines for successfully implementing project D.A.W.N.

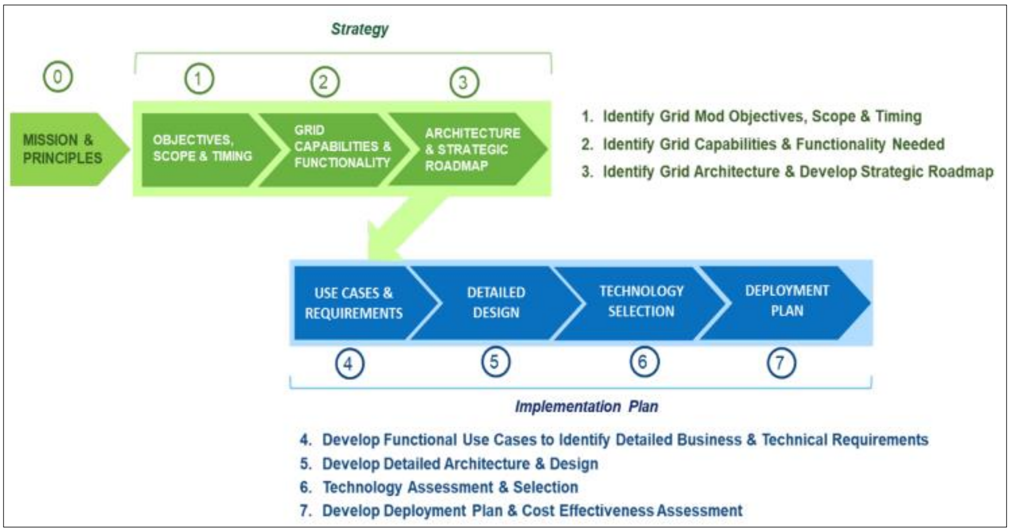

Fig 12: High-level Roadmap for Project D.A.W.N (U.S. Department of Energy, 2022)

Project Schedule

At a high level, project D.A.W.N will be divided into three phases: pre-implementation, implementation, and post-implementation. Each of these phases is discussed below in conjunction with the associated tasks and duration.

Pre-Implementation Phase

1. **Feasibility Study:** During this time the project will be assessed for its viability and strategic alignment.
   - **Dependencies:** Requires executive approval.
   - **Timeline:** 1 year.
2. **Stakeholder Engagement:** A heterogeneous group of key stakeholders including utility companies, government agencies, and consumers will be consulted through effective communication channels for the formulation of policies, standards, system requirements, and evaluation metrics (Paustian *et al.*, 2022; U.S. Department of Energy, 2022) [17, 23].
   - **Dependencies:** Feasibility studies.
   - **Timeline:** 5 years.
3. **System Architecture Design:** This task involves designing the system architecture that comprises renewable energy sources, advanced metering infrastructure, and energy storage systems. The design must consider scalability, interoperability, sustainability, and security requirements.
   - **Dependencies:** Stakeholder Engagement.
   - **Timeline:** 8 months.
4. **Vendor Selection:** Vendors for smart grid components are selected through a competitive bidding process. The selection criteria should include cost, quality, and compliance with industry standards.
   - **Dependencies:** System architecture design.
   - **Timeline:** 1 year.
5. **Contract Negotiation:** Contracts are negotiated and signed with the necessary service-level agreements in place. This task also includes setting up terms for delivery, installation, and post-installation support.
   - **Dependencies:** Vendor Selection.
   - **Timeline:** 2 months.

Implementation Phase

1. **Infrastructure Upgrade:** The existing grid infrastructure, encompassing high-voltage lines, substations, and transformers, will be upgraded to support smart grid technologies. This task is crucial for ensuring the grid can handle increased loads and new functionalities.
   - **Dependencies:** Conclusion of pre-implementation phase.
   - **Timeline:** 5 years.
2. **Installation of Smart Components:** Smart meters, sensors, and communication devices will be installed for real-time data collection and monitoring. The installation process would be carried out systematically to minimize disruptions.
   - **Dependencies:** Conclusion of pre-implementation phase.
   - **Timeline:** 8 years.
3. **Integration of Energy Storage Systems:** Flow batteries and other energy storage solutions will be integrated to balance supply and demand effectively.
   - **Dependencies:** Infrastructure Upgrade.
   - **Timeline:** 9 months.
4. **Blockchain Integration:** The blockchain network will

be implemented and integrated with other smart technologies.
- **Dependencies:** Installation of smart components.
- **Timeline:** 1 year.

5. **Quality Assurance and Testing:** A comprehensive testing of the smart grid system, including hardware, software, and communication networks, will be carried out to ensure that all components work together seamlessly.
    - **Dependencies:** Installation of smart components.
    - **Timeline:** 1 year.
6. **Pilot Deployment:** A pilot project will be deployed in a selected area to evaluate the system's performance and identify potential issues before full-scale deployment.
    - **Dependencies:** Quality assurance and testing.
    - **Timeline:** 3 months.
7. **Full-Scale Deployment:** After the successful completion of the pilot project, the smart grid solution will be rolled out across the North American region.
    - **Dependencies:** Quality assurance and testing.
    - **Timeline:** 1 year.

Post-Implementation Phase

1. **Evaluation and Review:** The system performance will be compared to metrics and key performance indicators to ascertain that the objectives have been realized. Feedback will be gathered from stakeholders and reviewed to identify areas of improvement.
2. **Training and Documentation:**
    - **Technical Training:** Technical staff will be trained on the operation and maintenance of smart grid components to ensure they are fully equipped to manage the system (U.S. Department of Energy, 2022) [23].
    - **Consumer Training:** Workshops will be conducted for consumers to educate them on the benefits and usage of smart grid technologies (Archana *et al.*, 2022) [2].
    - **Documentation:** Comprehensive documentation, including user manuals and troubleshooting guides, will be developed to assist in the operation and maintenance of the smart grid system.

Risk Management

Throughout the implementation phase, risk management strategies will be employed to mitigate potential issues that could arise. These strategies include:

Contingency Planning: Contingency plans for potential delays in equipment procurement or installation will be developed to keep the project on track. This includes identifying alternative suppliers and developing backup installation schedules (Zhao *et al.*, 2024) [28].

Quality Assurance: Quality assurance processes will be enforced to ensure that all hardware and software components meet the required standards and metrics (Chloros *et al.*, 2022) [6]. Regular inspections and audits will be conducted throughout the implementation process.

Communication and Coordination: Clear communication channels among all project stakeholders will be established to ensure that any issues arising are promptly addressed. Regular meetings will be held to review progress and coordinate tasks (Paustian *et al.*, 2022) [17].

Security Measures: Robust cybersecurity measures will be employed to protect the smart grid system from potential threats. This includes encryption, intrusion detection systems, and regular security audits (Coppolino *et al.*, 2023) [7].

Maintenance

The ongoing maintenance of the smart grid is essential for ensuring the long-term reliability and efficiency of the system. However, when done blindly, it can lead to inefficiencies such as high costs and unreasonable cycles (Zhou *et al.*, 2024) [29]. To mitigate this challenge, AI will be leveraged in combination with historical data to plan scheduled preventive maintenance efficiently (Ling *et al.*, 2024) [15]. This phase involves the regular upkeep of hardware and software components, system updates, and continuous monitoring to prevent and address any issues that arise.

Backups and Disaster Recovery

A comprehensive disaster recovery plan will be implemented to ensure the system can be quickly restored in the event of a catastrophic failure. This plan includes regular data backups, redundancy measures, and emergency response protocols (Chang *et al.*, 2024; Chen *et al.*, 2023) [4, 5].

System Monitoring and Updates

Monitoring systems including dashboards will detect any anomalies from defined operational parameters (Lin *et al.*, 2024; Talib *et al.*, 2024) [14, 22]. Furthermore, regular software updates will be applied to ensure the system remains secure and up-to-date with the latest features. This includes updating cybersecurity protocols, data analytics tools, and user interfaces (Chen *et al.*, 2024) [5]. Additionally, periodic hardware inspections will be carried out to prevent natural wear (Zhou *et al.*, 2024) [29].

Future Recommendations

Integration of a Digital Twin

Future work could involve integrating digital twin technology into the smart grid system. A digital twin is a virtual replica of a physical system created with sensors, ML, and data analytics. Digital twins would allow for real-time monitoring, simulation, and optimization of the grid, providing valuable insights for system improvements and cybersecurity measures (Coppolino *et al.*, 2023) [7].

Augmented Reality (AR) for Maintenance

Implementing AR technology could enhance maintenance processes by providing technicians with real-time visual guides and data overlays during inspections and repairs (Zhou *et al.*, 2024) [29]. This technology could reduce maintenance time and improve accuracy.

Conclusion

Evidently, building the smart grid is an ultra-large-scale project that requires considerable time, planning, and resources. However, it portends benefits in accelerating the transition to clean energy while providing efficient and reliable operations.

Studies revealed feasible solutions for different modules of the smart grid. These aspects were security, data management, and energy storage. Securing the grid is essential to preventing malicious attackers who could hijack the system causing huge economic losses. Managing data generated and processed by the grid will lead to efficiency by reducing decision-making time and automating self-healing. Storing energy generated from numerous sources sustainably will promote grid stability.

The design of a Smart Grid is, by nature, multi-faceted and has a variety of planning needs involving the application of advanced technologies with huge investment. Project D.A.W.N will combine DLR, PMUs, ADMS, FLISR, AMI, and DERMS in developing a resilient, effective, and sustainable power distribution system that will ultimately benefit the utilities and consumers.

The successful implementation of the smart grid project will depend on careful planning, effective execution, and continuous monitoring. By adhering to the project schedule, assigning clear tasks, and managing risks effectively, the project team will ensure that the smart grid is implemented within the stipulated timeframe and meets all functional and performance requirements.

Ongoing maintenance is critical for the sustained success of the smart grid. By implementing a comprehensive maintenance strategy, providing continuous training and support, and considering future technological advancements, the smart grid can remain reliable, efficient, and adaptable to future challenges. Finally, the recommendations provided offer a roadmap for enhancing the system's capabilities and ensuring its long-term viability.

References

1. Amulya N, Swarup KS, Ramanathan R. Cyber security of smart-grid frequency control: a review and vulnerability assessment framework. ACM Trans Cyber Phys Syst. 2024. doi:10.1145/3661827
2. Archana. Modelling barriers for smart grid technology acceptance in India. Process Integr Optim Sustain. 2022;6(4):989-1010. doi:10.1007/s41660-022-00255-1
3. Australian Energy Market Commission. Distributed energy resources. 2024 Aug 4. Available from: https://www.aemc.gov.au/energy-system/electricity/electricity-system/distributed-energy-resources
4. Chang YX, Zhang SC, Liu X, Liu DL, Sun MQ, Zhao FH, *et al*. Power data security risk assessment method based on probabilistic hesitant fuzzy multi-attribute decision making. 2024. doi:10.1145/3675018.3675772
5. Chen L, Ma Y, Zhang T. Power terminal identity authentication scheme for disaster recovery environment. 2023. doi:10.1145/3660395.3660406
6. Chloros D, Gerogiannis VC, Kakarontzas G. Use of software and project management metrics in agile software development methodologies. 2022. doi:10.1145/3571697.3571701
7. Coppolino L, Nardone R, Petruolo A, Romano L, Souvent A. Exploiting digital twin technology for cybersecurity monitoring in smart grids. 2023. doi:10.1145/3600160.3605043
8. Durvasulu V, Koripella RC, Mosier T. Supercapacitors technology strategy assessment. Washington (DC): U.S. Department of Energy; 2023. Available from: https://www.energy.gov/sites/default/files/2023-07/Technology%20Strategy%20Assessment%20-%20Supercapacitors.pdf
9. Grădinaru C. The big data effect: the quest for a new understanding of the public sphere. Hermeneia. 2024;(32):64-73.
10. Grigoraș G, Raboaca MS, Dumitrescu C, Manea DL, Mihaltan TC, Niculescu V, *et al*. Contributions to power grid system analysis based on clustering techniques. Sensors (Basel). 2023;23(4):1895. doi:10.3390/s23041895
11. Hafiz AM, Liaqat R, Jamil M, Asharf AK. A state-of-the-art review of smart energy systems and their management in a smart grid environment. Energies. 2023;16(1):472. doi:10.3390/en16010472
12. Hallmann M, Pietracho R, Komarnicki P. Comparison of artificial intelligence and machine learning methods used in electric power system operation. Energies. 2024;17(11):2790. doi:10.3390/en17112790
13. Jiang T. Guest editorial: artificial intelligence and data analytics for smart grids with high penetrations of renewables. IET Energy Syst Integr. 2021;3(3):223-6. doi:10.1049/esi2.12040
14. Lin R, Chen S, He Z, Wu B, Zou H, Zhao X, *et al*. Electricity behavior modeling and anomaly detection services based on a deep variational autoencoder network. Energies. 2024;17(16):3904. doi:10.3390/en17163904
15. Ling X, Li G, Luo C, Han J, Zhang Z. Application of artificial intelligence-based power outage demand rationality verification and window period recommendation technology in maintenance optimization. 2024. doi:10.1145/3677182.3677306
16. Mohamed AS, Deepa Kundur, Khalaf M. A probabilistic approach to adaptive protection in the smart grid. ACM Trans Cyber Phys Syst. 2024. doi:10.1145/3656347
17. Paustian S, Köhlke J, Mattes J, Lehnhoff S. The (still unexplored) social side of smart grid development. 2022. doi:10.1145/3538637.3539585
18. Reda HT, Anwar A, Mahmood AN, Tari Z. A taxonomy of cyber defence strategies against false data attacks in smart grids. ACM Comput Surv. 2023;55(14s):1-37. doi:10.1145/3592797
19. Reshaping cities. Films On Demand. New York: Films Media Group; 2010. Available from: https://fod.infobase.com/PortalPlaylists.aspx?wID=280005&xtid=47301
20. Ricco M, Loncarski J, Monteiro V. Guest editorial: energy storage in smart grids. IET Power Electron. 2022;15(13):1227-8. doi:10.1049/pel2.12332
21. Sánchez G, Elbez G, Hagenmeyer V. Attacking learning-based models in smart grids: current challenges and new frontiers. 2024. doi:10.1145/3632775.3661984
22. Talib Z, Faris Z, Rahaim LAA. IoT monitoring system-based enabling intelligent power transformer using Raspberry Pi technology. 2024 International Congress on Smart Grid; 2024. Available from: https://ieeexplore.ieee.org/abstract/document/10550691
23. U.S. Department of Energy. 2020 smart grid system report. Washington (DC): U.S. Department of Energy; 2022 Jan. Available from: https://www.energy.gov/sites/default/files/2022-05/2020 Smart Grid System Report_0.pdf
24. U.S. Department of Energy. Artificial intelligence: using artificial intelligence to advance the state of multiple industries. Washington (DC): U.S. Department of Energy; 2019 Sep. Available from:

https://www.energy.gov/technologytransitions/articles/artificial-intelligence-can-make-us-electric-grid-smarter-and-more

25. Vafaeva KM, Sanjeeva P. Comparative analysis of lithium-ion and flow batteries for advanced energy storage technologies. MATEC Web Conf. 2024;392:01176. doi:10.1051/matecconf/202439201176
26. Vishwakarma L, Das D, Das SK, Becker C. SmartGrid-NG: blockchain protocol for secure transaction processing in next generation smart grid. 2024.sss doi:10.1145/3631461.3631554
27. Washington Post. Amid record high energy demand, America is running out of electricity. 2024 Mar 7. Available from: https://www.washingtonpost.com/business/2024/03/07/ai-data-centers-power/
28. Zhao Y, Zhang X, Cao H, Zhao J, Wei F, Ma Z, *et al*. Research on machine learning-based knowledge graph completion technique for power grid contingency planning. 2024. Available from: https://ieeexplore.ieee.org/abstract/document/10587969
29. Zhou H, Xiang W, Dong Q, Qi W, Wu P. Research on power grid equipment maintenance based on multi-dimensional inspection image processing. 2024. doi:10.1145/3674225.3674236

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